District Heating BCIT's Sustainability Precinct Area

Prefeasibility Study
Final Report

Prepared for:
British Columbia Institute of Technology (BCIT)

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This study is based on upstream work conducted by Andrea Linsky, Energy Specialist at BCIT, and Alexandre Hebert, Energy and Sustainability Manager at BCIT. They acquired much of the key data and provided excellent support through their critical reviews of the various drafts of this report.

It has been a pleasure to work with these two energetic researchers. Our lively and challenging discussions greatly enhanced the quality of this report and demonstrated the valuable contributions that academic researchers can make to this leading-edge work.

If this report succeeds in garnishing support for an extended district energy system, I'd be happy to share the credits with them.

I would also like to thank Joe Newton, Steve Sallaway, Palvinder Moses, Jennie Moore, Rod Goy and all other BCIT employees who provided time, data and invaluable expertise for the report.

Cornelius Suchy, Revelstoke, BC. March 2011.

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SUMMARY

This study examines the general viability of a district energy system at the School of Construction and the Environment at BCIT's Burnaby Campus. The main findings of this prefeasibility study are listed below:

- Rationale of the study: BCIT seeks to become carbon neutral in its operations. The School of Construction and the Environment wants to showcase how material and energy consumption can be reduced by a factor of four without reducing existing service levels. The School has selected the seven buildings of the north-east area of campus as a study and demonstration area – a 'living laboratory.' This area is labelled the "Sustainability Precinct."
- District energy concept: One option under consideration is to generate and supply this Sustainability Precinct with heat from a district heating network, connecting multiple heat energy users through a network to a variety of heat energy producers.
- District energy in light of the aging building stock: The approach has merit because it would establish an energy infrastructure that can be used after buildings have been replaced. BCIT's building stock is approaching 50 years of age with 18% slated for demolition in the near term.
- Size of the 'Sustainability Precinct' may be too small: The seven buildings of the precinct hardly make a 'district,' especially since one of the buildings, the largest one, is already connected to the campus heating system. Expanding the research to the entire campus would contribute to improving the business case.
- Wood waste could cover most of the precinct's heat load: Wood waste generated at the Joinery and Carpentry departments could be turned into heat energy, supplying the baseload of the six buildings not yet connected to the central heating plant. This approach would allow the School of Construction to meet its carbon mitigation goal on a small scale, both in terms of physical size and capital costs.
- Factor-four reduction possible: Of a range of renewable and decentralized energy sources researched, biomass heat, combined heat and power, and condensing boilers are three mature technologies that that might be used to achieve a factor-four reduction in CO_2-emissions of the entire campus.
- Other energy sources worth considering: For further reduction of the precinct's environmental footprint, more renewable energy technologies would have to be looked into. Large-scale solar thermal and fuel cells are two heat sources that BCIT could employ to position itself as a leader in green heating technologies.
- High heat supply temperatures are an obstacle to renewable energy usage: The biggest technical barrier to implementing renewable and decentralized heating sources is the high temperature that both the existing heating pipeline and equipment inside buildings operate at. The extent of the need for an in-building retrofit should be researched. Low-temperature retrofit options could be demonstrated at selected buildings of the precinct that are slated for a major renovation.
- Heat density of the Burnaby campus: The heat energy demand of campus can be assessed as reasonably dense for a district heating system, comparable to that of the Lonsdale Energy Corporation in North Vancouver. Currently, however, only 13 of the 56 buildings on campus are heated by the central boiler plant.
- Monitoring of energy consumption is required: As a first step to a district heating master plan, we recommend doing an in-depth analysis of each building's energy demand. Consumption should be monitored using meters and data loggers for each individual building. This energy audit could be conducted as a guided student project.
- Campus as a hub for district energy in Burnaby: BCIT is well positioned to expand its already existing heating network into the Sustainability Precinct, throughout the remaining campus, and possibly even beyond the campus, becoming a hub for district energy in Burnaby.
- Long-term planning is essential to the success of district energy: Being an infrastructure development project, district heating requires more early-level, cross-sector planning than other energy technologies. Activities should be coordinated with upgrades of underground services, building renovation and, last but not least, BCIT's requirements for training and demonstration of an up-and-coming technology.

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Conversion of units used in this report:

1 metre (m)	=	3.3	feet (ft)
1 kilometre (km)	=	0.621	miles (mi)
1 hectare (ha)	=	2.5	acres
1 hectare (ha)	=	10,000	square meters (m^2)
1 square metre (m^2)	=	35	square feet (sft)
1 kilogram (kg)	=	2.2	pounds (lb)
1 cubic metre (m^3)	=	35	cubic feet (cft)
1 cubic metre (m^3)	=	1,000	litres (L)
1 litre (L)	=	0.001	cubic metres (m^3)
1 litre (L)	=	0.265	US gallons (USG)
1 metric tonne (t)	=	2,205	pounds (lb)
1 metric tonne (t)	=	1,000	kilograms (kg)
1 metric tonne (t)	=	1.1	short (imperial) ton
1 pound (lb)	=	2.2	kilogram (kg)
1 kiloPascal (KPa)	=	0.15	Pounds per square inch (PSI)
1 gigajoule (GJ)	=	0.278	megawatthour (MWh)
1 gigajoule (GJ)	=	0.95	mmBTU
1 kilowatthour (kWh)	=	3.6	megajoule (MJ)
1 kilowatthour (kWh)	=	3,415	BTU/h
1 megawatthour (MWh)	=	3.6	gigajoule (GJ)
1 megawatthour (MWh)	=	3.4	mmBTU
1 million British Thermal Units (mmBTU)	=	1.1	gigajoule (GJ)
1 British Thermal Unit (BTU)	=	0.239	watthours (Wh)
1 million British Thermal Units (mmBTU)	=	0.293	megawatthour (MWh)
1 megawatt (MW)	=	1,000	kilowatts (kW)
1 megawatt (MW)	=	3.4	mmBTU
1 million British Thermal Units per hour (mmBTU/h)	=	293	kilowatts (kW)
1 million British Thermal Units per hour (mmBTU/h)	=	0.293	megawatts (MW)

0. INTRODUCTION

Canada is one of the highest per capita energy consumers in the world, surpassed only by Iceland and Luxembourg. On a GDP basis, Canada is 33% less energy efficient than the United States. The only OECD nation that is less energy efficient than Canada is Iceland.[1]

The built environment, consisting of houses, buildings, and the communities they form, accounts for approximately 50% of all energy consumed in Canada.[2] The world's scientific community is calling for a four- to ten-fold reduction in global levels of energy and materials consumption to achieve ecological sustainability, meaning using ecological goods and services within nature's carrying capacity.[3]

British Columbia is a leader in green building technologies, and BCIT is integral to this success. Using the concept of the campus as a 'living laboratory,' the School of Construction and the Environment has implemented and is testing a wide range of innovative energy solutions under real-world conditions, maintaining existing service levels, while reducing the campus' environmental footprint.

The School has focused on the north-east portion of campus, selected as a study and demonstration area, labeled the "Sustainability Precinct." Seven buildings in this precinct will serve as test cases on how to achieve a 75% to 90% reduction in energy and materials consumption in our built environment.

This prefeasibility study explores the opportunities in energy and carbon savings that are achievable by supplying the Sustainability Precinct with heat from a district heating network. BCIT has contracted Cornelius Suchy of Canadian Biomass Energy Research (CBER) Ltd. to prepare this prefeasibility study.

0.1. BACKGROUND

The BC Clean Energy Act, released in 2010, calls for a 33% reduction of greenhouse gas emissions by 2020. The BC Government's Energy Efficient Buildings Strategy sets targets for commercial, industrial and government buildings. The average demand per home should be reduced by 20%; commercial and institutional buildings should reduce their energy demand by 9% per square meter of floor area.[4]

Comparing the 33% GHG emissions reduction target with the demand reduction targets shows that the energy supply side will have to be addressed too. The far more ambitious factor four to ten target that BCIT embraces will require efficient buildings and an efficient energy supply.

Changing the energy supply side, whether it is within the 'Sustainability Precinct,' the entire campus, or even an entire city, will require infrastructure that allows renewable and sustainable energy solutions to extend beyond individual buildings.

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[1] Environmental Indicators compares Canada to other OECD countries. See http://www.environmentalindicators.com/htdocs/indicators/9ener.htm

[2] Natural Resources Canada's CanmetENERGY , see http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/buildings_communities.html

[3] The factor-four-to-ten goal had been noted by the Organisation for Economic Co-operation and Development (OECD) environmental ministers in 1996 and was adopted by the United Nations General Assembly Special Session (UNGASS) in 1997.

[4] Energy Efficient Building Strategy of the BC Energy Plan. See http://www.energyplan.gov.bc.ca/efficiency/PDF/EEBS-2008-Web.pdf

BCIT's buildings stock is approaching 50 years of age. 18% of BCIT's Burnaby campus is slated for demolition and another 15% for major renovation. Implementing efficiency through retrofits is often more costly than through new construction and can lead to stranded investments if the building is demolished sooner than expected. An investment in infrastructure, such as a heating network, on the other hand, has a much longer life expectancy, reducing emissions and costs for existing and new buildings alike.

Economies of scale allow greater savings to be achieved at a district level rather than at an individual building level. For example, heating a home with a biomass boiler is technically possible, but not nearly as cost effective as it is on a district level. Studies suggest that district energy systems could reduce GHG emission by as much as 40% to 50%.[5] Cities such as North Vancouver have already zoned entire areas as 'district heating only.'[6]

District heating[7] consists of a network of pipes that supplies heat to a 'district' of buildings for space heating, domestic hot water, and in some cases even cooling purposes. This network can be fed by one central or several decentralized heating sources, including waste heat, renewables, and combined heat and power.

Scandinavia, the countries of the former Soviet Union and continental Europe use district heating on a much larger scale than Canada. In cities like Almaty, Kazakhstan more than 80% of the population of 1.2 million is supplied by district heating. In North America, campuses have been the most prominent applications of a centralized heat supply.

BCIT has operated a central boiler plant and a heat distribution network since the beginning of the campus in 1963. BCIT's Burnaby campus has a total of 56 buildings on an area of 56 ha. 13 of these buildings are connected to the central boiler plant. This heating network is a good starting point, but does not yet include any heat sources other than central, natural-gas-fired boiler plant. These will need to be renewable to "eliminate or absorb all carbon-based emissions on campus from fossil fuel combustion."[8]

The School of Construction and the Environment has adopted a sustainability framework to inform all educational programs, research and educational activities on campus. It has taken the initiative to demonstrate this framework in its 'Sustainability Precinct.' One of the six themes guiding implementation of the framework at this precinct is: "balance use and renewal of resources."[9]

The 'Sustainability Precinct' encompasses seven buildings, only one of which is connected to the existing heating network. The School of Construction and the Environment would now like to see whether the remaining six buildings should be served by a heating network, whether this network can and should be connected to the existing boiler house, and what type of sustainable heat sources are likely to be used in this network.

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[5] See http://oee.nrcan-rncan.gc.ca/communities-government/ices/about.cfm?attr=20

[6] Bylaw 8086 of the City of North Vancouver requires any new building of more than 1,000 square meters to connect to the district heating system for heating purposes unless it is determined by the City's Director of Finance that the cost to the City would be excessive. See http://www.cnv.org/server.aspx?c=2&i=98

[7] The terms 'district energy,' 'community energy,' and 'district heating' are used to describe a network of pipes supplying several buildings from a central source of heat.

[8] BCIT has the goal of becoming greenhouse gas neutral, see http://www.bcit.ca/sustainability/about/goals/ghgneutral.shtml

[9] See http://www.bcit.ca/construction/sustainability/

0.2. OBJECTIVES AND SCOPE OF THE STUDY

This report is a screening-level assessment of district heating opportunities at the Sustainability Precinct in the north-eastern corner of BCIT's Burnaby campus. This study is not a feasibility study. The School of Construction and the Environment is at an early stage of analysis, trying first to identify options and challenges they are likely to face when considering district heating as an alternative to the current status quo.

First, the study analyzes the existing situation regarding heat energy demand and supply in the precinct. The second chapter explores heat supply options and their applicability in the existing infrastructure and environment. Third, options for connecting the precinct to the existing heating network are discussed. This includes retrofits necessary at the building level, discussed in Chapter 4. Finally, the report lays down the objectives and likely scope of any future activity pertaining to district heating.

While providing a general overview of district heating, this study is tailored to the situation at the Sustainability Precinct, but with the understanding that much of the data could be applied to other locations.

This report is for decision-making purposes in an early stage only and is not sufficiently detailed to be used as a basis for investment.

0.3. EXISTING STUDIES

This report uses several excellent publications, reports and studies on district energy, the most important of which are available at the following internet sites:

- Canadian District Energy Association: http://cdea.ca/resources ;
- Community Energy Association: http://www.communityenergy.bc.ca ;
- Federation of Canadian Municipalities: http://www.sustainablecommunities.ca .

A full list of references can be found in Chapter 6. Bibliography

1. HEAT DEMAND OF BUILDINGS IN THE PRECINCT

As a first step towards district heating, the study investigated the thermal needs of consumers in the 'Sustainability Precinct.' While far from an energy audit, the level of detail achieved is sufficient to assess the buildings and conduct a preliminary design of the district heating system.

1.1.BUILDING STOCK

The Sustainability Precinct consists of the seven buildings of the School of Construction and the Environment. The School of Construction and the Environment is a part of the campus located in the North East, covering approximately 7% of campus area and one-tenth of the built-up area. Seven of the 56 buildings on campus are located in this precinct.

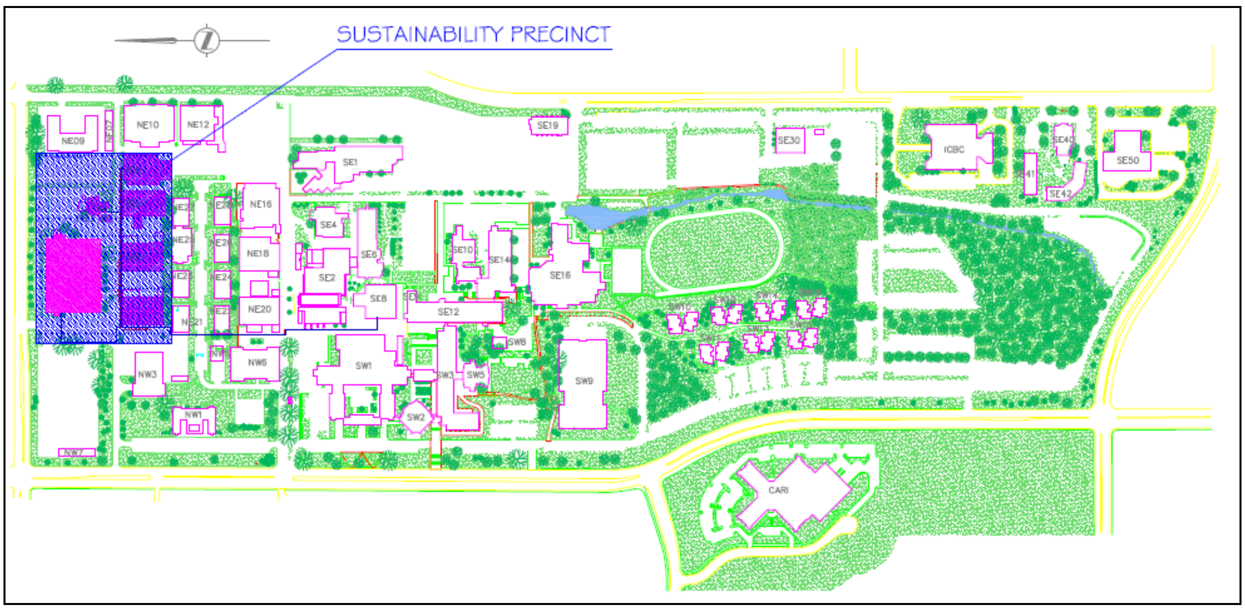

Figure 1.1 The Sustainability Precinct covers one-tenth of the built environment and 16% of the floor area of BCIT's Burnaby campus. The Sustainability Precinct is comprised of seven buildings ranging from a single-detached home to a four-storey building the size of a football field.

The precinct consists of seven buildings that range from a single detached home – the 'AFRESH house'[10] – to J.W. Inglis Building, a four-storey building with the footprint of an American football field.

Most of the buildings were erected in the early sixties. The Joinery Workshop (NE-02) and the Carpentry Workshop (NE-04) were old World War II hangars that were moved to the site shortly after the war.

[10] AFRESH House: Accessible and **A**ffordable, **F**lexible, **R**esilient, **E**nergy Efficient, **S**ustainable and **H**ealthy House

The J.W. Inglis Building (NE-01) is one of the newest buildings, erected in 1982. It contains a mix of classrooms, office space, a cafeteria and some small woodworking and metal fabrication shops located in the basement. It is also the second largest building on campus with more than 20,000 m² of floor area.

Most of the building stock is close to 50 years old and in need of an upgrade or replacement. Parts of the underground water and sewage piping system will require major upgrades should BCIT build up further.[22] This construction may present an opportunity to also upgrade the heating infrastructure to an extended heating system.

At the time of writing this report BCIT's internal planning foresees major renovations for the Joinery (NE-02), the Carpentry (NE-04), the AFRESH House (NE-03), and the Welding Department (NE-08). The Plumbing Department (NE-06) is slated for demolition.

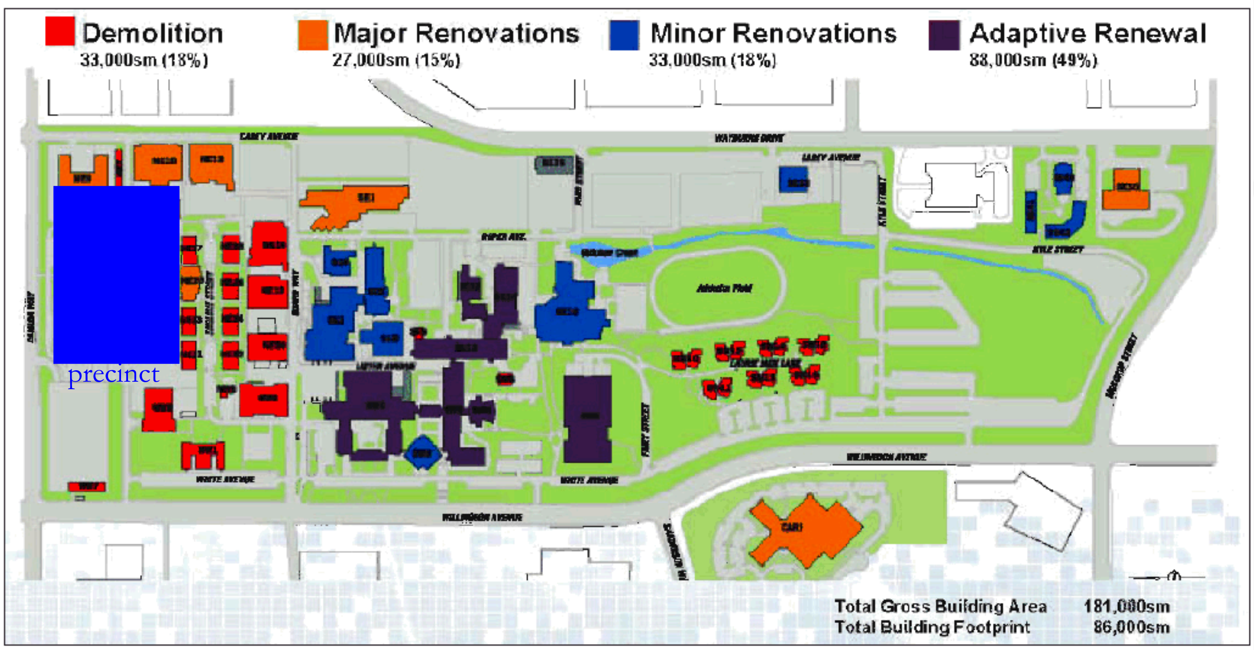

Figure 1.2 Building conditions at BCIT's Burnaby campus: 18% of the gross building area is slated for demolition, including the plumbing workshop building at the precinct. Map courtesy of BCIT Campus Planning.

Precinct Metrics in Comparison

	area	floor area	natural gas consumption	(gas) energy intensity	annual gas cost
entire Burnaby campus	565,000 m²	181,000 m²	134,000 GJ	0.72 GJ/m²	$1,200,000
existing heating network	191,000 m²	105,000 m²	64,000 GJ	0.61 GJ/m²	$576,000
sustainability precinct	**37,000 m²**	**30,000 m²**	**23,000 GJ**	**0.77 GJ/m²**	**$207,000**
single detached home	374 m²	186 m²	92 GJ	0.50 GJ/m²	$1,000

1.2. ANNUAL ENERGY CONSUMPTION

Determining the energy needs and characteristics of the buildings to be heated remotely is an initial step for the design of each district heating system. In particular, the maximum load and the load duration over the course of the year should be identified for each building.

Before the district heating system is designed, however, opportunities for demand-side reduction need to be investigated. Improved building insulation, for example, might reduce the demand significantly and the size of the district heating supply would need to be adjusted. While demand-side measures are beyond the scope of this study, a brief comparison of the benchmarking approach is given in Appendix 1.

Buildings that will be connected to a district heating system will replace their (generally) gas-fired furnaces, boilers or radiators with district heat as an energy source. Upstream losses of the existing building heat distribution system, such as boiler losses, had to be taken out of the equation as the central boiler house will only have to serve the end-use energy or heat energy demand[11] rather than the current natural gas or electricity consumption.

We assume the following heating appliance efficiency:

- A gross efficiency of 80% was applied to gas-fired infrared radiators used in NE-02, NE-04, NE-06 and NE-08;
- The natural gas boiler heating the Centre for Architectural Ecology was built in 1972 and is estimated to have a gross efficiency of 70%;
- The AFRESH house is heated by a geo-exchange system using a heat pump that is assumed to have a coefficient of performance of 3.0 typical for this kind of application. This results in 96 GJ of heat generated and consumed throughout the year;
- NE-06 has several new condensing boilers with an estimated efficiency of 90%;
- NE-08's make-up air units are expected to have an average efficiency of 80%;
- NE-01 is already heated from the central boiler house – i.e. it has no further conversion losses;

The Welding Department has a four times higher energy consumption than the remaining buildings in the precinct and should be a priority for an energy efficiency upgrade.

Next, the impact of annual fluctuations in weather had to be taken into account. Metered energy consumption was adjusted to long-term average climate conditions recorded by the Canadian Weather Office,[12] using daily

[11] End-use energy is the energy delivered to the building, after subtracting the losses incurring in the conversion process, such as the losses of a boiler or furnace.

[12] Canadian Weather Office, National Climate Data and Information Archive, Canadian Climate Averages 1971-2000. See http://www.climate.weatheroffice.gc.ca/climate_normals/index_e.html

readings of the Vancouver International Airport. Applying the model of heating degree-days,[13] 2010 was 11% warmer than usual while 2009 had 2,926 Kelvin-days, exactly the long-term average.

With these adjustments the following assessment of heat energy usage of the Sustainability Precinct can be given:

- Approximately 20,000 GJ of heat are consumed a year in the precinct. More than half of this is used in the biggest building the J.W. Inglis Building.
- Five out of seven buildings have heat consumption of 0.4 to 0.7 GJ per m² per year, slightly below the average of 0.79 GJ/m² of the entire Burnaby campus.
- The welding workshop is the top energy consumer, using 2.0 GJ per m² per year. The facility definitely needs an energy efficiency check, independent of establishing a district heating network. Ventilation heat recovery and occupancy-controlled fans are likely to be the most effective demand-side measures.

building	*annual gas or electricity consumption*	*heat consumption*[14]	*heated floor area* [15]	*specific consumption*	*rating*
NE-01 (classrooms)		11,243 GJ	20,077 m²	0.56 GJ/m²	D
NE-02 (Joinery)	1,370 GJ	1,096 GJ	1,877 m²	0.58 GJ/m²	C
NE-03 (Centre for Arch.)	268 GJ	201 GJ	483 m²	0.42 GJ/m²	C
NE-03 (AFRESH)	2.5 MWh	96 GJ	186 m²	0.52 GJ/m²	C
NE-04 (Carpentry)	1,290 GJ	1,032 GJ	2,057 m²	0.50 GJ/m²	C
NE-06 (Plumbing)	1,248 GJ	1,124 GJ	2,709 m²	0.41 GJ/m²	C
NE-08 (Welding)	5,939 GJ	4,751 GJ	2,395 m²	1.98 GJ/m²	G
TOTAL / AVERAGE		**19,542 GJ**	**29,784 m²**	**0.66 GJ/m²**	**D**

Table1.1 Energy consumption and energy rating for buildings in the Sustainability Precinct. Except for NE-01 energy consumption data are based on historical bills.

A so-called Energy Pass has been established for each of the buildings in the precinct. The two-page leaflet contains key data pertaining to district heating and is attached as Appendix 2.

1.3. HEAT DENSITY

District heating systems require dense build-ups with high energy usage within a given district.

13 Heating degree day is a measurement designed to reflect the demand for energy needed to heat a building. It is derived from measurements of outside air temperature. "Heating degree-days for a given day are the number of Celsius degrees that the mean temperature is below 18°C. If the temperature is equal to or greater than 18°C, then the number will be zero. For example, a day with a mean temperature of 15.5°C has 2.5 heating degree-days; a day with a mean temperature of 20.5°C has zero degree-days. Heating degree-days are used primarily to estimate the heating requirements of buildings." (Canadian Weather Office.See http://climate.weatheroffice.gc.ca/Glossary-popup_e.html#heatdegdays).

14 Consumption data for buildings in the precinct was extracted from BCIT's utility management database 'PUMA.'

15 The size of a building's floor area was either available from BCIT's facility management Department or calculated using the footprint and the number of floors. The footprint itself was obtained from a campus plan and was cross checked with satellite pictures (Google Earth).

Most of BCIT's campus is built densely enough to warrant an extended district heating approach.

A key factor affecting district heating viability is a project's heat density, i.e. the total heat energy consumed per land area (as opposed to floor area). Planning a district heating system usually starts with a heat density map of the area to be supplied. A heat density map allows areas with high or medium heat density – priority areas – to be visually identified.

Typically core densities are no less than 1,800 GJ per hectare and year.[16] The Lonsdale Energy Corporation in North Vancouver, for example has an average heat density of 2,900 GJ/ha per year.[17] The precinct consumes a total of 19,542 GJ of heat on a land area of 3.7 hectare.[18] The energy density of the precinct is hence 5,300 GJ/ha per year. This can be compared to the heat density of approximately 2,900 GJ/ha of the existing heating network, and 2,200 GJ/ha of the entire campus, i.e. comparable to that of the Lonsdale Energy Corporation.

The heat energy demand of campus can be assessed as reasonably dense for a district heating system.

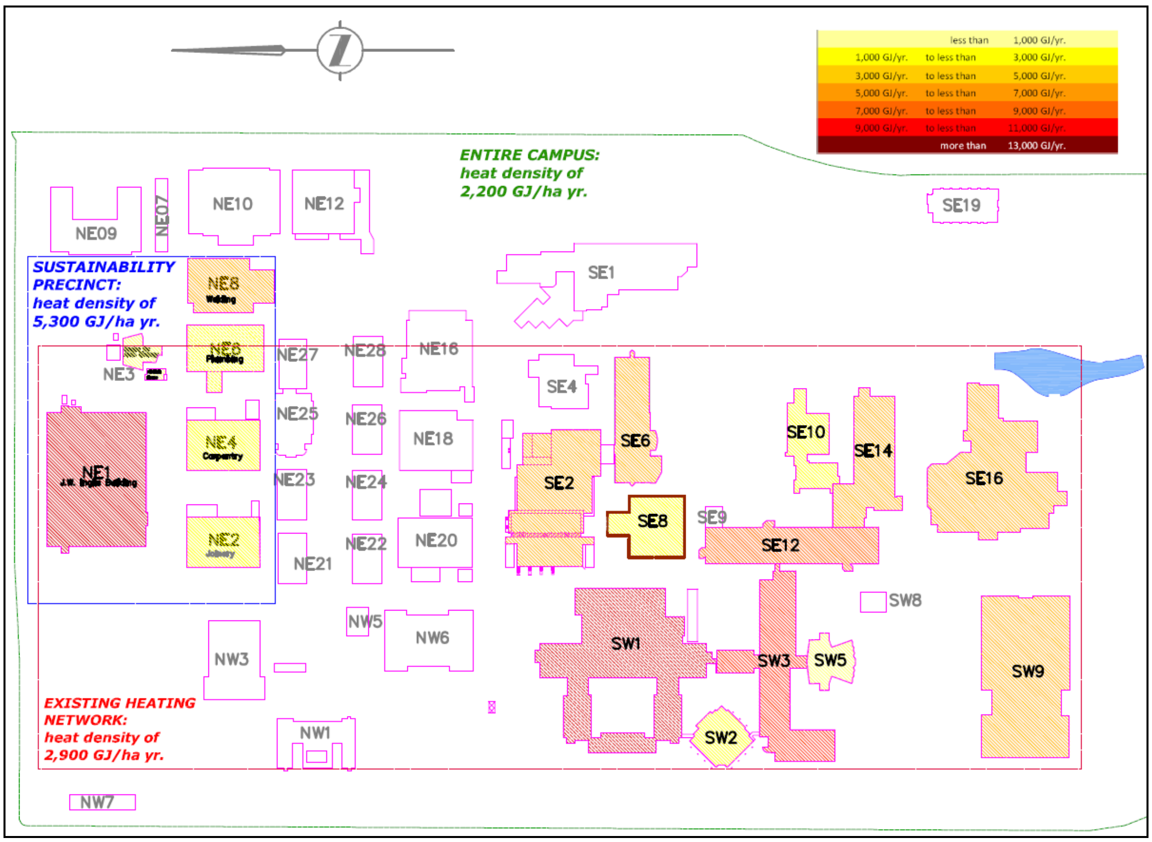

Figure 1.3 Heat density map of the northern section of BCIT's campus. The amount of consumption is classified by colour. This shows why large consumers, such as the J. W. Inglis Building (NE-1), are already heated from the boiler plant (SE-8), despite being farther away than most other buildings on the network. The precinct has a high heat density mostly due to this one large building (NE-1). Buildings not coloured in are those with no data available.

[16] International Energy Agency, see http://www.iea-dhc.org/reports/pdf/Energiteknik_IEA-Final-report-5.pdf

[17] Compass Resource Management: "District of North Vancouver District Energy Assessment." See http://www.dnv.org/upload/pcdocsdocuments/tf9f01!.pdf

[18] The land area is based on imaginary borders of the precinct as shown in Figure 1.3.

1.4. DOMESTIC HOT WATER CONSUMPTION

The heat demand of a building is comprised of a space heating demand and a demand for heating domestic hot water for sanitary purposes. The two are different as the former is weather dependent while the latter is related to the occupancy and is generally constant throughout the year. Domestic hot water thus constitutes a baseload that affects how a district heating system is designed and operated.

Hot water consumption was estimated using statistical averages.[19] Schools and colleges with showers in the building usually consume 50 to 70 litres per student per day of operation; those without showers use only 5 to 15 litres per student per day.[20] This data has been cross-checked with metered consumption of (cold) city water.[21] Using the above averages, the hot water consumption ranges between 1% and 25% of the total water consumption. See the table below.

Building	*Students / users*	*Showers in building*	*Daily DHW consumption ²*	*Annual DHW consumption*	*Annual metered city water consumption[22]*	*Hot water ratio*
NE-01 (J.W.Inglis Build.)	200	yes	12,000 litres/day	2,700 m³/yr.	18,762 m³/yr.	14%
NE-02 (Joinery)	64	no	640 litres/day	144 m³/yr.	1,672 m³/yr.	9%
NE-03 (Arch. Ecology)	3	no	30 litres/day	7 m³/yr.	615 m³/yr.	1%
NE-03 (AFRESH)	3	no	30 litres/day	7 m³/yr.	included above	
NE-04 (Carpentry)	40	no	400 litres/day	90 m³/yr.	1,923 m³/yr.	5%
NE-06 (Plumbing)	80	no	800 litres/day	180 m³/yr.	2,531 m³/yr.	7%
NE-08 (Welding)	50	yes	3,000 litres/day	675 m³/yr.	2,694 m³/yr.	25%
Total	**440**		**16,900 litres/day**	**3,803 m³/yr.**	**28,197 m³/yr.**	
Total without NE-01	**240**		**4,900 litres/day**	9%	of cold water	

² Based on 60 litres per student per day for facilities with showers, 10 litres without showers

Table1.2 Estimate of domestic hot water (DHW) consumption in buildings of the precinct. In most buildings, hot water consumption appears to be close to non-existent.

The numbers above do not account for stand-by losses of the hot water tanks and hot water circulation. Heat losses are independent of consumption and are dependent on the size of the water tank and the length of the circulation pipe. The table below provides a rough approximation of this:

[19] Both a user survey and a linear regression of weather dependence of consumption proved to be inconclusive.

[20] Design data of the Association of German Engineers, Norm VDI 3807

[21] Water consumption per building found in a 2004 report by EarthTech: 'Infrastructure Review 2004', Section 2 – Sanitary Sewer System. The table on page 2-3 was weighted and adjusted to campus-wide metered water consumption in the years 2007 to 2010.

[22] 2004 data. Source: EarthTech: 'Infrastructure Review 2004', Section 2 – Sanitary Sewer System. Table on page 2-3.

Building	*Annual hot water consumption*	*# of hot water tanks²*	*Estimated stand-by and circulation heat losses*		*Total annual energy consumption³ for DHW purposes*	*% of total energy consumption*
NE-01 (J.W.Inglis Build.)	2,700 m³/yr.	3 x 1000 l	1,000 W	31.5 GJ/yr.	416 GJ/yr.	2.5%
NE-02 (Joinery)	144 m³/yr.	1 x 250 l	200 W	6.3 GJ/yr.	27 GJ/yr.	2.4%
NE-03 (Arch. Ecology)	7 m³/yr.	1 x 100 l	100 W	3.2 GJ/yr.	4 GJ/yr.	2.1%
NE-03 (AFRESH)	7 m³/yr.	2 x 100 l	100 W	3.2 GJ/yr.	4 GJ/yr.	12.9%
NE-04 (Carpentry)	90 m³/yr.	1 x 250 l	200 W	6.3 GJ/yr.	19 GJ/yr.	1.9%
NE-06 (Plumbing)	180 m³/yr.	1 x 250 l	200 W	6.3 GJ/yr.	32 GJ/yr.	2.8%
NE-08 (Welding)	675 m³/yr.	2 x 250 l	300 W	9.5 GJ/yr.	106 GJ/yr.	2.2%
Total	**3,803 m³/yr.**		2,100 W	66 GJ/yr.	**608 GJ/yr.**	**2.5%**
Total without NE-01	**1,103 m³/yr.**		1,100 W	35 GJ/yr.	**192 GJ/yr.**	**2.3%**

² The size and number of hot water storage tanks are estimates only; ³ End-use energy based on 42°C hot water temp., 8°C cold water temp.

Table1.3 Estimate of domestic hot water (DHW) consumption and stand-by losses in buildings of the precinct. In some buildings stand-by losses exceed the actual consumption. Still, only a small fraction (less than 0.4%) of the annual energy is used for domestic hot water supply.

The estimate above shows that the total energy consumption for domestic hot water is 608 GJ a year, 2.5% of the total heat energy consumed in the precinct. This amount is small compared to residential facilities. Nation-wide, domestic water heating is estimated to be the second largest energy end-use for Canadian households, accounting for approximately 22% of total household energy consumption.[23]

Daily heat consumption for domestic hot water purposes is calculated at 2.7 GJ a day for the entire precinct, 0.85 GJ for the precinct excluding NE-01. The precinct seems to have only small amounts of domestic hot water consumption, limiting the economic operation of a district heating system to the heating season. This is dealt with in Chapter 2.1.

Energy usage for domestic hot water consumption appears to be negligible.

In some buildings stand-by losses are higher than the actual water consumption.

1.5. HEAT LOAD OF THE PRECINCT

Apart from the annual or monthly energy demand (measured in GJ), the heat load of a building (the energy required at any given moment of the year, measured in kilowatts (kW) or British Thermal Units per hour (BTU/h), needs to be established. While the energy demand largely determines the economic performance, the load determines the size and design of a district heating system.

The heat load of a building can be calculated from the heat losses, expressed as an R-value. R-values determine the heat losses through a building envelope. Typically the overall R-value of a building is established on a room-by room or wall-by-wall basis, measuring the size of each building component, such as a window, and assigning an expected R-value to this component using standard tables. The overall R-

[23] Canadian Building Energy End Use Data and Analysis Centre (CBEEDAC):" Domestic Water Heating and Water Heater Energy Consumption in Canada." Calgary, April 2005. See http://www.ualberta.ca/~cbeedac/publications/documents/domwater_000.pdf

value is then calculated by adding up these R-values, weighted by the size of the building component. This approach is time consuming and beyond what is needed for an initial assessment of the situation.

Instead, a first approximation was done using the footprint of a building (available from drawings), wall height and a roof angle (estimated by sight), to establish the total size of the building's envelope. Knowing the building's envelope size, its annual consumption (from metered data) and the annual degree-days (from a climatic database) the R-value could be determined. See Table 1.4 below.

R-values, when calculated on a room-by-room basis, do not take air exchange into account. The approximation done does not distinguish between air exchange losses and heat transfer losses though. The low R-value for NE-08 (R-0.8 in imperial units) is the same as that of a sheet of plywood with a thickness of 5/8." The insulation standard of the building is certainly above a sheet of plywood; the explanation is that the workshop has a high air exchange rate to remove welding fumes. While inaccurate, the data is still useful for approximating the heat load of the building.

Having established the R-values, the heat load – the amount of energy required per hour – can be calculated. The colder the outside temperature, the higher the heat load. The coldest hour on record in the past three years was -15.2°C.[24] Figures for the maximum load in the table below are based on this design temperature.

Building	***Heat consumption***	***Total envelope***	***Average metric R-value***		***Maximum load***	
NE-01 (J.W.Inglis Build.)	11,243 GJ	10,053 m²	0.23	m²K/W	1,476 kW	7,113,000 BTU/h
NE-02	1,096 GJ	2,516 m²	0.58	m²K/W	144 kW	491,000 BTU/h
NE-03 (Centre for Arch.)	201 GJ	635 m²	0.80	m²K/W	26 kW	90,000 BTU/h
NE-03 (AFRESH)	32 GJ	392 m²	3.09	m²K/W	4 kW	14,000 BTU/h
NE-04	1,032 GJ	2,512 m²	0.62	m²K/W	136 kW	463,000 BTU/h
NE-06	1,124 GJ	2,456 m²	0.55	m²K/W	148 kW	504,000 BTU/h
NE-08	4,751 GJ	2,730 m²	0.15	m²K/W	624 kW	2,131,000 BTU/h
TOTAL/AVERAGE	**19,542 GJ**	**21,293 m²**			**2,558 kW**	**8,735,000 BTU/h**
Total without NE-01	**8,299 GJ**	**11,240 m²**			**1,081 kW**	**3,693,000 BTU/h**

Table1.4 Heat load of buildings in the precinct. The load was determined for a design temperature of -15°C using the annual heat energy consumption and R-value. Two-thirds of the load comes from the largest building, NE-01, which is already supplied from district heating.

The maximum heat load of the precinct is 2,558 kW or 8.7 million BTU/h. Of this, more than half of the load comes from the largest building, NE-01, which is already connected to the existing district heating system. Extending the central heating system to the remaining buildings would add a load of 1,081 kW or 3.7 million BTU/h, half of NE-01.

1.6. ANNUAL HEAT LOAD DURATION

The maximum heat load only occurs on rare cold spells. During most of the year, the load of the precinct will be well below the value stated above. For an initial design of the heating system, the load during the course of the year has to be established.

A seasonal load curve – i.e. the cumulative load of all buildings at any given day of the year – illustrates how much, how often and when, peak loads occur. The graph below is a model that uses monthly meter readings and degree-days data[24] of the Vancouver International Airport.

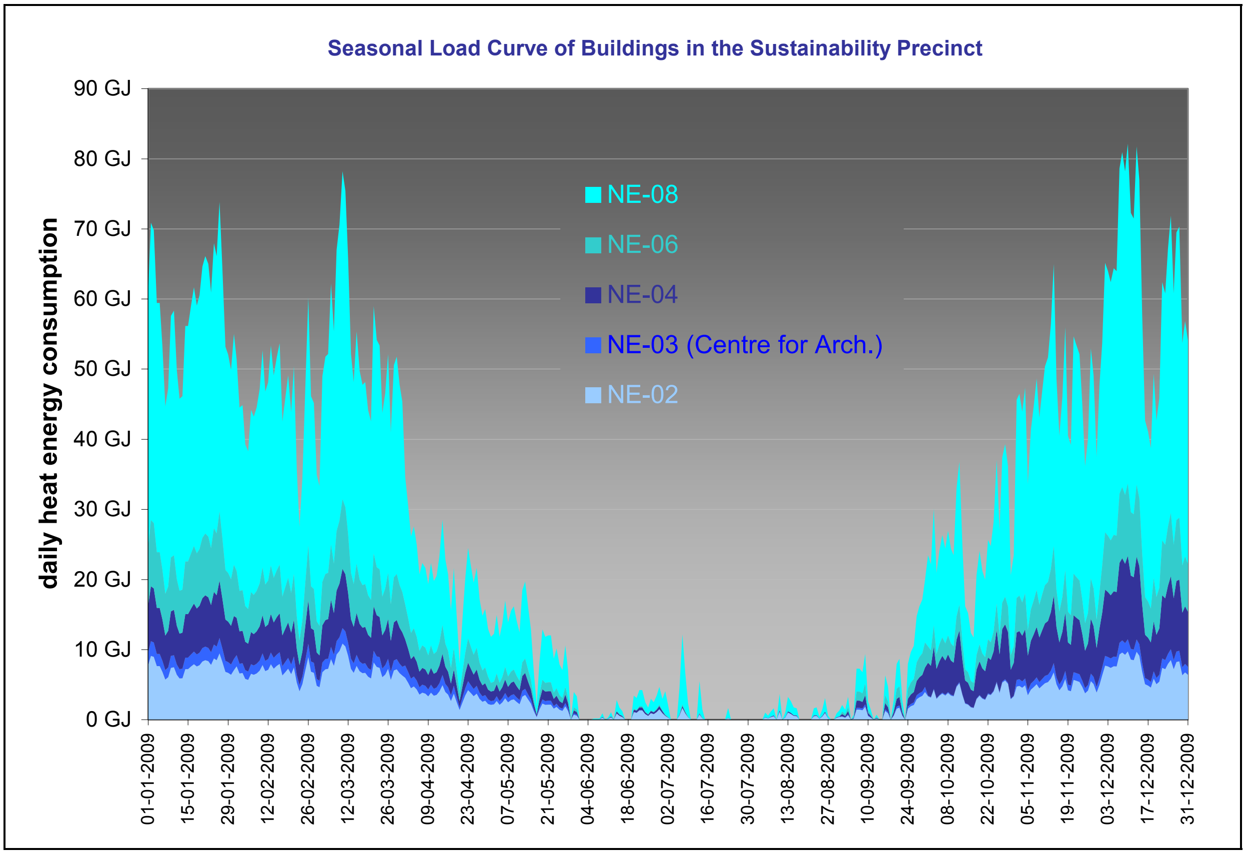

Figure 1.4 Using climatic data and historical bills, the daily heat consumption can be modelled. From the beginning of June to the middle of September there is hardly any load, while December sees a maximum consumption of 83 GJ per day. This graph does not include the largest building, the J.W. Inglis Building that is already connected to the district heating system.

This is a rough approximation only, based on average daily, rather than hourly, loads. The graph illustrates large variations in heat demand, both on a short-term and seasonal basis. Just like any other heating system, a district heating system would have to be able to follow this load curve. Some heat sources, such as solar, do not match the demand, while others, such as a combined heat and power plant, are designed to operate on a constant output rather than a fluctuating demand. These issues are discussed in Chapter 2.1.

As a first step for district energy planning gas and/or heat consumption should be monitored on a building level using data loggers.

The basis for the design of a district heating system is the load duration curve: rather than displaying the load in chronological order from January 1st to December 31st (as in Figure 1.4), daily loads are ordered by their size. Load duration curves show how many days (or hours) in a year a certain heat load needs

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[24] Temperature data source: Canadian Weather Office, see http://climate.weatheroffice.gc.ca/climateData/hourlydata_e.html

to be met by whatever heat source there may be.

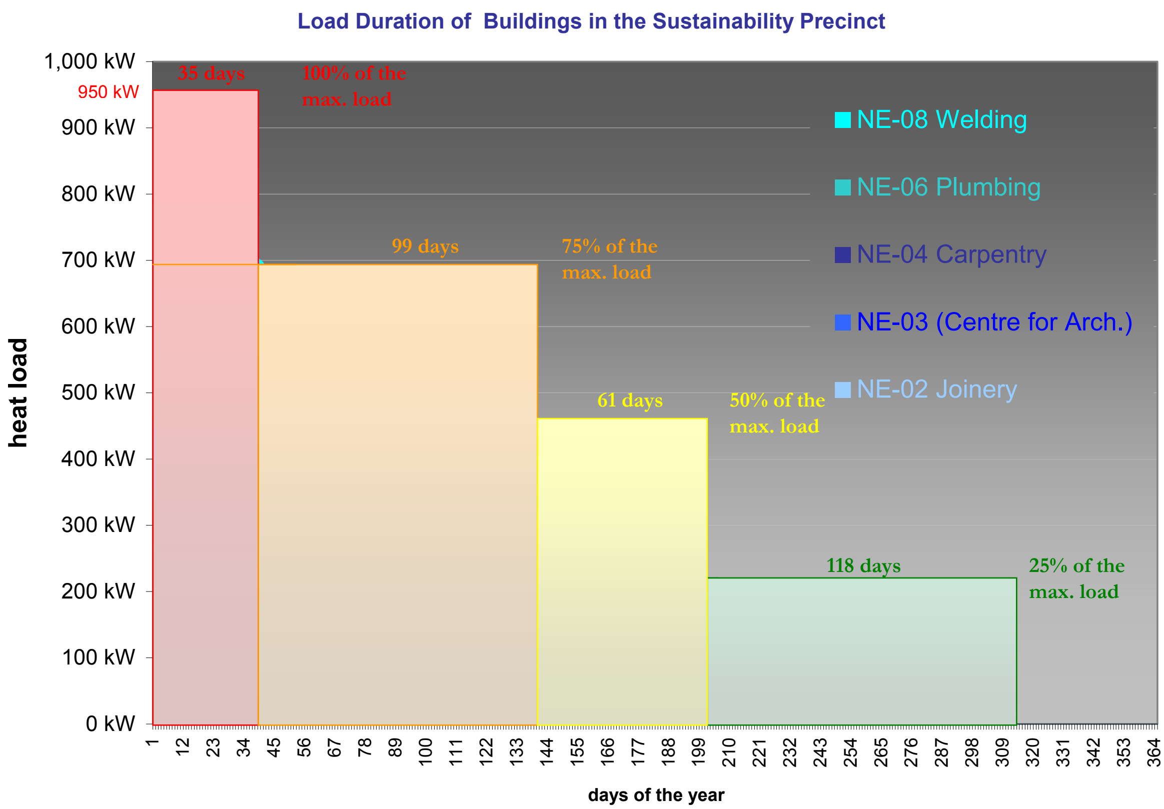


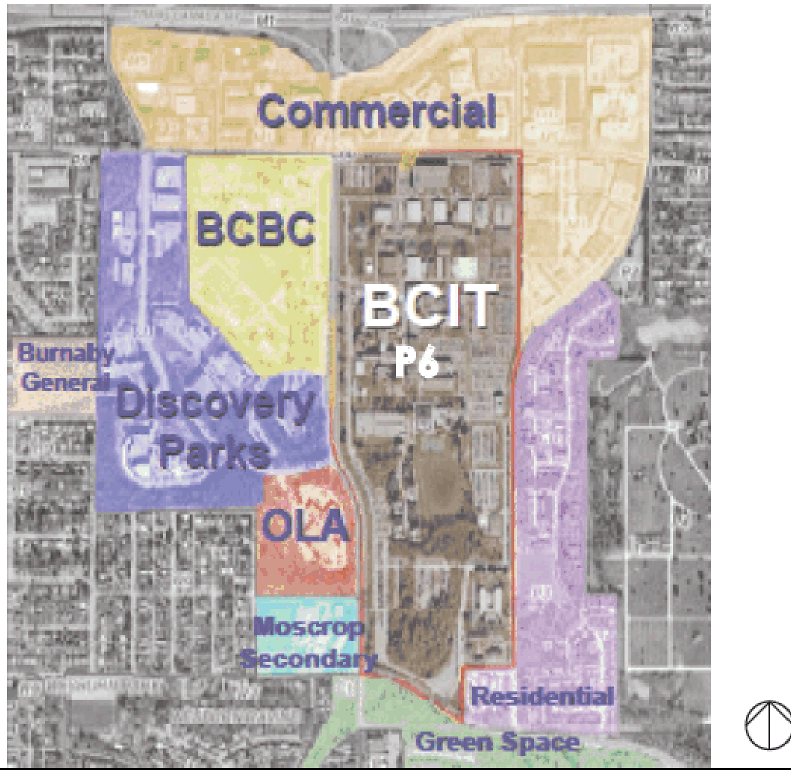
Figure 1.5 Load curves of the buildings in the precinct (excluding NE-01 already supplied by district energy). The curves show how many days in a year a certain heat load needs to be met by whatever heat source there may be. For example, a daily load of more than 75% of the maximum load happens 35 days a year. These days may not be consecutive days, though. The area of the load curve is a measure of the energy required.

The load duration chart above shows that the full capacity of a boiler supplying the precinct would only be required on 35 days a year. 75% of the boiler capacity would be needed on 99 days, half the capacity on 61 days and less than 25% on 118 days a year. On 52 days of the year there would be no load other than that of domestic hot water.

The load curve influences the way heat is generated and supplied to these buildings. This is discussed in Chapter 2.1.

1.7. Non-BCIT Heat Consumers Adjacent to the Campus

BCIT is located in an area of Burnaby with a medium to high build-up density. Especially the area around the northern section of the campus could be supplied by a district heating system that uses BCIT's existing plant as a hub.



ZONING:

BCIT: P6

NORTH:

- COMMERCIAL

EAST:

- RESIDENTIAL
- GREEN SPACE

SOUTH:

- GREEN SPACE

WEST:

- DISCOVERY PARK
- HOSPITAL
- SECONDARY SCHOOL
- OLA
- BCBC

Figure 1.6 Zoning of areas surrounding BCIT. Areas around the northern part of the campus are high-density build-up that might be served by BCIT's existing boiler plant. Map courtesy of BCIT Campus Planning.

Technically, most buildings in the neighborhood can be connected to the district heating system. Commercially, only consumers with a 'critical mass' (i.e. large consumers) and, preferably, with a fairly constant heat demand are worth considering. A heat density map, such as the one given on Figure 1.3, can help identify areas with high energy consumption that are worth being looked into further.

Another approach to selecting areas of interest for district heating is based on identifying buildings that typically have favorable consumption patterns. Laundry facilities, such as the one located across the north-east corner of the campus on Canada Way, are regarded by many utilities as ideal customers, as they consume large quantities of heat at a fairly constant level. Hospitals, such as the Burnaby General Hospital, or recreation centers are also preferred customers since they require heat largely independent from outside temperature or seasons.

Having an infrastructure, an existing mechanical system, and 24/7 supervision by very well trained staff at hand, BCIT might consider expanding its services beyond the campus boundary. From a financial and environmental point of view, many buildings surrounding BCIT are likely to be 'better' – i.e. larger and more constant – consumers than buildings on campus itself.

BCIT is also well positioned to expand its already existing heating network beyond the campus, becoming a hub for district energy in Burnaby.

This, however, would turn BCIT legally into a utility and would step beyond the mandate of a teaching and training institution. The process of becoming a utility is also perceived as cumbersome and time consuming. At present BC's legal framework for energy supply currently does not favor entrepreneurship in this sector. An alternative approach may be a joint venture with one of the established utilities.

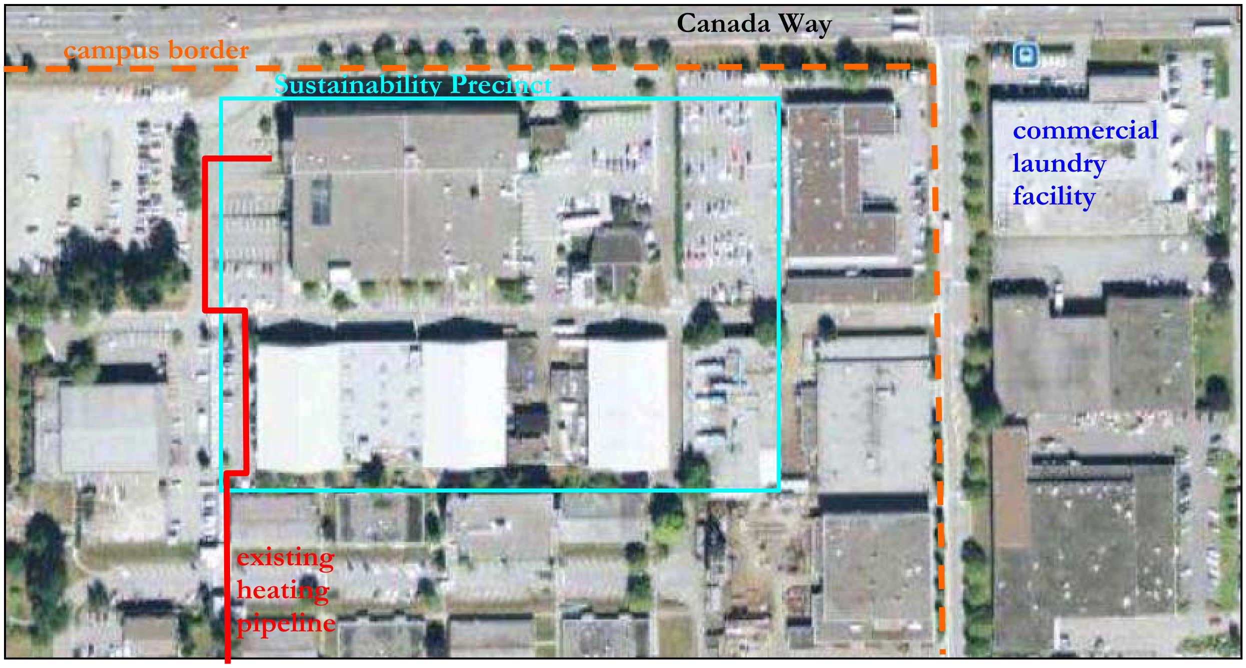


Figure 1.7 Location of a commercial laundry facility adjacent to BCIT's campus and in the vicinity of the Sustainability Precinct. The existing pipeline would have to be extended by approximately 400 m. Source of underlying satellite image: Google Earth.

2. HEAT GENERATION

The fundamental idea of district heating is similar to that of the electric grid: connect multiple energy users through a network to a variety of energy producers. Some experts call district heating a thermal grid.[25] As with the electric grid, a multitude of heat producers can feed into a thermal grid.

Some experts call district heating a 'thermal grid'.

As with the electric grid, a multitude of heat producers can feed into a thermal grid.

Heat producers can be renewable energy sources such as biomass, geothermal or solar, waste heat sources from industrial applications or sewage, or fossil fuelled generators, such as gas-fired boilers or combined heat and power (CHP) plants. European cities, such as Copenhagen, Graz, or Mannheim, integrate renewable energy into a grid that is primarily run by fossil fuels. Drake's Landing in Okotoks is the first community in North America to feed multiple energy sources into a district energy system.

This chapter describes the heat generation side of district heating. As in the former chapter, the description is general but is tailored to the Sustainability Precinct and the existing boiler plant that already heats large parts of the campus.

2.1. DESIGN AND OPERATION OF THE HEAT GENERATORS

District heating systems rarely rely on a single heat generator. Often one single unit is not powerful enough and needs to be supplemented by additional peaking capacity. When using renewable energy sources, supply usually does not match demand as, for example, is the case of solar thermal technologies. Even with conventional heat generation technologies, such as natural gas boilers, a boiler plant consists of several boilers, either for back-up purposes, or to share the load.

The design and operation of these heat generators primarily depend on the heat demand of the buildings to be supplied. Surplus heat generation is to be avoided yet the heat demand needs to be met at all times.

The basis for the design of a district heating system is the load duration curve, as given in Figure 1.5. A load duration curve shows how many days (or hours) in a year a certain heat load needs to be met by whatever heat source there may be.

Three types of loads can be distinguished: a baseload, a peak load and a low load (sometimes referred to as a 'partial baseload'). These loads are depicted in the graph below.

[25] Jim Manson, VP of FVB Energy Inc. during the CanBio 2010 conference in Vancouver on October 1 , 2010.

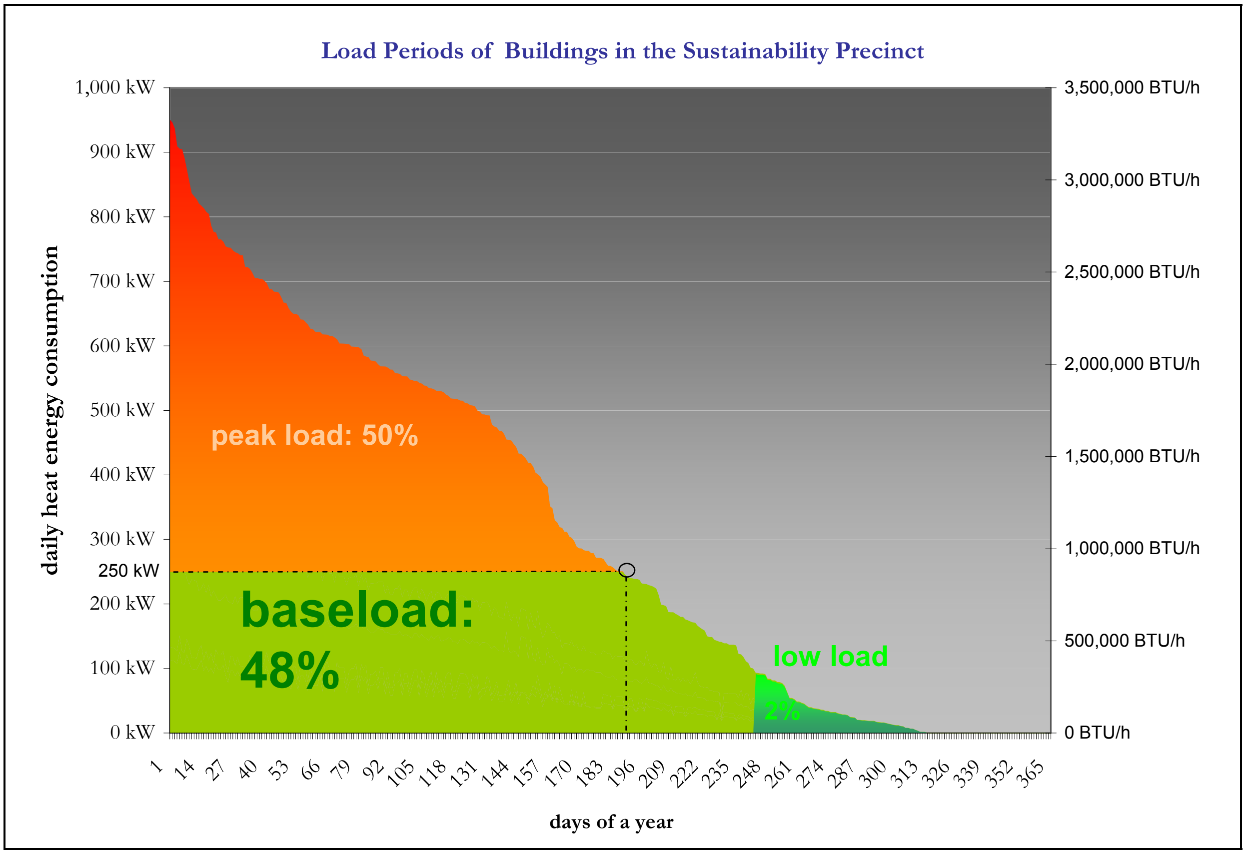


Figure 2.1 Load periods of all gas-heated buildings in the precinct (excluding NE-01). A baseload plant with an output of 250 kW (one quarter of the maximum of 960 kW) would cover 48% of the energy requirements of the precinct. This baseload plant would operate for a total of 250 days a year, including 200 days at full load (dashed line). Low load periods would be covered by another source.

The maximum daily heat consumption of the buildings in the precinct to be supplied by district heating is 960 kW. This load only occurs on one day of the year. During half the year (170 days) the heat consumption is less than 1/3 of this maximum. This load is called the baseload.

Baseloads are characterised by a fairly constant output, allowing a heat generator to operate at its maximum output most of the time it is running. Loads above this are peak loads that are typically served by more flexible plants that can be started up and ramped up at short notice. Peak load plants only operate during limited hours of a year. They often also cover the low load periods when there is not enough heat demand for the baseload plant to operate. Heat storage tanks may also be used to cover these low loads.

Thorough analyses of the hourly heat load, particularly the baseload is key to the design of a district heating system.

Baseload plant	***Peak load plant***
• Designed to operate at their performance maximum; • Long periods of operation; • Few changes in output; • Sometimes unreliable availability (e.g. solar thermal).	• Designed to operate at partial load, i.e. below max. output; • Short, intermittent periods of operation; • Frequent changes in output; • High availability throughout the year.

Tab.2.1 Characteristics of baseload and peak load heat generators

Baseload sources operate the longest of all heat sources. A baseload plant covering one-third of the load of the precinct could operate close to 250 days a year, most of the time at full load. The high usage of baseload plants allows employing technologies with high capital cost but low fuel costs, such as biomass boilers. Biomass heating is discussed in Chapter 2.3.6.

Fossil fuelled boilers are still required to cover peak demand. The more heat supplied by the baseload the better the economics of a district heating system. The load curve at the precinct is not very favourable, as it requires a high amount of peak load energy.

The model above is a rough approximation only and has to be taken with a grain of salt. An engineering design would require a detailed hourly load curve for a summer day and a winter day. Certain loads, such as the make-up air for the welding shop, should only occur during hours of operation, Monday to Friday, 8:00 am to 5:00 pm, creating additional peaks that need to be taken into consideration.

An engineering design would also have to consider that not all individual loads occur at the same time. The showers in one building may not be used at the same time as those in the building next to it. In district heating, a coincidence factor is applied to these loads to find the effective load. Typically effective loads are less than the total connected load, depending on the size of the network, the nature of the building and the hours of usage. Finally, some loads, such as domestic hot water, are covered by heat storage tanks to even out the load over the course of the day.

2.2. BCIT'S EXISTING CENTRAL BOILER PLANT

BCIT's Burnaby campus was designed for centralized heating. Thirteen of the 56 buildings on campus are supplied by the central boiler plant located in the heart of the built-up area.

In March 2004, Prism Engineering Ltd reported on BCIT's Central Heating Plant: [26]

> The three (3) heating boilers for the campus are 600 hp Cleaver Brooks (CB) fire-tube type, each with an input capacity of 25 million btuh. Boilers #3 and #4 were installed in 1963 and Boiler #5 was installed in the mid-seventies. Two of the boilers are operational, Boilers #3 and #5. Boiler #4 has been decommissioned and disconnected, as the load on the plant has never required the third unit.
>
> The normal winter heating load for the campus can be supplied by one boiler. Only on peak heating days is a second boiler required to accommodate the campus heating load.

[26] Prism Engineering Ltd.: "BCIT Central Heating Plant Analysis", Burnaby, March 2004, page 2.

The boilers have the original gas burners supplied with the boilers. On this style of burner, a modulating motor controls the combustion airflow and gas valve with tie-rod type air-fuel mixture controls. An adjustable cam allows the fuel and air ratios to be adjusted throughout the firing range.

The burners reportedly have been set up at a maximum firing rate of 75% on high fire and can turn down to about 20% of full load on low fire. When the heating load is less than the 20% low fire setting, the hot water supply temperature rises until the boiler finally trips off at about 235°F [113°C].

The burners are convertible to oil by a manual changeover, which takes about an hour. The gas supply to the heating plant is on an interruptible basis and the boilers are run on oil at the request of the gas supplier or when the price of oil is less than the cost of gas.

#	*heat generator*	*fuel source*	*rated output*	*seasonal efficiency*	*supply temperature*	*year installed*	*comments*
1	boiler #3	natural gas /heating oil	6 MW (600 BHP)	83%	107° - 110°C (225 – 230F)	1963	baseload plant used 5,000 hrs /yr.
2	boiler #4	natural gas /heating oil	6 MW (600 BHP)			1963	decommissioned and disconnected
3	boiler #5	natural gas /heating oil	6 MW (600 BHP)	83%	107° - 110°C (225 – 230F)	1975	baseload plant used 5,000 hrs /yr.
4	steam boiler	natural gas /heating oil	n/a	n/a	140°C (300 F)	n/a	for educational purposes only
	TOTAL		**12 MW**				

Table2.1 Boilers at BCIT's central boiler plant.

The boiler plant used to be operated year-round but for the past few years it has been turned off in July, August and the first half of September to reduce distribution losses.[27] Hot water is then supplied by satellite boilers in each of the buildings. Gas consumption of the boiler plant recorded for the summer period are probably due to hot water demand in the same building (SE-08) or in a building next to it that is connected to the same gas meter.

Connecting the precinct to the central boilerhouse would add another 950 kW, including pipeline and heat exchanger losses close to 1.0 MW to the load at the boiler plant. The graph below shows that one of the two existing 6,000 kW (600 BHP) boilers suffice to supply all of the buildings currently connected. When connecting the precinct buildings that are currently gas-fired, the second boiler in the boiler plant would have to be fired up 13 days a year only.

[27] Distribution losses are estimated to be 25 W per meter for the supply line, 20 W for the return line at a diameter of 100mm (4"). The 500-meter-long pipeline supplying NE-01, for example, is expected to have a heat loss of 23 kW. If shut down during the summer for a period of 75 days, energy savings of 146 GJ can be achieved, 1.3% of the total consumption of NE-01, but 170% of the summertime consumption of NE-01.

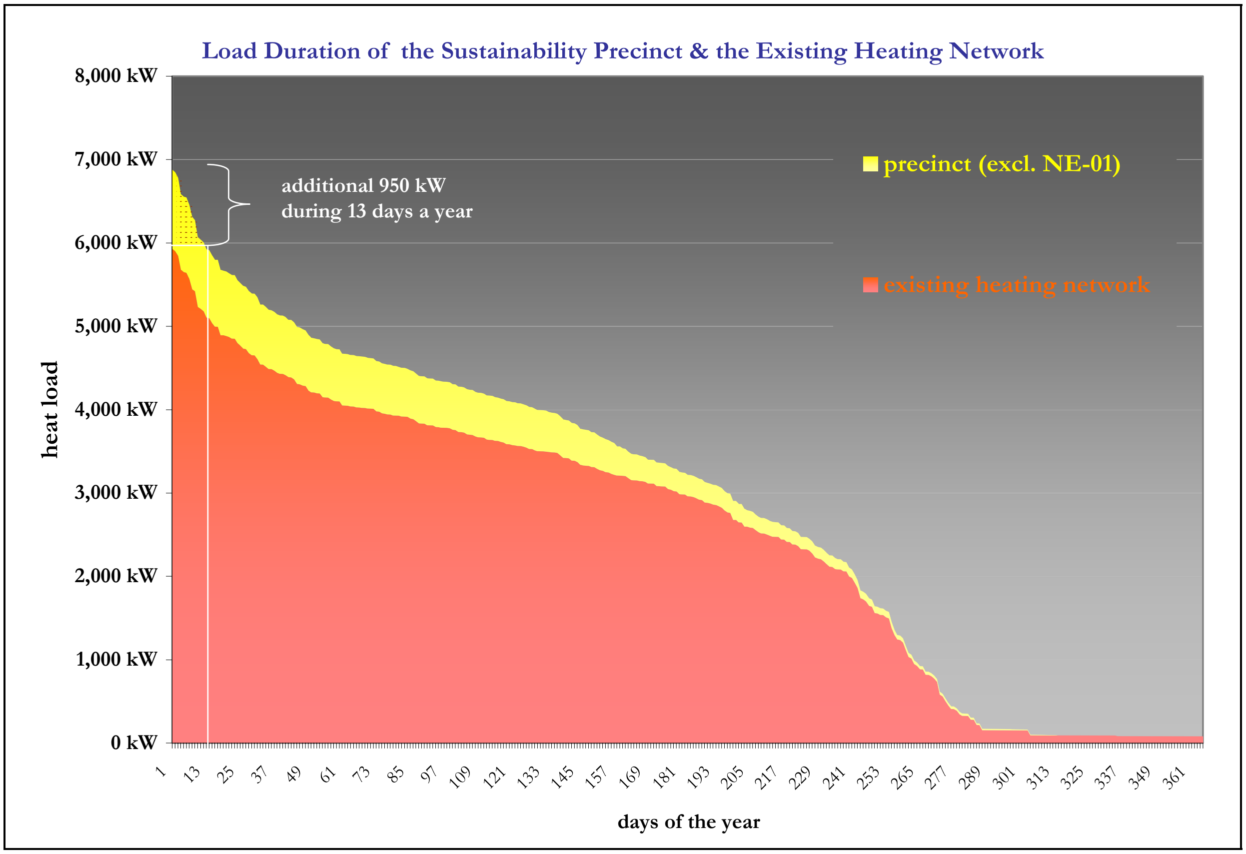


Figure 2.2 Load of the precinct added onto the existing district heating system. A single boiler at the plant could cover the load, except for 13 days. During these peak periods the second boiler would have to be fired up. Alternatively the precinct could supplement heat from existing gas-fired appliances on site.

Commercial district heating systems are operated by utility companies supplying heat to a variety of consumers. Heat supply contracts stipulate that the utility has to supply all of the heat required by the customer. This requires a certain amount of redundancy from the utility's side, making sure that heat can be delivered even, for example, if a boiler malfunctions. The situation is different at the campus where there are no contracts and all buildings are owned by the same institution as the boiler plant. This opens up the possibility of intermittent or baseload supply.

Rather than relying entirely on heat from the district heating system, the existing boilers, furnaces and infrastructure may be kept alive to act as back-up, summertime or peak load plants. The boiler plant would then have a fairly constant heat consumer during a good part of the year without having to cover peaks. Moreover, the district heating may be turned off during the summer, reducing pipeline losses during a period of low demand. The graph above illustrates this approach to heat supply.

Boiler capacity available at the central boiler plant would easily allow connecting the precinct to the existing heating network.

2.3. RENEWABLE AND DISTRIBUTED HEAT SOURCES

This section describes the potential for, and challenges with, using renewable sources, waste heat, and CHPs for district heating purposes. Some of the technologies described are low temperature, lower than needed by the existing heating network. These technologies might require a heat pump.

2.3.1. HEAT PUMPS

When talking about heat pumps, most people think of a system taking heat at low temperature from the ground or the air. However, other heat sources are possible as well. Geothermal heat, solar heat, and waste heat have been used in combination with heat pumps.

Heat pumps are used to increase the temperature of a heat source to a level that allows feeding the heat into a heating pipeline. Heat pumps are essentially 'inside out' refrigerators that increase the temperature of a heat source by using a compressor. A refrigerator removes heat from its inside and transports it to the outside, venting the heat off on the back side. Conversely a heat pump removes heat from, for example, the ground or a waste heat source, but deposits it to the district heating pipe via a liquid-to-water heat exchanger. In the process, the temperature is increased, just as the fins in the back of a refrigerator are much hotter than the food in the fridge used to be before it was cooled down.

Heat pumps require a source of high-value energy, such as electricity to operate. Depending on the temperature of the heat source and the temperature of the district heating pipeline, typically between one half to one quarter of the energy contained in the heat source needs to be added in the form of electricity to 'pump' the temperature to the desired level. In technical terms this is called the Coefficient of Performance (COP): a heat pump that delivers 3 kW (= 0.01 GJ = 10,000 BTU) of heat for every kW of electricity it consumes is said to have a COP of 3. The higher the temperature of the heat source and the lower the temperature of the district heating pipeline the higher the COP and the less electricity is required.

How green is BC's Electricity?

When talking about the environmental impact of electricity, the fact that BC has considerable hydroelectric power is often cited.[28] The BC Ministry of Environment states an average GHG emission factor of 25 kg per MWh of electricity used. [34] Average emission factors are, however, largely irrelevant when accounting for the impact of additional electricity usage or electricity generation and electricity savings.

With the system being maxed out, BC Hydro will have to serve growing demand, e.g. from a heat pump, by importing additional power from Alberta. The BC Ministry of Environment states that power from Alberta, where most of BC's imported power is purchased from, has an average emission factor of 870 kg of CO2-eq per MWh of electricity.[34]

If, on the other hand, power is saved or additional power is generated – e.g. by a fuel cell – those power plants with the highest variable cost (the highest fuel cost) to BC Hydro are likely to be turned down. Usually these are gas-fired thermal plants or imported power. It is unlikely that BC Hydro would spill water from its hydro dams, while continuing to import power or operate plants with high fuel costs.

In BC, gas-fired plants are reported to have an efficiency of 36.5%, resulting in an emission factor of 498 kg of CO2-eq per MWh of electricity. The Burrard Thermal plant has an efficiency of only 34% with a corresponding emission factor of 535 kg of CO2-eq per MWh. In Alberta, the gas-fired plant with the lowest efficiency and hence the highest variable cost, Rossdale 8, has an efficiency of 27.9% and GHG emissions of 651 kg of CO2-eq per MWh of electricity.[30]

All of the factors are about 20 to 35 times higher than the average emission factor of 25 kg/MWh in BC.[34]

The assessment above is unlikely to change significantly after 2016 when BC is supposed to have regained electricity self-sufficiency: power will still be traded with neighbouring provinces and states. Electricity saved or electricity generated in BC is likely to translate into exports that generally replace plants with the highest variable or fuel costs.

The time of day when electricity is consumed does play into the assessment. Being able to store water and therewith electricity, however, an increased demand will likely result in increased imports at the time of consumption or at a later stage, when hydropower, that could be used elsewhere has already been consumed and needs to be substituted by imports.

The issue is controversial and has been debated in various editorials, such as in the Globe and Mail, see http://www.theglobeandmail.com/news/national/article748683.ece .

A more detailed explanation is given in Appendix 4.

The environmental benefit of heat pumps depends on (a) how much electricity is consumed, i.e. the COP and (b) how this electricity is generated.[28] While it might seem at first that this is a technical issue, the answers are likely to be based on economic, possibly even political considerations. An initial assessment is given in the box above, a longer analysis is provided in Appendix 4.

Currently additional load on BC's electricity grid is served by power imports, mostly from Alberta. This is likely to remain unchanged as long as BC Hydro can export its power at a significantly higher price than it pays for imported power. For this reason the additional load produced by a heat pump will likely be powered by imported electricity rather than electricity generated in BC.

If powered by electricity from a low-efficiency (23%) coal fired power plant, a heat pump would have to have a minimum COP of 4.3 to break even – i.e. to generate the same amount of energy as is consumed by operating the heat pump. [29] The graph below illustrates this.

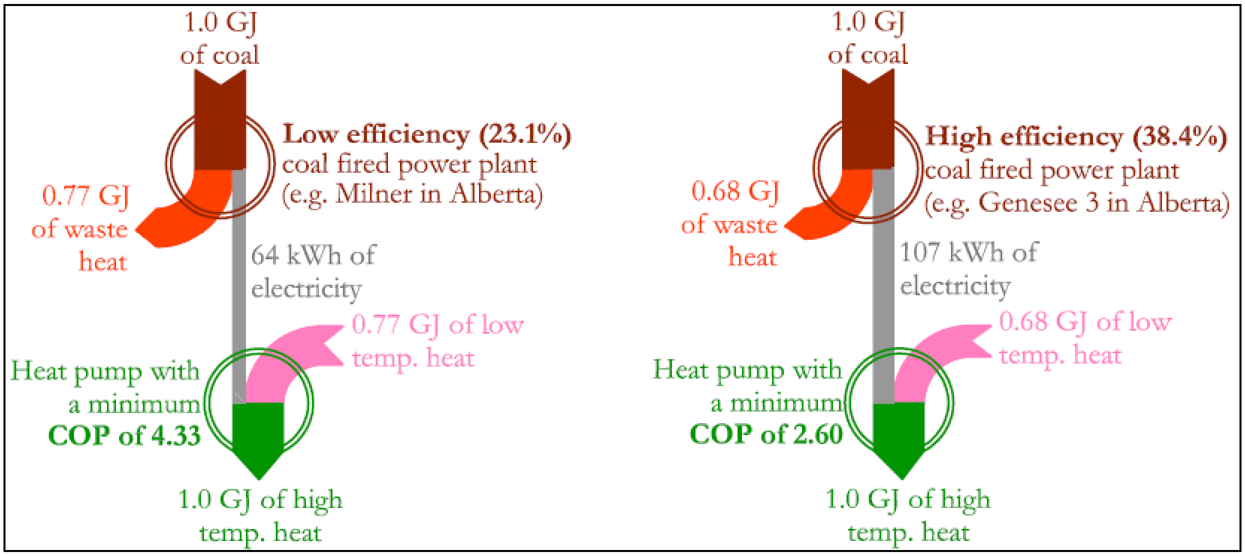


Figure 2.3 Primary energy balance of a heat pump using imported electricity from a low-efficiency (worst case) and a high-efficiency (best case) coal-fired power plant.[30] To generate the same amount of primary energy as is consumed in a low efficiency power plant, the heat pump needs a Coefficient of Performance (COP) of 4.33, i.e. it needs to generate 4.33 kWh of heat for every 1 kWh of electricity. The break-even point is a COP of 2.6 when using electricity from a high efficiency power plant. Below this, less energy would be consumed by heating the campus directly with coal. Monitoring of ten homes in Manitoba showed a seasonal coefficient of performance ranging from 1.8 to 3.5 with average of 2.8 for a one year period.[31]

[28] BC Climate Action Plan, Chapter 4, page 15; http://www.env.gov.bc.ca/cas/pdfs/climate_action_21st_century.pdf
Or: BC Hydro, Annual Report 2010, page 50, http://www.bchydro.com/etc/medialib/internet/documents/annual_report/2010_annual_report.Par.0001.File.2010_annual_report.pdf

[29] The argument may be made that this choice of a coal fired power plant does not reflect the average import. The Alberta utility exporting power, however, will sell electricity with the lowest variable cost which, in Alberta, is coal fired power. Coal fired power plants in Alberta have a conversion efficiency between 23.1% (Milner plant) and 38.4% (Genesee 3)[22]. They are owned by two separate utilities.

[30] Power plant emission factors were taken from: JEM Energy & Associates: "A Study on the Efficiency of Alberta's Electrical Supply System - Project # CASA-EEEC-02-04 For Clean Air Strategic Alliance (CASA)," Calgary, October 2004. See http://www.hme.ca/reports/CASA_Report_--_The_Efficiency_of_Alberta's_Electrical_Supply_System_EEEC-02-04.pdf

[31] Manitoba Hydro: Appendix 44 – Attachment 5 to a one year study on ten homes with ground source heat pumps. See http://www.hydro.mb.ca/regulatory_affairs/electric/gra_2010_2012/Appendix_44-Attachment_5.pdf

Average performing heat pumps are likely to have a negative environmental impact, consuming more primary energy and generating more global CO_2-emissions than an average gas-fired boiler.

From a GHG emission point of view, a heat pump with a COP of 3, using electricity imported from Alberta, will emit 290 kg of CO_2-eq [32] – 4.5 times more than a mid-efficiency gas-fired boiler.[33] This number is based on GHG emission factors as stated by the BC Ministry of Environment.[34]

From an economic point of view, heat pumps with an average COP of 3 are economically more beneficial than an average gas boiler as long as the price of electricity is less than 3.5 times the price of natural gas. When this report was written, the price differential between the two energy sources was only a factor 2.5 and 1.2: BCIT paid 8.15 cents per kWh of electricity (first 14,800 kWh of each month) and 3.93 Cents/kWh (everything above 14,800 kWh) [35] ($22.6 and $10.9 per GJ), while its fixed-rate gas supply contract resulted in an average blended price for natural gas of $9 per GJ.

2.3.2. GEO-EXCHANGE OR GROUND-SOURCE HEAT PUMPS

Heat removed from the ground can be used to heat a district heating system. Systems that work close to the earth's surface, at less than 200 m depth, rely on constant temperatures to either extract heat or cold from the ground. These are called geo-exchange system and are different from geothermal systems that operate at greater temperatures and greater depth. At depths below 1,000 m, the Earth's crust is heated by upward conduction and convection from the Earth's core and by the decay of radioactive elements in the crust.

Geo-exchange systems use either horizontal or vertical collectors. Horizontal collectors require large areas that are usually not available in urban areas where district heating is applied. Most geo-exchange systems for district heating take ground water as a heat source. Ground water has a temperature of 10°C regardless of the season. The water is pumped to the surface, run through a heat exchanger and returned to the aquifer, usually downstream of the first pipe and at no less than 5°C.

Problems have occurred with ground water heat pumps in areas with hard water: calcium-carbonate may crystallize in the cooling process, clogging pipes and possibly the well itself. Chemical testing of the water wells is done to anticipate the issue prior to installing a costly collector system. Closed loop systems that circulate water, often with an antifreeze glycol component, avoid this problem. The geo-exchange system installed behind (north of) the AFRESH house is a closed-loop system.

Geo-exchange systems can be used for cooling purposes provided there are district cooling pipelines. Cooling pipelines are physically separate from heating pipelines, allowing cooling and domestic water heating at the same time.

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[32] Carbon dioxide-equivalent (CO2-eq): a factor taking the potency of a specific GHG into account and comparing it to the GHG effect of CO2

[33] Emission factor for natural gas: 50.5 kg of CO2-eq per GJ of gas burned [34]; using a boiler efficiency of 80% results in 63.1 kg of CO2-eq per GJ of heat generated. Emission factor for electricity purchased from Alberta: 870 kg of CO2-eq per MWh of electricity. [34] 870 kg / 63.1 kg = 13.8

[34] Ministry of Environment, "Methodology for Reporting B.C. Public Sector Greenhouse Gas Emissions" – Version 1.0, Victoria Feb 2011. See http://www.env.gov.bc.ca/cas/mitigation/pdfs/Methodology_for_Reporting_BC_Public_Sector_GHG_Emissions.pdf

[35] All of BCIT's buildings are on a Large General Service' (LGS) rate. In 2010 the LGS rate had a declining block rate with a step-down between two pricing levels: the first 14,800 kWh consumed in each month was charged at 8.15 cents per kWh; everything above this was charged at the lower rate of 3.93 cents per kWh. A new rate structure has been implemented in 2011. Rates charged now depend on past consumption, the so-called 'baseline'. Consumption above this historic baseline will be paid for at 6.68 cents/kWh.. Consumptions below the baseline will remain at 8.15 cents/kWh. A consumption reduced below the baseline, however, will be credited at a rate of 6.68 cents/kWh.

The performance of the geo-exchange system used at the AFRESH house should be monitored for one year.

Obtaining data on seasonal efficiency allows judging the aquifer's suitability for district heating.

Geo-exchange systems require a heat pump and are therefore sometimes called ground-source heat pumps. While the heat in the ground is almost infinite, the electricity used to run the pump and the refrigeration unit is not. The higher the supply temperature of the district heating system, the more electricity is consumed when boosting the temperature to the required level.

Given the temperature level of the existing heating network, it is unlikely that a COP above 2.6 can be achieved. Using a geo-exchange system to feed heat into the existing heating system would likely have a negative environmental impact. Lower supply-line temperatures could potentially result in a net positive energy balance. As a starting point, we recommend monitoring the seasonal performance of the heat pump installed at the AFRESH house. The monitoring results would allow the environmental benefits of this – and likely other geo-exchange systems working off the same aquifer – to be assessed.

UBC's Okanagan campus installed a geo-exchange system in 2009 to heat two buildings. The university has plans underway to expand to a campus-wide system replacing an existing natural-gas-fired heating system. All new academic buildings are designed to use the geo-exchange system for heating and cooling; all existing academic buildings have been retrofitted to enable heating with a ground water heat pump.[36] Upon completion, the geo-exchange project is expected to be the largest university geo-exchange system in North America. The heat pump is reported to have a COP of 3.0, heating groundwater from an aquifer at 60 meters depth from a temperature of 10.5 to 54°C.[37]

2.3.3. GEO-THERMAL HEATING

Geothermal heating systems consist of two pipes introduced into deep bore holes with a depth of one to two kms. Water is injected into the outside pipe and heats up as it descends. At the bottom of the pipe the hot water is extracted through the inner, insulated pipe. The energy is transferred to the district heating network by a heat exchanger.

Geothermal heating systems require high up-front investments for drilling efforts that face geological uncertainties. Geological modelling has become an important factor in reducing this risk. Commercially successful geothermal district heating systems have used existing boreholes left behind by the oil industry.

The Lower Mainland features a number of geological anomalies with high temperatures at low depths. The Burnaby area, however, is not a zone with high geothermal potential.

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[36] University of British Columbia: "Sustainability Report Okanagan Campus, 2009" Kelowna, 2009, see http://www.ubc.ca/okanagan/sustainability/__shared/assets/CNAR17271.pdf

[37] Roger Bizzotto: "From the Ground Up", in the June 2010 edition of the 'Shift Magazine', see http://www.ubc.ca/okanagan/sustainability/__shared/assets/917907.pdf It is not clear from the publication whether the "300 per cent efficiency" accounted for electricity use of the pump and auxiliary consumers.

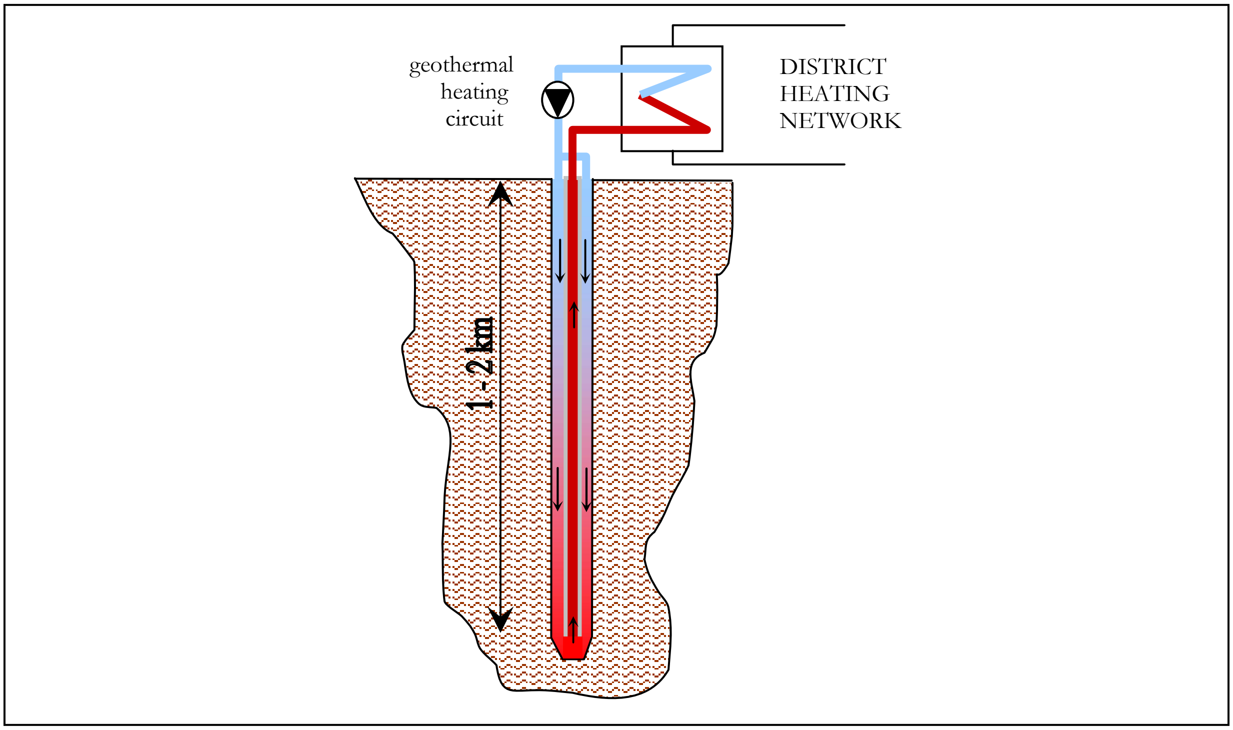

Figure 2.4 Schematic of a geothermal deep borehole. Water is heated by geothermal heat at a depth of between one and two kms. The closed-loop geothermal circuit transfers heat to the district heating system.

In Hot Dry Rock (HDR) systems, two wells are drilled into high-temperature crystalline basement rock. Water is injected through one well and then circulated though the fractured hot rock where it creates a man-made reservoir. Bedrock temperatures are high enough, typically above 180°C, to pressurize the reservoir and extract steam for power generation or district heating. The technology is also called an Enhanced or Engineered Geothermal System (EGS) as reservoirs are created artificially rather than by using fluids available in the rock.

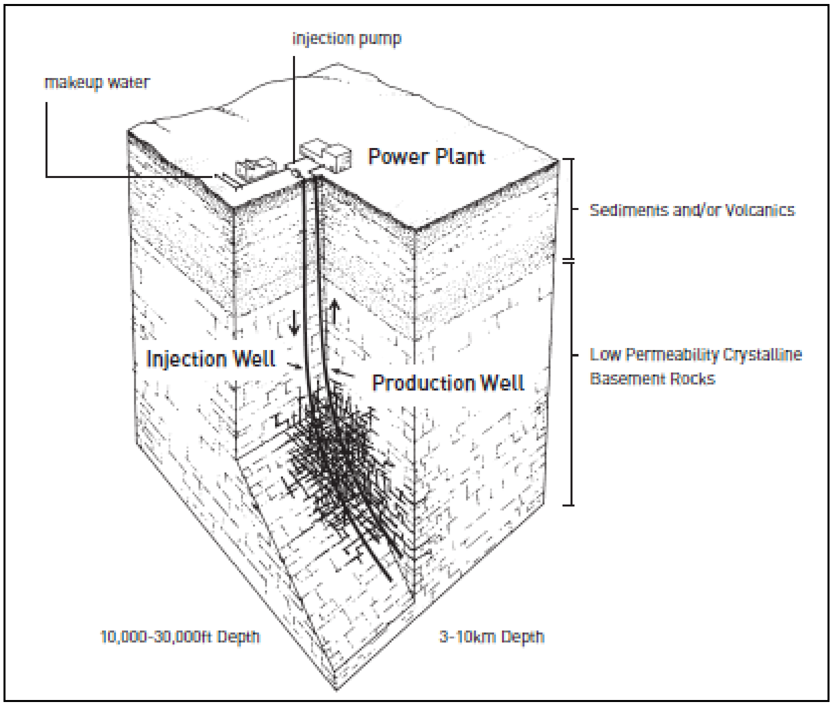

Figure 2.5 Schematic of a two-well Engineered Geothermal System (EGS) in hot rock in a low-permeability crystalline basement formation. Wells are created at a depth of three to ten kms. Source: MIT: *The Future of Geothermal Energy*, 2006

EGSs operate at the depth of three to ten kms required for power generation. For district heating, the waste heat from the power generation can be used. The technology is at a development stage.

While the footprints of geothermal and EGS systems are small, they might still be too large for the Burnaby campus. Economies of scale require large applications with a heating capacity above 20 MW to be economically viable.

2.3.4. WASTE HEAT RECOVERY

Waste heat – any heat not used for heating or cooling – can potentially be used in a district energy system. The two key requirements are that the waste heat is physically close to the heating network and that temperatures are high enough to be used in the district heating system.

In most cases, waste heat used in district heating stems from industrial processes. On campus the only sizeable waste heat source is the server room at SE-12. This source might be worth researching as it might also reduce the cost of operating the server. Being located outside the precinct, this opportunity has not been researched in this study.

Waste heat from the computer server could be used for district heating purposes, reducing operating costs for the server itself.

Another waste-heat source is the existing sewer system. As shown in Chapter 1.4, the precinct is estimated to consume a total of 28,000 m³ of water a year, of which 3,800 m³ is heated water. Cold water is estimated to enter the building at 8°C, then it is heated up to 10°C with the building's heating system by the time it leaves the tap. Domestic hot water is typically used at 38° to 41°C. Since 13% of the water (3,800 of 28,000 m³) is domestic hot water, the sewer temperature should, in a first-order approximation, be 14°C. Cooling the sewage down to 5°C would yield 1,060 GJ of low-temperature heat a year, 5%

of the entire precinct.

An initial estimate showed that the amount of sewage heat available at BCIT's Burnaby campus is too small (5% of the total consumption) and too cold (14°C) for district heating purposes.

The increased temperature of the heat source will require less electricity to pump the heat source to a level usable for district heating. The energy output mentioned above is only a rough approximation based on the sewage temperature, which should be measured to confirm this assessment.

A sewage heat pump is unlikely to be economically effective for a small area, such as the precinct. Instead the sewage from the entire campus should be tapped into. The sewage system at BCIT is divided into two catchment areas, each with its own gravity sewer collection system.[38] The pipes from these two catchments discharge directly into the City's trunk sewer at Canada Way and at Willington Green. A 2004 report of EarthTech recommends an upgrade of sewer pipes

> "between Manholes SE5 and SE4 […] and Manholes SE 4 and SE3 […] – this is the sewer north of NW1 to Smith Street. These sewer lengths should be upgraded to 250 mm. It may also be appropriate to upgrade sewer sizes as far as Canada Way."

Along with these upgrades comes an opportunity for waste heat recovery using pipe-in-pipe technologies. The upgrades are located outside the precinct though. At the time of writing this report it remained unclear whether these upgrades have partly been implemented already.

Commercially successful sewage heat recovery systems are often located at waste-water treatment plants or sewage pumping stations[39] where waste heat is available on a continuous basis. Using sewage heat at the municipal level has legal implications as the sewage is technically owned by either the municipality or the utility in charge.

While it may be worth researching sewage heat recovery, indications are that the amount of sewage heat available at BCIT's Burnaby campus is too small (5% of total consumption) and too cold (14°C) for district heating purposes.

2.3.5. SOLAR THERMAL

Solar thermal technologies use solar radiation to generate heat. At Burnaby's latitude, on a bright, sunny day, up to 1,000 watts per square meter can be expected, generating water with a temperature of up to 95°C. On overcast days, however, only a fraction of this, typically 200 W/m², are available, resulting in much lower temperatures.

Figure 2.6: Large field of evacuated tube collectors with a parabolic concentrator installed on a roof. Photo source: solarserver.com

The Vancouver area receives an average solar radiation of 4.5 GJ per square meter.[40] Vacuum tube collectors have an efficiency of 30% to 50%, depending primarily on the temperature they need to achieve. At a mean collector temperature of 40°C, around 2.5 GJ (53%) of heat can be produced per m² of collector

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[38] EarthTech: Infrastructure Review 2004, Section 2 – Sanitary Sewer System.

[39] The False Creek community energy centre uses a sewage heat recovery system at a sewage pump station. For a description see http://vancouver.ca/sustainability/neuTechnology.htm

surface. At a 70°C collector temperature, the output is reduced to 1.6 GJ per m² (36%). These numbers are for a vacuum tube collectors facing due south and inclined at 50°C. Feeding into a low temperature heating network yields higher outputs than feeding into a high temperature pipeline.

A total of 4,000 m² of south-facing solar collectors could be installed in the precinct.

This would make it the largest solar collector field installed in Canada.

The output of a solar collector obviously changes with the season. At Burnaby's latitude, summer outputs are approximately five times those available in winter. An inherent problem of solar heating is that the supply of solar energy does not match the demand for heating a building. This creates deficits in winter and surpluses in summer.

Using all the roof space available at the precinct, a collector area of 4,000 m² could be installed. See Figure 2.7 below.

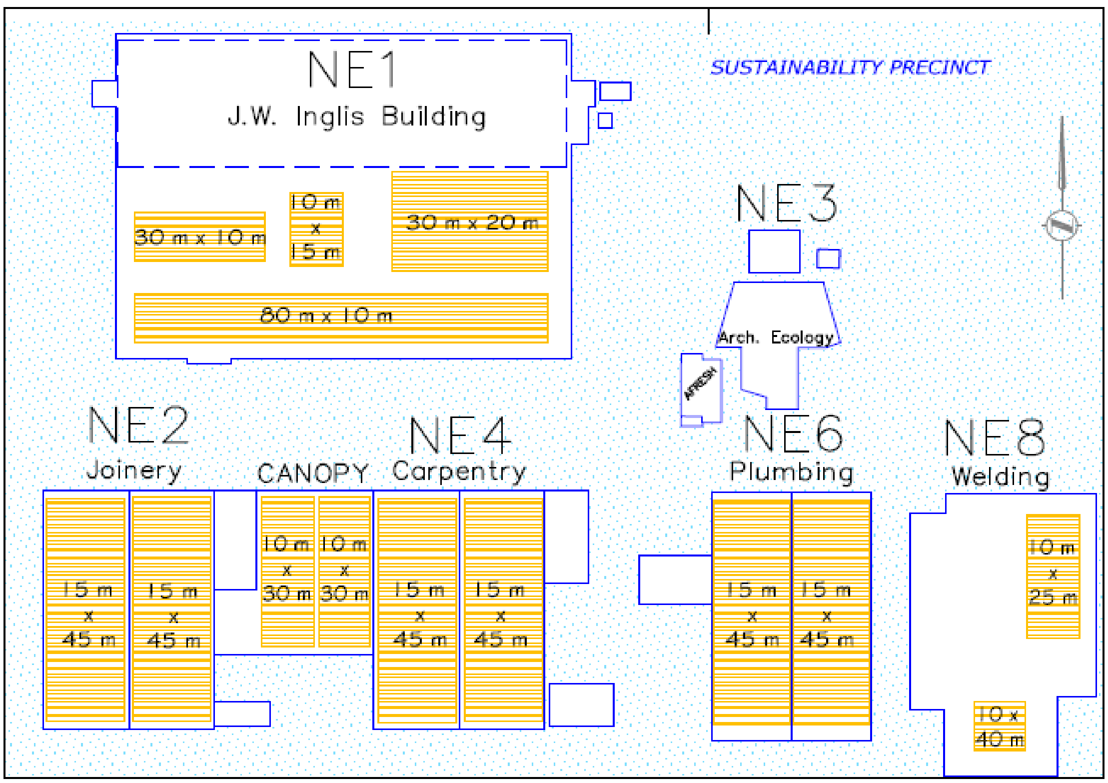

Figure 2.7 A total of 6,550 m² of roof area in the Sustainability Precinct is available for solar collectors. Approximately 4,000 m² of south-facing collectors could be installed on this area.

A rough model has been developed by calculating daily outputs of a collector area of this size. Based on solar radiation data in Vancouver,[40] the solar collectors would be able to supply 5,300 GJ to the precinct at 45°C, or 4,200 GJ to the existing heating network at 96°C.[41] The lower output that would go to the existing

[40] Solar radiation data is available at Services for Professionals in Solar Energy and Radiation (SODA). SODA's software simulates daily mean solar irradiance aggregated from 15-minutes Meteosat satellite images, see http://www.soda-is.com/eng/services/service_invoke/gui_result_demo.php?InputXML=SoDaParam_130116201456.xml&ServiceXML=nasa_helioclim_daily.xml

[41] Outputs are rough estimates based on a collector characteristic of a concentrating vacuum tube collector and Vancouver weather data. A more realistic result can be obtained using simulation software, such as Polysun. See http://www.velasolaris.com

heating network is due to higher pipeline temperatures that reduce the seasonal collector efficiency to less than 12%. The performance characteristic of a vacuum tube collector is explained in Appendix 3.

In the case of the precinct, however, the fraction of solar heat that is actually useable is only 40%; the rest of the energy would have to be discarded as there is no demand for it. The situation is a bit more favourable for the much-larger existing heating network, where 53% of the heat generated can be used. In both cases the lack of summertime heat demand creates this low fraction of useable heat. The district heating system is entirely shut down during the summer months. The two graphs below illustrate the situation.

In the precinct example, 14% of the heat requirements would be from solar. When feeding into the much larger existing heating network, only 3% of the natural gas currently consumed would be replaced. To avoid having to discard large amounts of heat, solar collectors are often sized to only cover a small fraction of the total heat demand, typically a part of the baseload, leaving the rest to conventional boilers. A 100m² collector area would cover 1% of the total heat requirements of the precinct, but avoid having to discard more than 4% of the total energy produced. Increasing the tilt of the collector increases winter output while decreasing summer production. These types of optimizations are usually done using commercially available simulation software, such as Polysun.[41]

Seasonal storage systems, as the Drake Landing Solar Community in Okotoks, AB[42] try to overcome the lack of coincidence of supply and demand, but are very costly. For example, to store 1,000 GJ – 15% of the collector output of collectors at the precinct – a storage volume of five Olympic pools is required. New chemical storage systems (latent heat storage) are being developed that have less volume and fewer storage losses, but they are not commercially available yet.

Even without the objective of storing summer-time energy for winter use, solar thermal collectors need heat storage tanks to match the daily fluctuations in supply with those on the demand side. As a rule of thumb, 50 litres of hot water storage are required for each square meter of collector surface. The 4,000 m² collector surface would thus require a 200 m³ storage tank with a footprint of 10 x 10 metres.

The collectors on the J.W. Inglis Building (NE-01) alone would require close to 100 m³ in storage volume. Such large storage tanks are typically non-pressurized above-ground tanks with a nitrogen overlay to avoid pipe corrosion. Heat storage tanks are used extensively by BC's greenhouse industry.

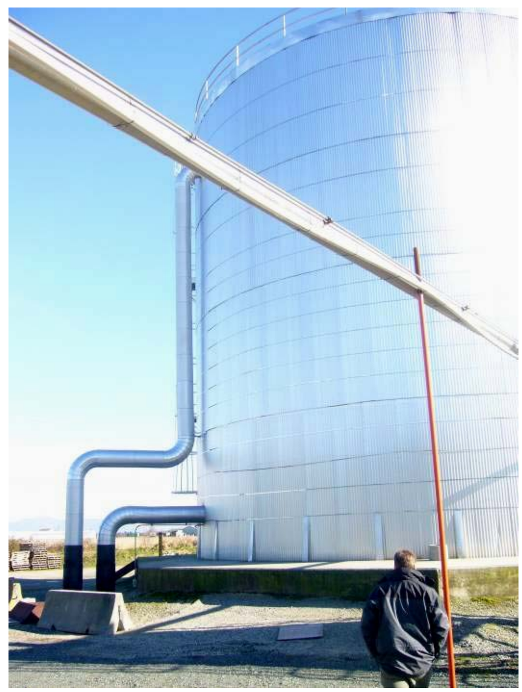

Figure 2.8 Two million litre (2,000 m³) heat storage tank at a greenhouse in Delta, BC. A 4,000 m² solar collector array would need a storage one tenth of this size.

[42] Drake Landing Solar Community (DLSC). See http://www.dlsc.ca/

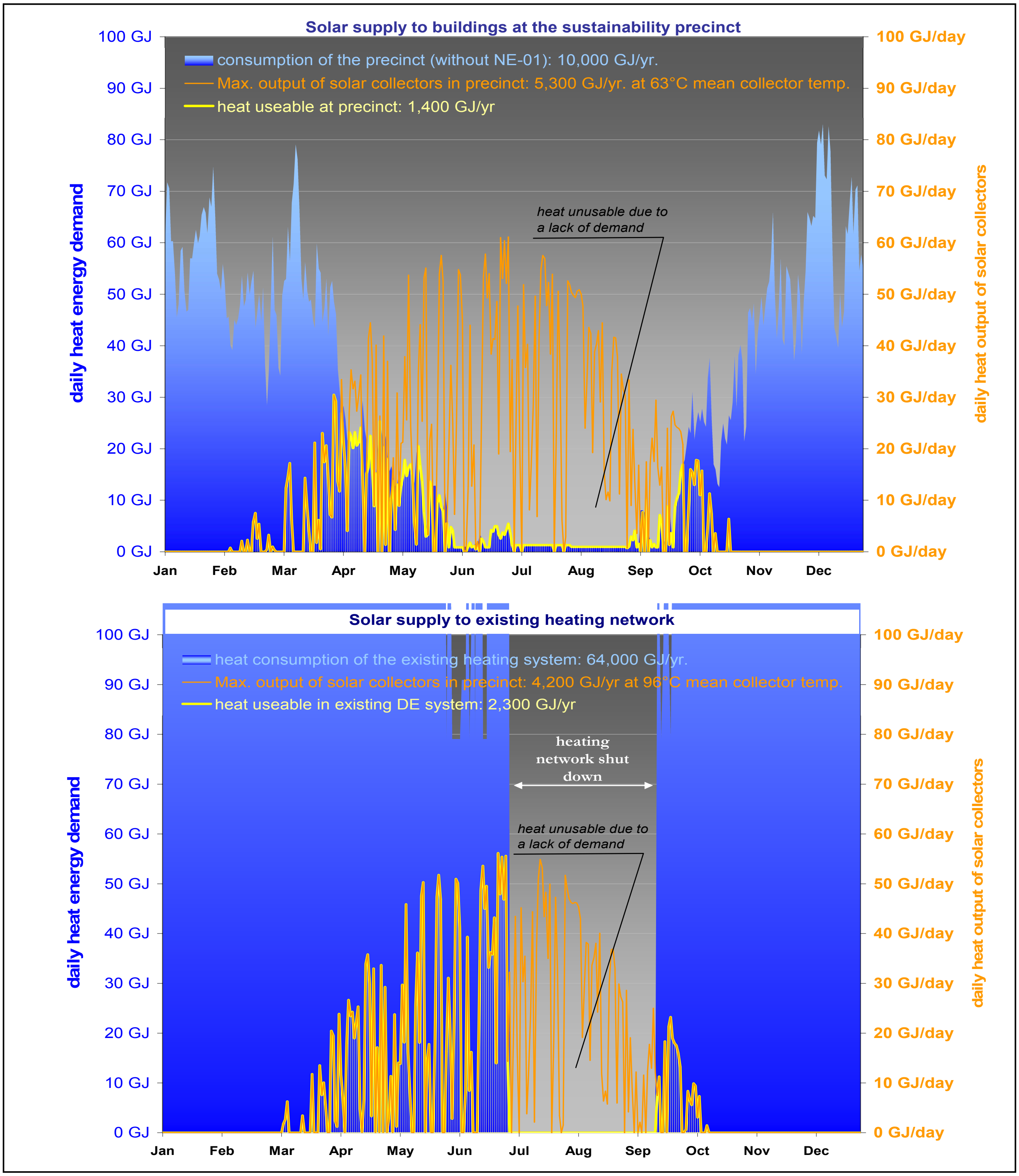

Figure 2.9 Low-temperature and high-temperature solar heat supply: 4,000 m² of solar collectors could cover 30% of the precinct's heat requirements (upper graph), but only 6% of the existing heating network's heat demand (lower graph). Surplus heat generated in the summer will have to be dumped. The existing heating network has a much larger demand than the precinct, resulting in the disposal of less heat. Based on Vancouver weather data.

When feeding into the grid, some solar systems are designed to only pre-heat the return line. Having a lower temperature than the supply line, the collector will be more efficient. Conventional boilers in the plant would only need to boost the temperature before feeding it back into the supply line. Certain appliances, such as a condensing boiler, however, rely on a low return temperature to work effectively. The solar plant would thus 'fight' the condensing boiler plant rather than supplement it. The decision to include solar thermal in the portfolio should be taken in view of the overall master plan for the district heating system.

The fact that the J.W. Inglis building uses a satellite boiler to produce domestic hot water might open an opportunity to install a non-integrated solar thermal system on the roof of NE-01. The solar collector array would feed the domestic hot water system of the building only. This would not be a district heating approach and has not been investigated.

Other challenges of solar water heaters are health and safety requirements. Domestic water is typically delivered below 42°C, but water tanks need to be heated up to above 55°C at least once a week, to kill Legionella germs, the bacteria that causes Legionnaire's disease. These bacteria may colonize hot water heaters and can pose a lethal health risk. The Canadian Plumbing Code requires that water tanks are kept at 60°C at all times.[43] The collectors have to operate above this temperature and at a reduced efficiency. The problem can be addressed by using buffer storage tanks preheating the water only using other heat sources to raise the water temperature to 60°C.

The decision to include solar thermal in the portfolio of heat generators should be taken in view of the overall masterplan for the district heating system.

2.3.6. WOODY BIOMASS

Biomass energy is one of the lowest-cost renewable sources still available. The GLOBE Foundation's "Endless Energy Project" assessed BC's potential for 'district scale biomass energy generation to 42.5 PJ, representing 47% of the province's total remaining renewable energy potential.[44] The provincial government has put a special focus on biomass, developing a bioenergy strategy that calls for "at least 10 community energy projects that convert local biomass into energy by 2020."[45]

Wood is the largest bioenergy feedstock resource in British Columbia. As a result of the pine beetle infestation, a large amount of low-value wood is available from the forest. Local mill residues will increase over the next two decades because the harvested beetle wood is of lower quality and less of it will meet the quality standards for traditional wood products.

A source more readily available in the Lower Mainland is wood from construction and demolition: Waste can be separated and untreated wood can then be used for energy generation, after separating out impurities and metal, and after chipping the wood.

Currently demolition waste may not be used as a fuel. Metro Vancouver, however, plans to divert wood waste from its landfills. The legislation will likely be changed in the near future to allow using this fuel stream.

[43] For an explanation of recent changes to the plumbing code see http://www.cashacme.com/_images/pdf_downloads/products/thermostatics/General/Canadian_Plumb_Code.pdf

[44] Globe Foundation: "The Endless Energy Project – A Blueprint for Complete Energy Self-Sufficiency in British Columbia," January 2007. The report is available at http://www.globeadvisors.ca/media/368/globe_endlessenreport.pdf

[45] BC Bioenergy Strategy. See http://www.energyplan.gov.bc.ca/bioenergy/

Biomass produces CO_2 when converted into energy. However, the same amount of CO_2 would be released if the biomass decomposed on the forest floor or landfill. Biomass is therefore classified as carbon neutral.

Figure 2.10 Biomass-fuelled combined heat and power plant using an Organic Rankine Cycle (ORC) technology. The plant has an electrical output of 1.6 MW.

Biomass energy may be in solid, liquid or gaseous form, permitting a wide range of applications. This report only deals with woody biomass energy supplied in solid form, such as forestry residue, woody construction debris, or urban wood waste. Other forms of biomass, such as agricultural residues, municipal solid waste (MSW), sewage solids, and other organic solid waste have been disregarded as they are not readily available in large enough quantities at or in the vicinity of BCIT's Burnaby campus. Trucking these low-energy fuels into the urban setting of the campus is unlikely to be politically acceptable.

Biomass-to-energy technologies can be separated into heat-only processes and combined heat and power applications. Heat-only processes – typically combustors with hot water boilers – are commercially matured and have been on the market for more than 30 years.

Biomass-fuelled combined heat and power (CHP) technologies

There are several biomass-fuelled combined heat and power (CHP) technologies; the most proven employs a classic Rankine-cycle steam turbine. Organic Rankine Cycle (ORC) turbines operate essentially the same way but, instead of using water, it uses an organic fluid such as silicone oil that evaporates at a lower pressure. The BC Safety Authority recently exempted ORC turbines from continuous supervision requirements. ORC units thus have a commercial advantage for small-scale (< 2 MW_{el}) power generation. Above this threshold higher staffing costs of conventional steam engines are justified by their higher conversion efficiency.

Figure 2.11 Sterling engine with a 35 kW electrical output. The heat exchanger on the left is inserted into the combustion chamber of a biomass boiler with a heat output of 250 kW, the size that is planned at BCIT's Joinery Workshop. Photo source: MAWERA Austria and Sterling Denmark.

Wood gasification employing internal combustion engines is another CHP technology that has received enormous attention in the past decade. The key advantage of internal combustion engines is their higher conversion efficiency: While ORC-units achieve an overall electrical efficiency of 14% to 15% of the energy contained in the biomass, small-scale internal combustion engines can convert up to 25% of the same energy into electricity. Technical challenges are, inter alia, related to tars in the wood gas that tend to stall engines in the long run. The technology is not yet commercially proven. However, some companies have operated wood-gas fuelled combustion motors more than 8,000 hours and have passed the proof-of-concept stage.

Most biomass CHP technologies are industrial-sized plants with footprints similar to that of the Joinery Workshop. The plants would likely have to be located outside the precinct.

The most applicable small-scale biomass CHP technology usable in the precinct is a Stirling engine, also called a 'hot air motor'. Like a steam engine the Stirling motor is an external combustion engine, as all combustion happens outside the engine. Unlike a steam engine that converts a gas (steam) into a liquid (water) a Stirling engine, though, operates only on gas (air). Using the heat generated by combustion of wood air is compressed and subsequently expands inside the engine to drive a piston. In the absence of steam there is no supervision requirement.

Since the motor is heated from the outside it can be easily cleaned and does not affect moving components inside the engine. More important, Stirling engines come in small sizes (below 100 kW) that could be fuelled by the wood residue available from the Joinery Department and the Carpentry Shop in the precinct. No additional fuel would have to be trucked in.

The technology has passed the proof-of-concept stage but is not yet an 'off-the-shelf' piece of equipment. Key challenges are deposits of fly ash and soot on the heat exchanger surface, requiring frequent cleaning for effective heat transfer. For this reason, only low-ash and low-chlorine woody biomass can be used. Melamine faced particle board used at the Joinery department might not meet this requirement.

Suppliers of biomass fuelled hot air engines include Stirling Denmark (http://www.stirling.dk/) and Talbotts (www.talbotts.co.uk).

Biomass-fuelled heat only boilers

Biomass boilers (a heat-only technology) don't differ significantly from natural gas fuelled boilers. However, using a solid fuel requires a different kind of operation than a natural gas-fired boiler:

- Fuel is not pipe bound and needs to be stored on site. Wood chips are bulky; a volume of no less than 110 m^3 per MW of output is required. For small units, as required by the precinct, the size of fuel delivery truck needs to be taken into account. The storage should be able to hold at least 1.5 times the load of the delivery truck;

- Starting up the boiler is more involved. It takes more time and usually results in above-average emissions;

- The turndown ratio is generally limited to 25% - 30% of the rated output. At loads below this, the boiler either turns off or switches into idle mode;

- On/off operation is to be avoided; the boiler should be designed as a baseload boiler;

- Fly ash and particulate matter emissions need to be controlled with filtering technologies. Metro Vancouver requires biomass boilers to have particulate matter emissions below 18 mg/sm^3 and a chimney height of at least 20 m;[46]

- Fuel handling issues are the single most frequent reason for break downs.

[46] Greater Vancouver Regional District: "Boilers and Process Heaters Emission Regulation Bylaw No. 1087", 2008, item 28

A key challenge for a biomass heating system has been the location of the plant and storage facility.

There are few areas within the precinct that could host a biomass boiler plant and have easy access for large trucks to deliver fuel.

The Joinery Department has been proactive in finding ways to use its wood residue along with that from the neighbouring Carpentry Department. The plant would not require outside fuel to be trucked in. As a first step, a new centralized dust extraction system was installed in 2010, collecting dust from both departments to a single hopper on the west side of the joinery workshop. A chipper for solid cut-offs will be set up under the canopy between NE-02 and NE-03. The chipper will be attached to the dust extraction system in 2011. With these modifications, close to 255 tonnes of dry wood residue will be available. See the graph below:

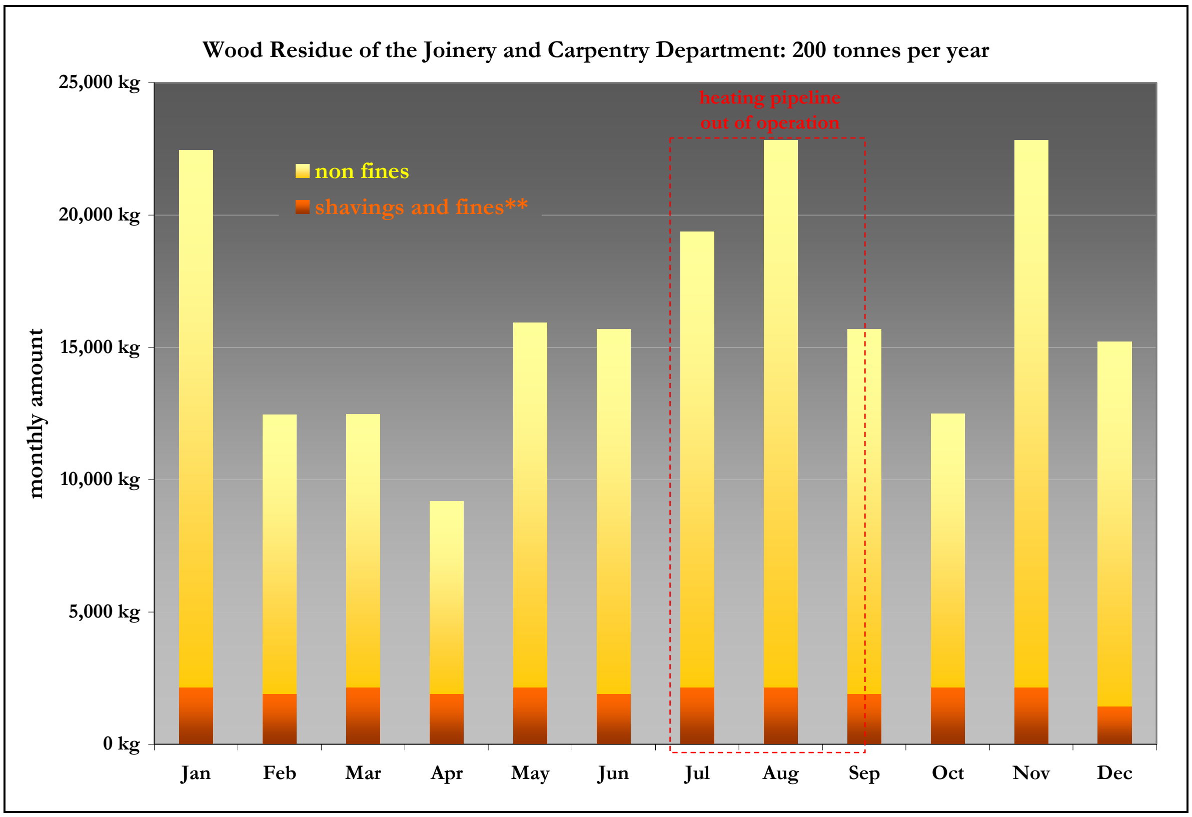

Figure 2.12 Between the joinery and carpentry workshops, 255 tonnes of dry wood waste are generated a year. Waste incurred during the off-heating season, when the heating pipeline is shut down, will have to be trucked out. Seasonal storage would require too large a silo.

A 250 kW (900,000 BTU/h) firebox boiler would be able to turn all the residue into heat. This heat would be fed into the heating pipeline, passing along the west side of NE-02. The biomass boiler would have no problem with high supply water temperatures. Waste generated during the summer, when the heating network is shut down, will have to be trucked out. Alternatively, the heating network could operate throughout the year, using the boiler at the joinery workshop to cover most of the summertime load. The reason for the summertime shut down of the heating pipeline is mainly gas savings.

The 250 kW biomass boiler plant could be used to cover almost half the heat energy requirements of the precinct (See Figure 2.1). Load variations on a day-night basis or even on an hourly basis will, however, result in frequent starts and stops, resulting in increased emissions. Feeding the heat generated into the existing pipeline would allow a much more constant operation of the firebox boiler. The main pipeline supplying NE-01 passes right by the Joinery Workshop keeping costs of the hook-up low.

Another option would be to get the precinct baseload (excluding NE-01) covered by the biomass boiler plant running in steady state. The peak loads would have to be covered by other heat sources. Some of the wood waste will have to be stored or trucked out, particularly during the shoulder season and the summer time when there is little to no demand for heat.

Various locations have been considered for the plant. The north-west corner of the joinery workshop is likely to fit best, also in light of visibility and training purposes. The option of covering one side of the container with glass to allow larger numbers of students to viewing the boiler from the outside rather than trying to fit them inside the container has been discussed. Being an educational facility, use of equipment for training purposes should be considered in the planning stage already.

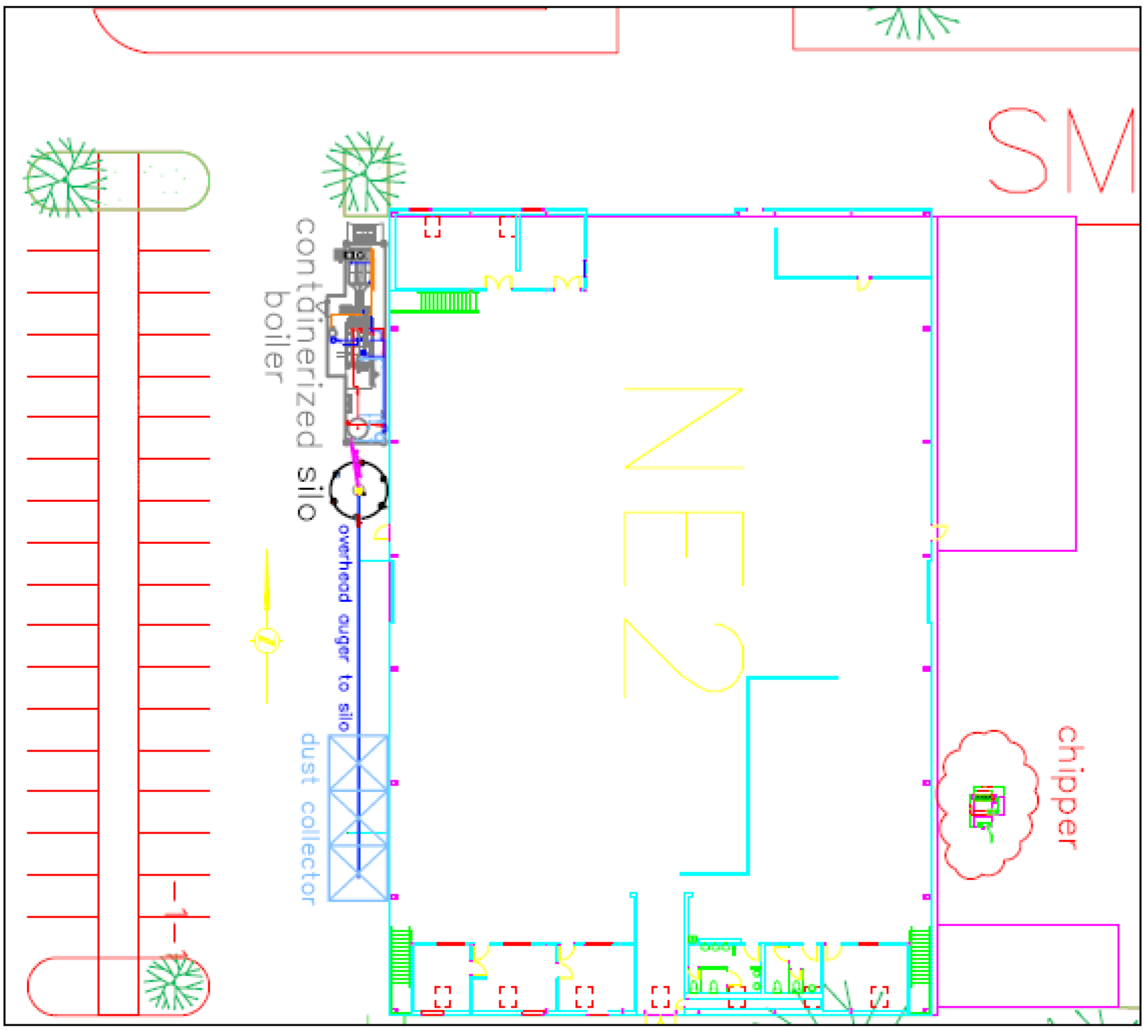

Figure 2.13 Potential location of a biomass heating plant along the west side of the joinery workshop where the hopper for the central dust collection system is located.

2.4. NON-RENEWABLE ENERGY SOURCES

Fossil fuels will, in the near-to mid-term, remain part of the fuel mix of any district heating system, whether as a backup source or to meet peak demands to supplement non-firm energy sources, such as solar energy.

The development of district heating in Sweden is a good example of how district heating systems that were initially primarily run by fossil fuels have, within a period of 30 years, transitioned to using a diverse mix of heat sources ranging from biomass and municipal solid waste to industrial heat recovery.

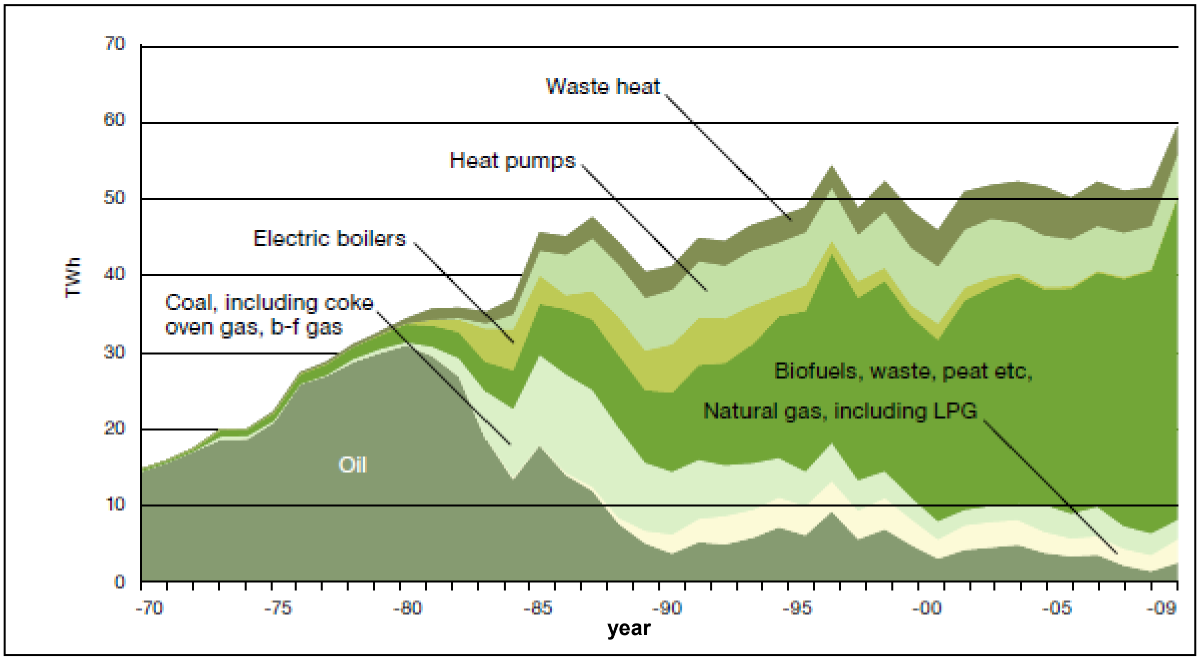

Figure 2.14 Energy input to district heating systems in Sweden, 1970–2009: The supply of district heating has increased by a factor four since the seventies, while the amount of fossil fuel has decreased. Today, district heating supplies about half of the total heating requirement of residential and commercial premises in Sweden. Source: Swedish Energy Agency.[47]

District heating in Sweden went within three decades from primarily fossil fuelled to a diverse mix heat sources, most of them non-fossil fuel.

Natural gas, due to its availability and competitive prices will likely, in the short term, be a significant fuel source, whether for a small district heating system at the precinct or for the existing heating network. Today natural gas is the dominant primary fuel type used by district energy systems in Canada.[48] As in Sweden, the share of natural gas can be expected to diminish over time as prices for natural gas rise and capital costs for renewable thermal energy equipment decrease.

District heating, when done with natural gas boilers, has environmental and economic disadvantages because it has to account for heat distribution losses that boilers in the building itself do not have. In the

[47] Swedish Energy Agency, "Energy in Sweden 2010", Nov 2010, see http://www.energimyndigheten.se/

[48] Canadian District Energy Association: "District Energy – A National Survey Report", Toronto, March 2009. See http://cdea.ca/resources/

future, the high value of natural gas will need to be capitalized on, either in combined heat and power plants or to supplement an inexpensive heat source during periods of peak demand.

2.4.1. COMBINED HEAT AND POWER PLANTS

Combined heat and power (CHP) plants generate, or 'co-generate,' heat and electricity. The fuel used is thus turned into two products: a low-value and a high-value energy resource. A conventional, single-purpose gas-fired thermal power plant, such as the single-cycle Burrard Thermal plant, extracts 34%[49] of the energy in fossil fuels as electricity and dumps the rest (66%) as waste heat. A combined heat and power plant uses this mid-temperature waste heat to heat a factory, a district or even an entire city, as is the case in most cities of the Former Soviet Union.

To be economically viable, most 'co-gen' plants require a revenue stream from selling heat on top of selling electricity. A district heating system is the most common way to generate an income stream for the heat.

A single purpose thermal power plant, as the Burrard Thermal Plant, wastes 66% of the energy.

A combined heat and power plant uses an additional 56% and thus only leaves 10% for losses.

The most developed form of small-scale CHP plants are diesel generators in which the heat of the motor and its oil circuit and the heat contained in the flue gases is recovered using heat exchangers. Temperatures of the waste heat range between 80°C and 120°C maximum.

Besides natural gas, diesel, bio-diesel, landfill gas or biogas from anaerobic digesters have been used. Wood gases or syngases are not yet commercially viable sources as they tend to clog up the engine.

Gas-driven combined heat and power plants can be internal combustion engines, turbines or micro-turbines, or fuel cells. Internal combustion engines have a higher conversion efficiency than turbines, but are also more maintenance intensive. Fuel cells are poised to become a game-changing technology once they become an off-the-shelf piece of equipment. Internal combustion engines generate 30% electricity and 60% heat – i.e. they have a power-to-heat ratio of 1:2. Fuel cells generate the same amount of electricity as heat – i.e. they have a power to heat ratio of 1:1. In other words, they generate more high-value and less low-value energy. Currently, fuel cells still have a low overall efficiency though, partly because they need so-called reformers that first convert natural gas into hydrogen.

Most cogeneration plants at district heating systems are driven by the demand for heat. Without heat consumption – e.g. in the summer – the heat needs to be dumped or the plant turned off. So called 'heat-driven' CHP plants are operated to meet a certain heat demand and generate electricity as a by-product.

The fact that electricity is co-generated results in clear net environmental benefits, even if natural gas is used as a fuel; electricity is displaced from the public grid that would have been generated elsewhere. As discussed in Chapter 2.3.1, BC Hydro is likely to reduce the output of plants with high variable costs. Depending on the time of day, the electricity replaced will be from gas-fired thermal power plants, such as Burrard Thermal or power imported from Alberta.

With the load existing at the precinct – excluding the J. W. Inglis Centre (NE-01) – a CHP plant with an electrical output of 50 kW and a heat output of 100 kW could be operated 257 days a year, generating 2,160 GJ of heat and 300 MWh of electricity. Assuming this electricity would replace electricity generated by the

[49] Average efficiency between 2005 and 2010. See http://www.bchydro.com/about/company_information/reports/2010_gri/f2010_economic_EU11.html

Burrard Thermal plant, a net emission reduction of 110 tonnes of CO_2-eq [32] could be achieved. Using Alberta power imports as a baseline, emissions of 211 tonnes of CO_2–eq could be saved.

Replacing gas-fired boilers at the precinct with gas-fuelled cogeneration plants would reduce total emissions from heating by 12% to 31%, depending on what power source is replaced.

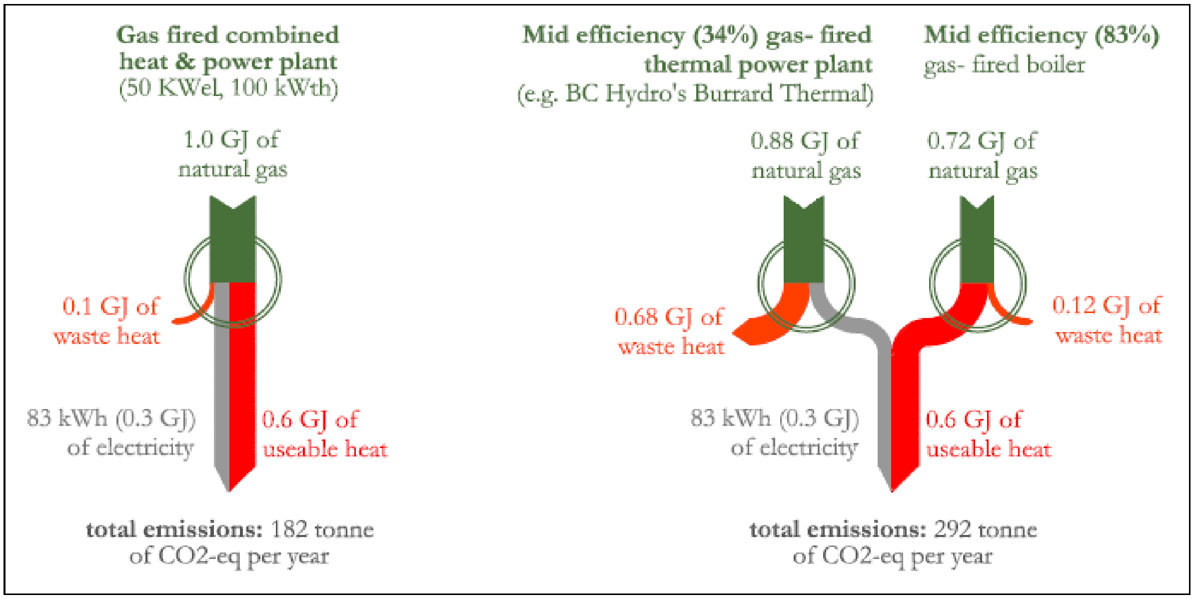

Figure 2.15 Primary energy balance of a combined heat and power plant. Separate generation of electricity and heat requires 60% more natural gas. A small cogeneration plant (50 kW electrical output, 100 kW heat output) covering the baseload of the precinct would allow reducing emissions by 110 tonnes of CO_2-equivalent despite using the same kind of fuel. Numbers are based on the assumption that power generated at BCIT and fed into the public grid would result in BC Hydro turning down the output of the plant with the highest variable cost. Currently this is likely to be the Burrard Thermal Plant. It should be noted though, that under Bill 44, The Greenhouse Gas Reduction Target Act, carbon savings of combined heat and power plants are only accounted for by the average emission of power generators in BC (25 kg of CO2-eq per MWh of electricity).[34]

Using the existing heating network as a heat sink, a larger CHP plant with a maximum thermal output of 2.0 MW and an electrical output of 1.0 MW could be installed. This larger plant could operate for approximately 250 days a year at full load; see the load curve in Figure 2.2. Total GHG emission abatement would be approximately 20 times that mentioned for the 50 kW CHP plant above. Generating electricity would be an important step towards BCIT's goal of becoming a net energy producer, exceeding the needs for campus facility operations.[50]

The economic viability of combined heat and power plants depends less on the prices of natural gas and electricity and more on the ratio between the two commodities.

Combined heat and power plants convert natural gas into electricity and heat. The price of these three commodities, particularly the price of natural gas compared to electricity, determines the economic viability of combined heat and power plants. In most of BC, electricity is priced at approximately twice the rate of natural gas. This ratio would have to be larger for most small-scale CHP technologies to become economically viable.

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[50] http://www.bcit.ca/sustainability/about/goals/energyproducer.shtml

Combined Heat & Power plants are bound to play a major role in Canada's energy future.

As a vocational school BCIT might want to consider preparing the future work force for this.

According to the BC Energy Plan, co-generation with an overall efficiency (heat and electricity production) in excess of 80% is eligible for BC Hydro's Standing Offer Program.[51] A base price of 8.386 cents per kWh is offered. Additional 10 cents per kWh would be obtainable for electricity generation during 'Heavy Load Hours.' Those involved would need to calculate whether this electricity price is sufficient to justify an investment into a cogeneration plant. Generation during peak hours only and storing the excess heat in hot water storage tanks might improve the economic viability.

Apart from financial considerations, BCIT as a vocational school might want to consider training students on a technology that will almost certainly become a contributor in Canada's future electricity generation portfolio.

Combined heat and power plants can also be fuelled by renewable energy sources, such as biomass. Mature biomass CHP technologies are, however, in the MW range. With fuel available from the Carpentry and Joinery departments, however, only a small-scale biomass-to-electricity plant, such as Stirling engines can be fuelled . This technology is discussed in the previous paragraph 2.3.6.

2.4.2. NATURAL GAS BOILERS

Natural gas boilers are required for peak loads and as back-up heat generators. Peak-load gas boilers are typically water tube boilers that can react quicker to a change in heat demand than the fire-tube boiler currently used at the boiler plant.

Condensing boilers recover latent heat contained in the flue gases and can achieve boiler efficiencies of close to 100% (of the Lower Heating Value[52]) but they require return temperatures below 60°C to condense efficiently. Preheating the return temperature – e.g. with a solar collector field – would be counterproductive to a condensing boiler.

2.5. ASSESSMENT OF RENEWABLE AND DECENTRALIZED HEAT SOURCES

The heat sources available to a district heating system at the Sustainability Precinct can be assessed according to a variety of factors. The table below provides some key factors when deciding on what heat source to focus on:

[51] BC Hydro, „Standing Offer Program Rules", Feb 2009, page 11. See http://www.bchydro.com/etc/medialib/internet/documents/info/pdf/info_-_20090224_sop4.Par.0001.File.20090226_SOP_Program_Rules_Clean.pdf

[52] Lower heating value refers to the energy contained in a fuel disregarding the latent heat contained the flue gases

	Geo-exchange	Geo-thermal	Sewage Heat Recovery	Solar Thermal	Biomass Boiler	Biomass CHP	Natural Gas Engine CHP	Natural Gas Fuel Cells	Condensing Natural Gas Boiler
Operation at high temperature	--	o	--	-	+	-	-	-	--
Foot print / space requirements	o	o	o	++	-	--	+	+	++
Maturity of the technology	+	-	o	+	++	-	++	-	++
Capital costs	-	--	-	-	o	--	o	--	++
Operation & maintenance costs	o	++	o	++	+	o	o	o	+
Environmental benefits	--	+	-	+	+	++	++	++	+
Applicability in the precinct	-	-	--	o	+	--	o	++	+
Overall assessment	**-**	**o**	**-**	**o**	**+**	**-**	**+**	**o**	**+**

++ very good, + good, o average, - poor, --very poor

Table2.2 Assessment of potential heat sources for district heating in the precinct.

Three heat-generating technologies applicable in a district heating network at the precinct appear to be worth a detailed analysis: a biomass boiler; a natural-gas fired combined heat and power plant; and condensing boilers.

- A biomass boiler plant is probably the renewable energy closest to being commercially competitive. The Joinery Department and the School of Construction have recognized the potential and have worked for a number of years on a business case for a waste wood boiler. Numbers appear to be promising and the project is in an advanced stage.
- A small natural-gas-fired CHP engine would, as the biomass boiler plant, be able to supply roughly half the heat required by the precinct.
- A condensing natural gas boiler could be the peak load supply source

Three heat sources could achieve a factor four reduction in global CO2-emissions at the precinct.

The CHP-plant would be competing with a biomass boiler: both would vie for the baseload hours. Implementing both of these technologies would reduce the operating hours of either one of the two plants – see Figure 2.1. Another option would be supplying heat to the outside of the precinct by using the heat load of buildings connected to the existing heating network. This set-up – biomass heat to the existing network, heat from the CHP plant to the precinct – will depend on if and how the precinct is connected to the existing boiler plant. Chapter 3 looks into this and offers a number of solutions.

The three technologies mentioned above are the economically 'low hanging fruits' that, if combined with demand side measures, might achieve the desired factor-four reduction in global CO_2-emissions and a factor-two reduction in local natural gas consumption.

All of these technologies are proven and commercially available. For further reduction of the precinct's environmental footprint, the renewable energy technologies mentioned above would have to be looked into.

Large-scale solar thermal and fuel cells are two heat sources that BCIT could employ to position itself as a leader in green heating technologies.

Educational facilities like BCIT have a leading role in demonstrating and training students on equipment that is not yet commercially viable, but has the potential to enter the market. Two technologies stick out as not yet being implemented in other BC post-secondary schools and worth considering for implementation at BCIT's Burnaby campus: large-scale solar thermal and fuel cells. Both are beyond the proof-of-concept stage but have not yet entered the Canadian market as a mainstream choice.

3. HEAT DISTRIBUTION

Chapter 1 described the heat consumption of the precinct. Chapter 2 discussed the current boiler plant and other potential heat generators that may be used to supply heat to the precinct. This chapter describes how the precinct buildings can be connected to these heat sources.

3.1. BCIT EXISTING HEATING NETWORK

BCIT has an existing heating network. One obvious solution, though not the only one, would be to connect the precinct to this existing network.

3.1.1. EXTENSION OF THE EXISTING HEATING NETWORK.

BCIT's existing heating network supplies 13 of its 56 buildings, covering 105,147 m² of floor area, 17% of the entire floor area on campus. The reason for the low connection rate is related to former property lines and the way in which BCIT grew to be the campus that it is today. The northern part of the campus, including the Sustainability Precinct, used to be the Pacific Vocational Institute (PVI). BCIT merged with PVI in 1986. Other buildings were only erected or purchased at a much later stage.

The J.W.Inglis Building, the largest building on campus, was erected in 1982, but was only connected to the heating network after the merger. South campus buildings such as SE-40, SE-41 and SE-42 were added to the Institute's portfolio at a later stage. Residences (SW-10 to SW-16) are all heated with electric baseboard heaters. The satellite building (CARI - also known as Mathissi place) was added to BCIT after 2000.

BCIT's heating network supplies only 13 of the 56 buildings on campus.

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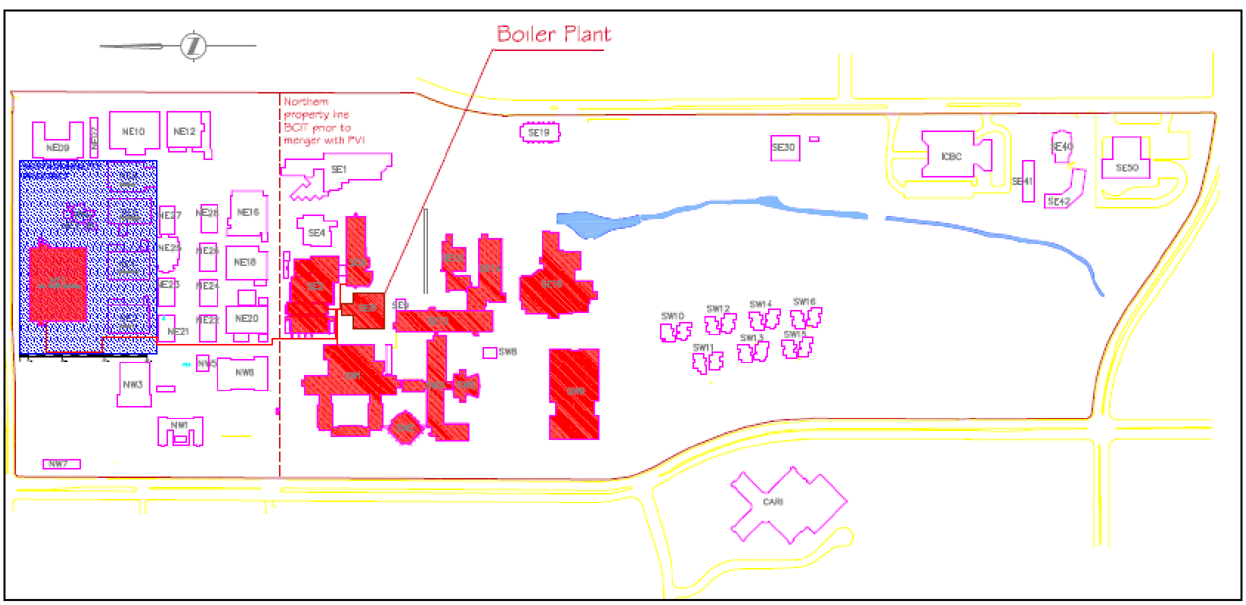

Figure 3.1 Only 13 of the 56 buildings on BCIT's Burnaby Campus are connected to the heating network. This is because BCIT was built in stages. The northern part (left in the map above) used to be an independent facility, the Pacific Vocational Institute.

Today, the network consists of five independent loops. The J.W. Inglis Building (NE-01) is on the same loop as the office building SW-01. This arm of the network, if big enough, could be used to connect to the remaining buildings.

3.1.2. NETWORK TEMPERATURE

The heating network was originally designed to operate as a high-pressure steam system with a supply temperature of 149°C (300 F). Supply temperatures were eventually lowered, possibly to avoid continuous supervision requirements. Because of this, the buildings were undersupplied as the heat exchangers no longer operated at the temperature they were designed for.

The substations at the building level were subsequently changed from indirect to direct connections, replacing heat exchangers with a set of control valves. As the heating water flowing through a building is the same water flowing through the central boiler, any loss in pressure – e.g. due to a leak in a heater – will result in a pressure loss for the entire system and is compensated for by adding fresh water at the boiler plant.

Mostly for this reason, modern district heating systems at the scale of BCIT use indirect connections with heat exchangers for every building. Direct connections that were common in district heating systems in Eastern Europe and Russia have been replaced by more costly but easier to control building substations with heat exchangers.

Generally there are two ways of controlling the heat supply to a building: 1) by increasing or reducing the temperature and 2) by increasing or reducing the flow, i.e. the amount of water pumped through the building. The primary loops – i.e. the network between the boiler plant and the building – are primarily temperature controlled; the secondary loops at the building level are primarily flow controlled.

The primary loop seems to be kept at a rather high temperature. The author was unable to obtain detailed information on the temperature regime applied. A 2008 report by Prism Engineering Ltd states:[53]

> "During mild weather conditions, the hot water supply header temperature is now maintained at approximately 82°C (180°F) rising to about [104° - 110°C] 220-230°F at near peak load conditions."

Measurements undertaken by BCIT staff on March 4, 2011 resulted in much higher primary temperatures though. Secondary temperatures measured at NE-01 at the same day and time yielded much lower supply and return temperatures. Secondary supply temperatures were 12 Kelvin[54] lower than primary supply.

High heating network temperatures are the single biggest barrier towards the use of renewable and decentralized heat sources.

[53] Prism Engineering: "Hot Water Distribution System Review – BCIT Burnaby Campus", Burnaby, January 2008.

[54] Kelvin is a metric temperature scale based on centigrade. Degrees Celsius denote a temperature, Kelvin denotes a temperature difference. The temperature difference between 95°C and 107°C is 12 Kelvin, not 12°C.

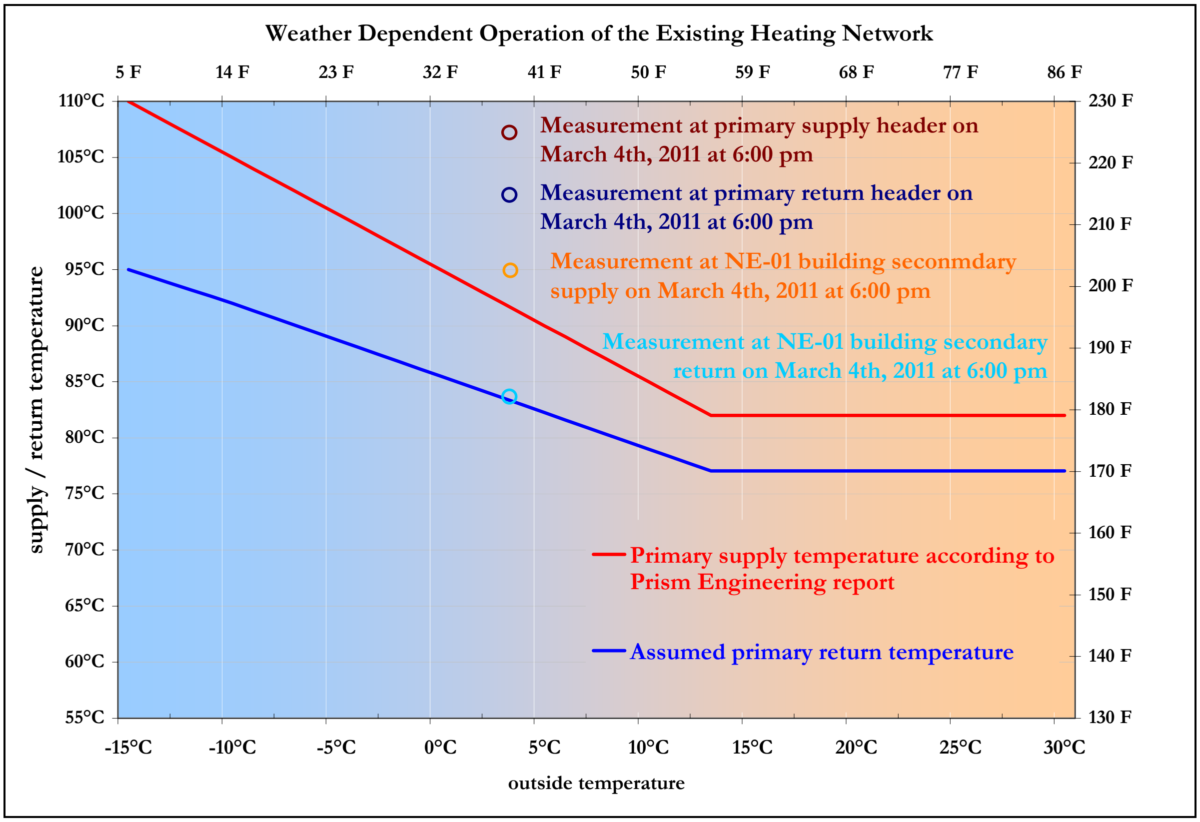

Figure 3.2 Supply and return temperatures of the existing heating network at BCIT. The heating characteristics described by Prism Engineering Ltd could not be verified with measurements. The measurements, however, indicate that supply temperature at the building level are up to 13 Kelvin lower than that of the primary heating supply pipe.

This might provide an opportunity to reduce supply temperatures. The J. W. Inglis Building (NE-01) would receive sufficient heat if primary supply temperatures were 12 Kelvin lower. Moreover, lower primary supply temperatures may, within limits, be made up for by an increased flow. A detailed assessment of valve settings would be required. Particularly the need for bypasses and the amount of return water mixed into secondary supply lines needs to be looked at to see whether primary supply temperatures may be reduced.

The Prism Engineering report[26] indicates that there is no consistent design at the building level, requiring a building-by-building investigation.

Lowering supply temperatures would greatly enhance the ability to use renewable and decentralized heat sources. Lower supply temperatures require upgrades to in-building mechanical systems that are designed for high water temperatures. Chapter 3.2 below explores options for a low-temperature supply to buildings of the precinct.

3.2. Heating Network Options for the Precinct

As for the electric grid, a thermal grid's operating parameters are defined by the user's requirements and the grid infrastructure. Electric grids are designed to a certain voltage. The key parameter of a heating network is the supply temperature. Other than the voltage of an electric network that can be stepped up or down, the supply temperature of a heating network can be reduced, but not easily increased.

In order to use low-temperature heat sources, the heating network will have to be low temperature as well. Many heat sources discussed in the previous chapter cannot be applied effectively at the temperature the existing network is operating at.

This leaves three options for heating the precinct with district energy:

Option 1: A micro-grid that connects the buildings in the precinct only. The largest consumer, the J.W. Inglis Building (NE-01), could become part of this precinct (Option 1 A) or remain being supplied by the existing central boiler plant (Option 1 B). With some modifications to the buildings' heating appliances, this grid could be operated at a low temperature.

Option 2: An extension of the existing system to the remaining, currently independently-heated buildings in the precinct. Supply and return temperatures would be the same as for the current heating network, constraining the use of low-temperature heat sources. Preheating the return line might be still viable though.

Option 3: A sub-grid, operating at low temperatures. Similar to the low-voltage distribution network at the far end of an electric network, the precinct would receive heat from the boiler plant, but could not feed any heat back into the high-temperature pipeline. The flow of heat energy would be one-way only, from the high-temperature to low-temperature network. Heat generated in the precinct would have to be consumed inside the sub-grid and could only be exported to the existing heating network using a heat pump.

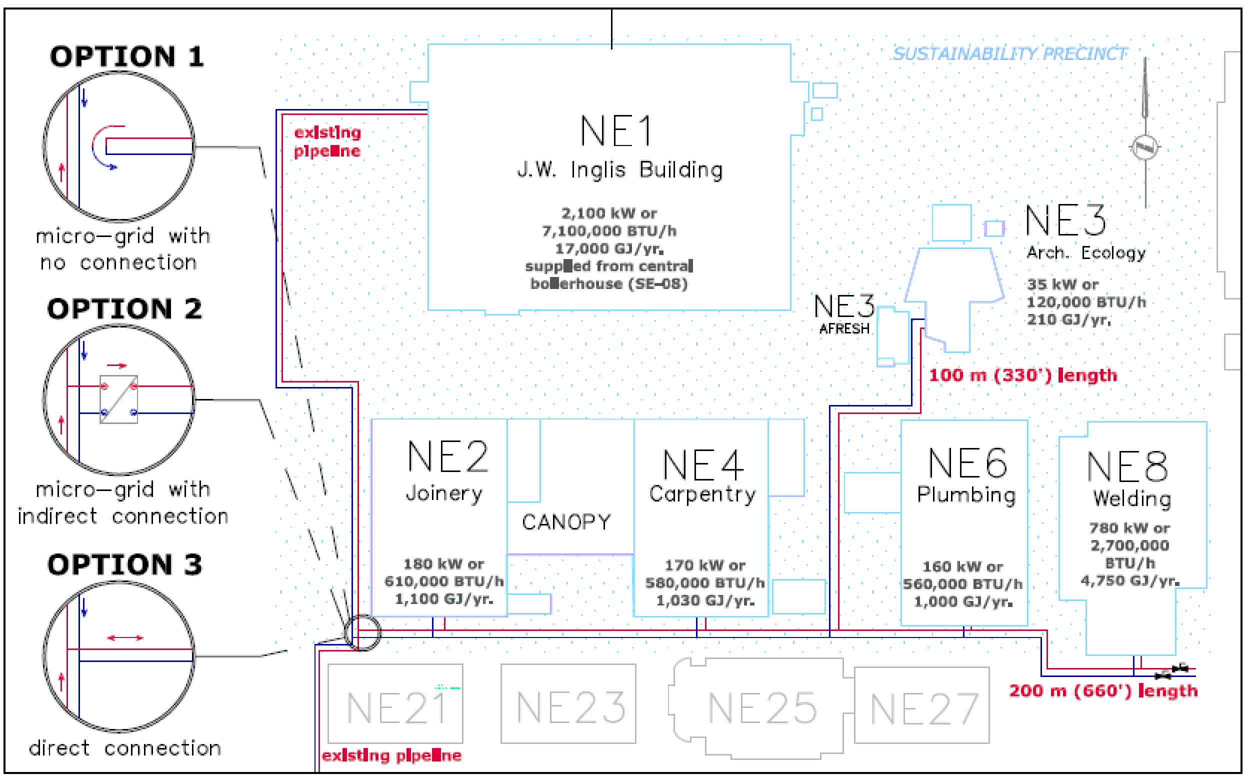

Figure 3.3 Options for district heating at the precinct. An independent micro-grid could be established that is later directly or indirectly connected to the existing heating network.

BCIT will have to decide at the design stage whether to maximize the use of renewable energy sources or to optimize an existing heating network. Larger networks have economies of scale that are not achievable with micro-grids of only five to six buildings.

A phased-in approach may be taken, building a stand-alone micro-grid that is connected to the main network at a later stage – Option 1 in the illustration above. This solution would still limit the use of renewable and distributed energy sources though. District heating systems, like the one in Copenhagen, Denmark, initially consisted of several independent district heating systems that were eventually joined to form one large network.

3.3. LAYOUT OF THE HEATING NETWORK IN THE PRECINCT

District heating networks can be designed as two-pipe systems (one supply and one return line) a three-pipe system (the third, smaller pipe is for domestic hot water) and a four-pipe system (the fourth pipeline is for circulation of domestic hot water). Three- and four-pipe systems have the advantage of allowing operators to shut off the two main pipes when the heating period is over, reducing heat losses. Mostly for economic reasons, however, modern heating networks are almost exclusively designed as two-pipe systems. The two pipes are in a closed circuit, delivering heat but no water that can be consumed directly. Instead, domestic hot water is generated indirectly using heat exchangers at the building level.

The layout of the network may be: 1) a 'grass structure' in which every consumer is directly connected to the boiler plant; 2) tree-shaped with a main pipeline that branches off at various points; or 3) ring-shaped with a main pipeline connecting various boiler houses along the way. The structure of the network depends on the size, topography and existing infrastructure in the district.

The precinct alone would generally be considered too small an area for a stand-alone district heating network; the 'network' would essentially consist of a single pipeline branching directly into each of the buildings.

A prerequisite for connecting the precinct to the existing heating network would be surplus pipeline capacity.

The diameter of the pipe to NE-01 should be checked.

BCIT's existing heating network has no main pipeline, but consists of five branches connecting 13 buildings. Some branches only connect a single building. The precinct could be connected to one of these five branches, the one connecting the J. W. Inglis Building. The diameter of this existing pipe would have to be checked for surplus heating capacity.

The buildings under consideration at the precinct are all adjacent to Smith Way and could be connected to the existing heating network with a straight 200 m long, straight pipe. Each building would tee into the main pipeline. The existing HVAC infrastructure of most buildings, however, is along the south side of the building. Laying the pipe along the alleyway south of NE2 would avoid running long pipes through the buildings, but require a second branch to the Centre of Architectural Ecology and the AFRESH house. Total pipeline length would increase to 300 m, resulting in average of 32 m² of floor area per meter of trench or 34 GJ of heat consumption per meter of trench.

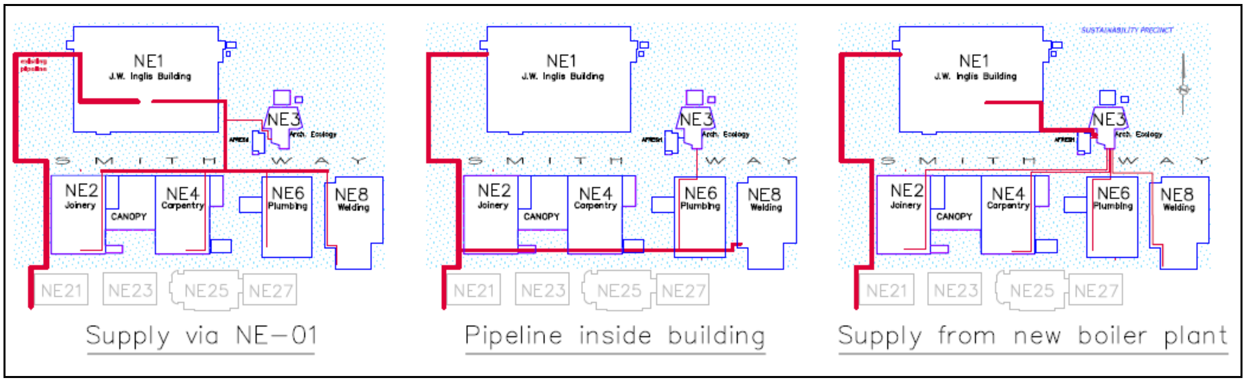

Figure 3.4 Options for district heating at the precinct. An independent micro-grid could be established, that is later directly or indirectly connected to the existing heating network. Total pipeline length varies between 300 m and 700 m; trench length is approximately 50 m if pipelines are primarily laid inside the building, 300 m if outside the building.

If connection to the existing heating network is the preferred option, an entire new branch would have to be built should the additional 960 kW of the precinct be beyond what the existing pipe could supply. The decision on how to connect the precinct will also be affected by plans regarding connection of other buildings outside the precinct and possibly outside the campus. A campus-wide district heating plan should be established before detailing a design for the precinct. Knowing what buildings will be connected to a district heating system is required to help determine the size of the pipes, the cost of a system and the potential return on investment.

3.4. PIPELINE DESIGNS

Heating pipelines can be above or below ground. Above-ground pipelines are common in Eastern Europe and Russia but, mostly for aesthetical reasons, have not been popular in Western countries. Instead, pre-insulated pipe-in-pipe systems have been developed that can be laid into trenches with a minimum of labour on site. A waterproof jacket surrounds the insulation. Pre-insulated pipelines have been used to cross (salt water) fjords in Sweden.

Pre-insulated pipes keep heat losses to a minimum. A 14 km pipeline between the city of Mannheim and Heidelberg has an average temperature drop of 2 Kelvin (2 centigrade in temperature difference) from one end to the other. Being underground, leaks can result in massive excavation needs. Advanced pipe technologies include a leak detection system. The 1.8 km pipeline of the City of Revelstoke had one leak since its inauguration in 2005. As the leak was successfully located with the built-in leak location system, repair costs were kept to a minimum.

Flexible, pre-insulated pipes are available up to a diameter of 100 mm (4") and come in 100-meter-long coils, minimizing the need for coupling pipes on site. Laying flexible, pre-insulated pipes reduces costs as trenches don't need to be straight and pipes can be uncoiled from a truck directly into the trench. Flexible pipes are available with steel, stainless steel or PEX as water carrying pipes. They are self-compensating and do not need expansion joints or meandering trenches to compensate for thermal expansion and contraction. Flexible pipelines are particularly advantageous where existing underground services have to be crossed.

Figure 3.5 Pre-insulated pipe with leak detection wires. Source: www.permapipe.com

Smaller diameters are even available as twin pipes, with supply and return in the same insulation and jacket. Instead of two pipes, only one pipe needs to be laid. These twin pipes are often used for connecting individual buildings to a main pipeline.

Figure 3.6 Pre-insulated flexible pipes being covered at UNBC, Prince George.

Underground pipes may be laid without a defined slope, without de-gassing valves and without any additional ducts. Concrete canals or ducts are more expensive than pre-insulated pipes laid directly into a trench and are no longer used. Some of these techniques, however, may be explored for demonstration and teaching purposes, allowing access to the pipe. In densely populated areas, pipes are sometimes laid inside the building, connecting basement to basement.

Frequently the choices of piping material and design are influenced by costs rather than for technical reasons. In general, cheaper pipelines have higher installation costs than more expensive pipelines. PEX pipes[55] might be an exemption to this, but may only be used for temperatures up to 95°C and 400 kPa (60 PSI). The existing supply temperatures would not allow the use of PEX as a piping material.

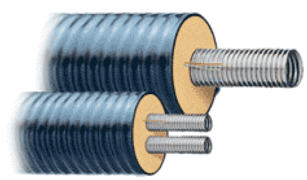

Figure 3.7 Flexible, pre-insulated single and twin pipe.

Source: http://www.nmc.eu

District heating pipelines are typically not frost-protected with antifreeze. Instead, enough redundancy is built into the heat supply system, keeping the pipeline warm at all times during the frost period. The City of Kokshetau in northern Kazakhstan had its entire city-wide, above-ground pipeline network destroyed when the utility ran out of fuel during a typical Siberian winter. Laying pipelines below the frost line helps protect most sections of the network.

The classical trench design is for double pipes laid next to each other on the same drainage (sand) bed. The trench can be made narrower, resulting in reduced excavation and handling of soil by using twin pipes or stacking pipes on top of each other. Especially in inner cities where excavation and pavement resealing is expensive, this arrangement of the pipes reduces the costs of civil works. Concrete channels hosting pipes are no longer used, but might be employed to expose a part of the pipeline for education purposes.

The pipeline technology applied to the precinct will depend on a number of factors, including existing infrastructure, easements, and plans for extension that cannot be determined at the pre-feasibility stage.

[55] PEX pipes are made from cross-linked HDPE (high density polyethylene) polymer, i.e. a 'plastic' material.

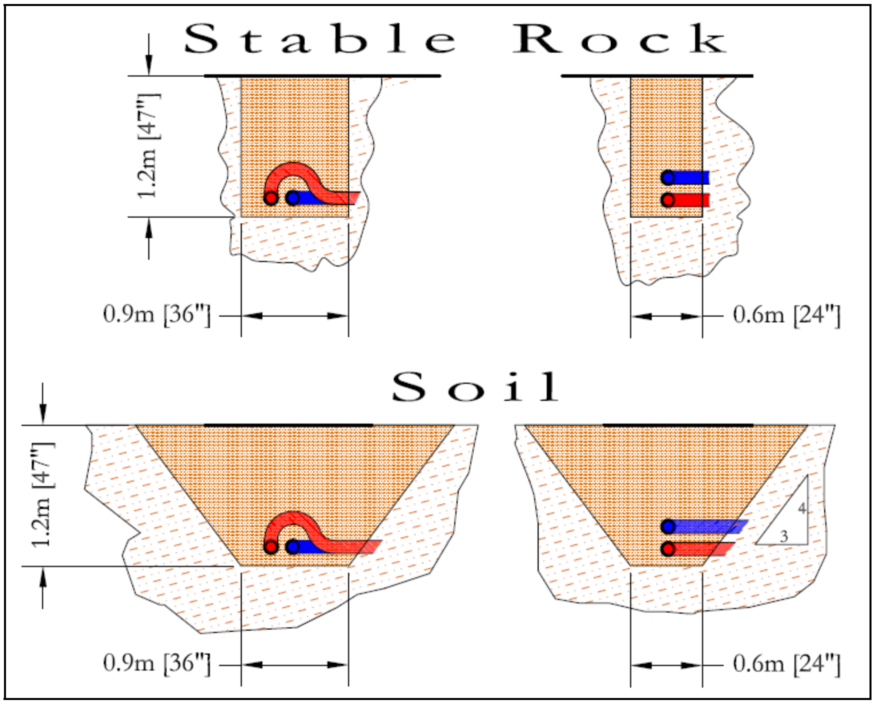

Figure 3.8 Cross section of a pipeline trench for stable rock and soil: Stacking pipes on top of each other avoids elbows when branching off. It also allows reducing the width of the excavator bucket, reducing the amount of excavated material.

The cost of a pipeline is largely dependent on the local conditions, particularly the soil quality and the need for resurfacing. The 1.8 km pipeline in Revelstoke had specific costs of $650 per meter of trench (2 pipes included), while a smaller scale network at Baldy Hughes, BC was around $200 to $250 per m of trench. Trenches in inner cities have been quoted at costs of $1,200 per meter of trench, including traffic control, excavation, pipes, pipe joints, sand infill, refill, and resurfacing.[25]

4. CONSUMER CONNECTION

The last chapter discussed options for the heating network and equipment upstream or outside the building. This chapter looks into downstream equipment inside the building, including pumps, heat exchangers and related controls.

4.1. BUILDING SUBSTATIONS

A building substation, also called an energy transfer station, is the link between the upstream network and the downstream consumers. It usually consists of two heat transfer stations, one for domestic hot water (DHW), the other for space heating. Other than the circulating loops used for space heating, the hot water used for sanitary purposes is consumed rather than re-circulated and re-heated.

Domestic hot water may be heated on demand or using a water storage tank. On-demand heaters have little to no heat losses, but require that capacity is available instantly. Heat storage tanks, on the other hand, cover peak loads and can be heated when demand for space heating is low, e.g. at night when temperatures are lowered. DHW can thus be given a lower priority, resulting in a more balanced load curve.

Some district heating systems use the heat left in the return line to pre-heat the sanitary water, then use the supply line to boost temperatures, see 'two-stage on demand heater in the drawing below. This way the return temperature in the main pipe is reduced.

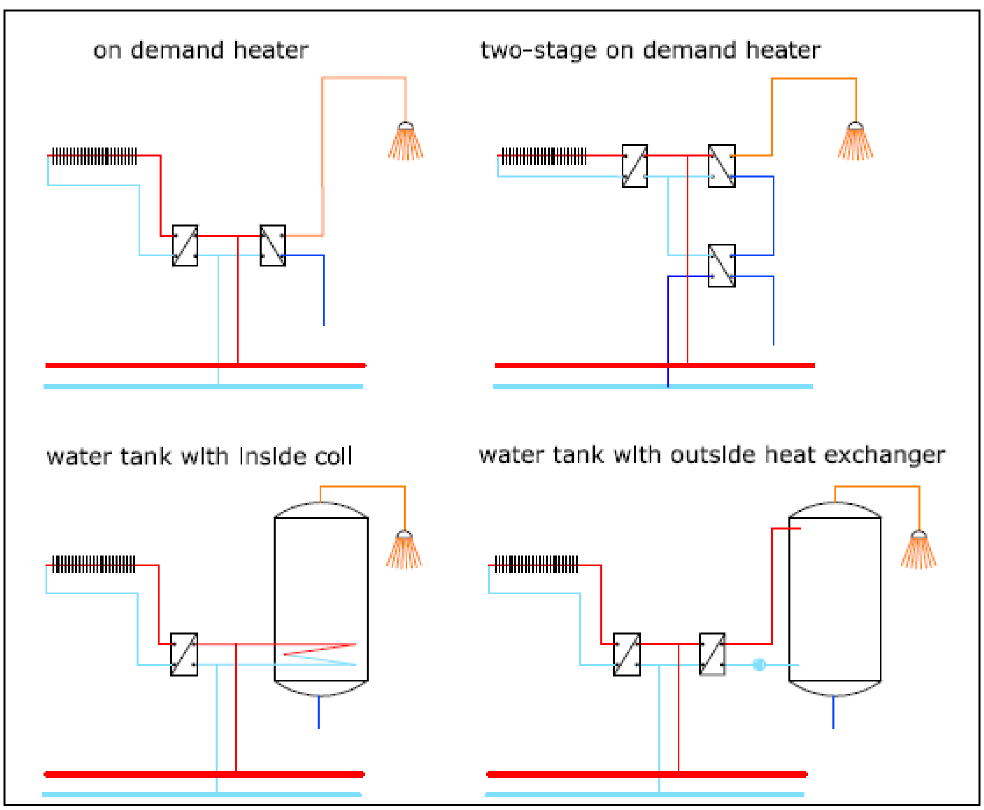

Figure 4.1 Options for building substations: substations with on-demand domestic water heaters are less expensive, but require more heating capacity. Substations using water tanks reduce peaks by storing heat in the tank at periods of low demand from space heating.

The price of building substations obviously depends on the capacity as well as on the way heat is transferred and stored. Substations with on-demand heaters are less expensive. Connecting a single detached B&B to Revelstoke's DE-system cost $50,000 in 2004.

Prefabricated substations are common in Europe where wages are higher than in Canada. A substation for a single detached home ranges between €5,000 and €8,000, that for an apartment building with 36 condos between €20,000 and €30,000. To the author's knowledge there is no supplier of prefabricated building substations in North America.

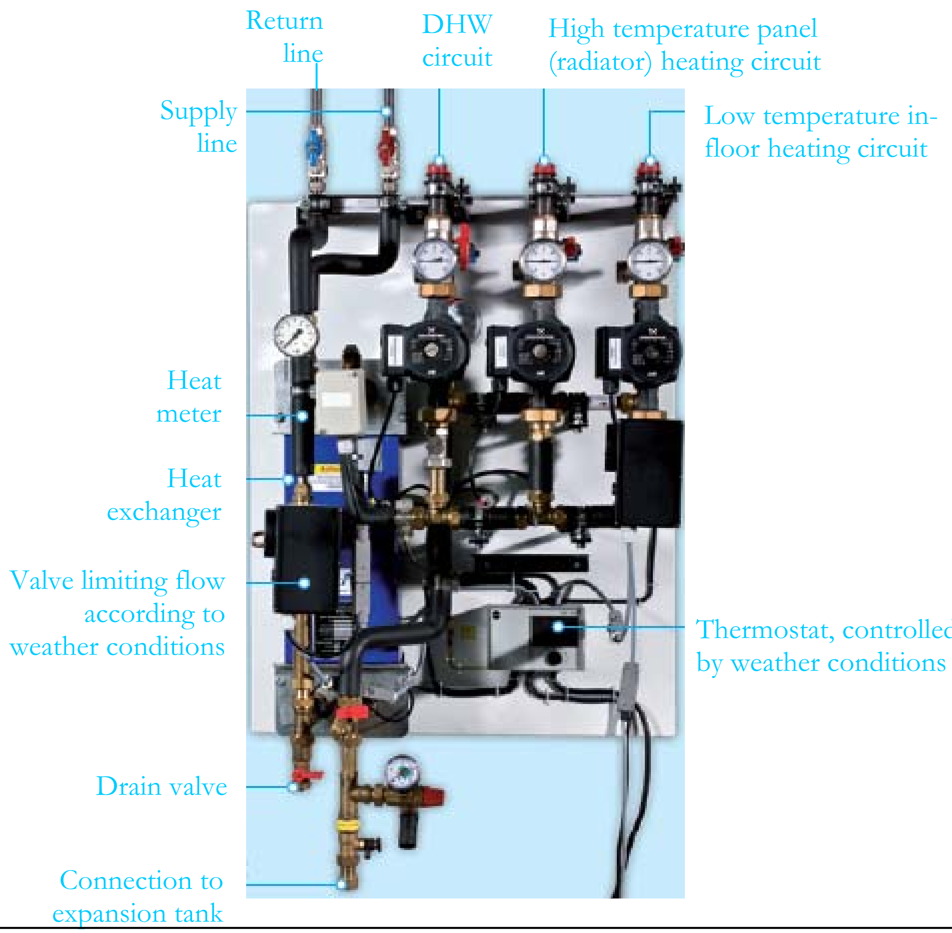

Figure 4.2 Prefabricated building substation transferring heat from a district heating pipeline into a building. An experienced HVAC contractor can install this wall mounted substation in less than 4 hours. Source: MVV Energie AG www.mvv.de

4.2. Conversion of the HVAC System

Appliances to be supplied by the building substation will have to be converted to hydronic heating. While in most buildings, part of the existing heating system is already heated with hot water, some applications, such as gas infrared radiators, will need to be replaced by other means of heating.

The information in this section is based on a seven-hour site visit on February 17, 2011, and on information provided by BCIT staff.

4.2.1. J.W. INGLIS BUILDING NE-01.

The J. W. Inglis Building is already heated by the existing heating network. No conversion would have to be done. The building may, however, be used to test the effect of lower supply temperatures. Since the HVAC system of the building is zoned into a western and an eastern end, a demonstration of the effect of lower temperature supply could be constrained to one side of the building, taking the other side as a reference or baseline.

Figure 4.3 Panel heater/radiator with thermostat. These radiators operate at temperatures of 50°C to 90°C. Source: www.danfoss.com

- The building is mainly supplied with heat from BCIT central plant (SE-8). Supply and return temperatures at the secondary side are 95°C and 84°C, respectively. Staff should test on a cold day whether the supply temperature can be reduced and, if there is a supply deficiency, what appliances are falling short.

- Heat supply to classrooms is done by forced air. A lower supply temperature is likely to result in less heat being injected into the rooms. This could be made up for by higher air volumes. Alternatively a coil of the fan coil system may be replaced by a larger one.

- It should be established whether roof-top units with natural gas burners are used for purposes other than chilling. This information was not available at the time of writing this report.

- In the past few years, summer and winter, domestic hot water (DHW) has been produced independently from the main boiler plant by a single 88 kW (300,000 BTU/h) gas boiler.[56] This opens opportunities for renewable energy usage, especially solar water heating. In this case a second hot water storage tank should be installed upstream of the existing water tank. The solar panels would not feed into the district heating pipeline but instead it would go directly into the hot water tank. The energy generated would not be exported to other buildings though.

4.2.2. JOINERY DEPARTMENT NE-02.

The joinery department consists of the main workshop and offices and meeting facilities. Three offices are located at the north end and four offices and two wash rooms are at the south end of the building.

- The workshop is heated by eight natural-gas-fired infrared radiators that are suspended from the ceiling, radiating downwards. Users are not entirely satisfied with this form of heating as it heats up work pieces too much, especially if they have been exposed to the radiators for a while.[57] In-floor heating could replace the radiators. The floor, consisting of upright 2 x 4" pieces of lumber, could be easily replaced by an in-floor or under-floor heating system. This conversion could happen in a phased approach with classes continuing in one part of the workshop.

- Offices are heated by hydronic baseboard heaters. Most of these heaters have no control valves or the valves are not used because they are hard to reach. Space allowing, these baseboard heaters could be replaced by low-temperature European-style 'panel radiators' or 'panel heaters' that have a more effective output, are aesthetically more pleasing and, most important,

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[56] According to the report written by Prism Engineering [26] there is no DHW production from the central boiler plant.

[57] Rob Sawatzky, Instructor during a site visit on Feb 18, 2011.

are typically equipped with thermostatic radiator valves. These valves are at a height of 2' to 3' and can be reached and adjusted without having to bend or kneel down.

- Heat for these panel heaters is supplied from a boiler located on the south end of the building. The district heating supply and return lines would have to be brought into this mechanical room. This boiler could be kept in place for back-up purposes.

- A new dust extraction system was installed in 2009. The air extracted is replaced through grills located above the windows at a height of approximately seven to eight meters.

- The heating source for domestic hot water should be determined. An inexpensive (cold) water meter should be installed to collect data on hot water consumption.

- The heating is centrally controlled through the BCIT DDC system. Currently the infrared heaters are turned off by the DDC system if one of the main doors is opened. Once the infrared radiators are replaced by a floor heating system, the control may be switched to the make-up air heater.

- The building is slated for a major renovation. Many of above recommendations should be implemented at that time. It is essential to have a heating concept in place and to incorporate this concept into the renovation.

4.2.3. CENTRE FOR ARCHITECTURAL ECOLOGY NE-03.

The Centre for Architectural Ecology was used for accommodation of guest researchers before being turned into an office building and laboratory. Little conversion that would need to be done beyond the boiler room as the building already has a hydronic heating system.

- The building is heated by a three-stage boiler (make: Hydrotherm MG Series Multi-temp) with an input capacity of 264 kW (900,000 BTU/h). The boiler is almost 40 years old (model 1972) and is estimated to have a net efficiency of 75% or less.

- On Feb 18, 2011, the supply temperature was at 68°C (155F) and the outside temperature was 6°C, indicating that the building is already operating at a comparatively low temperature.

- The heat is distributed via a hydronic heat distribution system In addition, forced air fan-coil ceiling units supply heat to the lab/classroom area.

- Domestic hot water is supplied by a 60 US gallon natural gas 55,000 BTU/h DHW heater/tank. The boiler and the DHW tank could be replaced by a district heating system.

- Heat and domestic hot water generated in NE-01 could be brought out to NE-03. This would be the minimum form of a micro-grid. Note that the distance between the two buildings is much less than the length of NE-01. NE-03 could be looked upon as a 'room' or part of NE-01.

4.2.4. CARPENTRY WORKSHOP NE-04

The carpentry workshop consists of a main floor used as a workshop and several offices on the north and south ends of the building. A canopy on the west side, covering the area between the joinery and the carpentry workshop, is open to the outside and unheated. Most of what has been said about the joinery department also applies to the carpentry building.

4.2.5. PLUMBING WORKSHOP – NE-06.

As for the other workshops, the building consists mainly of workshops, classrooms and some offices. Other than the carpentry and the joinery workshop, though, the floor area is subdivided by dividers into various zones. Any major investment into the building will have to take into account that the building is slated for demolition.

- In 2008-2009, heat to the office space and classroom was provided by a boiler located in a neighbouring building. In the beginning of 2011, two high-efficiency condensing boilers were installed. These boilers as well as any other boilers in the building would become redundant if the workshop were connected to a district heating system. They could be used for peaking or back-up purposes though.

- The large main shop floor area is heated by six radiant infra-red heaters. These heaters may be replaced by a concrete in floor heating system. Other than in NE-02 and NE-04, this could only be done during a major renovation.

- Make-up air could be converted to hydronic heating with changes to the building itself.

4.2.6. WELDING WORKSHOP – NE-08.

The welding workshop, like the plumbing workshop, is subdivided into several zones. A hallway runs along the west side of the building connecting to a lunch room, offices, and a washroom.

- Make-up air units are the largest heat consumers. The ventilation is divided into six zones. Currently the following capacities are installed:
  - Three make-up air units at 3,600,000 BTU/h max;
  - One make-up air unit at 650,000 BTU/h max;
  - One make-up air unit at 1,800,000 BTU/h max;
  - One roof-top unit at 120,000 BTU/h max;

  The existing units can be retrofitted with custom coils inserted into the duct. These coils will be directly exposed to outside air and should preferably be heated by a water-glycol mixture to avoid freezing. A heat exchanger will separate the secondary loop containing antifreeze from the primary loop containing water only.

- The large main shop floor area has seven radiant (infra-red) natural gas heaters. As with the plumbing workshop, these could be replaced by in-floor heating. This could only be done during a major renovation though.

Figure 4.4 In-floor radiant heating using PEX pipes on top of an insulating vapour barrier. Heating with renewable or decentralized energy requires low-temperature consumers such as hydronic in-floor heaters to be effective. Hydronic floor heating operates at supply temperatures of 35°C. When used for education purposes, part of the floor might be covered by glass rather than concrete. Source: http://www.radiant-floor-heating.com/

5. RECOMMENDATIONS FOR FURTHER STUDY AND NEXT STEPS

1. The School of Construction's push for renewable and decentralized energy in general and for district energy in particular is timely. The new BC Energy Plan talks about community energy being a part of the energy solution and cities such as Surrey and North Vancouver have already zoned entire areas as 'district heating areas.' As a vocational school, BCIT would want to prepare students for this development by creating on-site teaching and training opportunities.

2. The concept of demonstrating environmentally-friendly building technologies in the Sustainability Precinct is worth pursuing. The seven buildings of the precinct, however, hardly make a 'district', especially since one of the buildings is already connected to the campus heating system. District energy would require a larger building stock. We recommend expanding the research to the entire campus, possibly even into densely built-up areas surrounding the campus.

3. Although the precinct is too small to become an economically interesting district energy system, it would be technically possible to achieve factor four reduction. Excluding NE01, which is already connected to another district system, the entire heating base load of the six-building precinct could be covereed using wood waste that is currently shipped to the landfill. This approach would allow BCIT to meet its reduction goal on a small scale, both in terms of size and capital costs.

4. Energy audits of the remaining 49 buildings should be undertaken. These audits could be done by students, providing that a standardized assessment form is developed. The Energy Pass developed within this project could be refined to become a template for building assessments. The data procurement process would thus become an opportunity for training students.

5. In the next phase of design energy consumption, data and load curves should be measured rather than approximated or simulated. We recommend monitoring energy consumption at the building level. Domestic hot water consumption, for example, could be measured with inexpensive cold water meters. As for district heating, every building should have its own heat meter installed. All meters need to be read hourly for a couple of representative days or be equipped with data loggers.

6. The high temperature level of the existing heating system is a barrier to the use of renewable and distributed heat sources. Research should be conducted on how, and how much, supply temperatures can be reduced. Equipment that would need to be replaced with low-temperature equivalents should be identified. This would have to be done for all buildings that are, or should be, connected to the heating network.

7. The next step of research – presumably a feasibility study – should be coordinated with the planning department, taking plans for further build-up, major renovations, replacement and demolition of buildings into account. A district heating master plan should identify which parts of the campus should become part of an expanded heating network.

8. Aging underground infrastructure, especially water services, in need of significant upgrades provides opportunities to expand the existing heating network. Coordinating activities related to the sewer and city water service upgrades could help reduce investment costs.

9. BCIT is in a prime location to expand its heating network to the dense urban neighborhood surrounding its urban campus. Building on its existing infrastructure and very well trained staff, BCIT's boiler plant could become a hub for district energy in Burnaby. Since operating as a utility is not in BCIT's mandate, a joint venture with an established utility company might be considered.

10. District energy is a technology that is relatively new to Canada. As a vocational school, BCIT will want to prepare the future workforce for this. A hands-on district energy system on campus should

be planned and built for education, including features such as visibility (e.g. large windows or open trenches), accessibility (facilities built large enough for groups of students to enter and observe and monitor system components), and redundancy (allowing students to alter or rebuild a component without interrupting its service).

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7. GLOSSARY & ACRONYMS

°C	Degree Celsius, sometimes referred to as 'Centigrade'.
AB	Alberta
AFRESH House	Accessible and Affordable, Flexible, Resilient, Energy Efficient, Sustainable and Healthy House
BC	British Columbia
BCIT	British Columbia Institute of Technology
bdt	Bone-dry tonne, a forestry unit used to measure the pure wood content of moist wood fibre
BTU	British Thermal Unit; an imperial unit used for heat or steam energy; 1,000,000 BTU = 273 kilowatt hours (kW)h
CEA	Community Energy Association
CHP	combined heat and power
CO2	Carbon dioxide
CO2-eq	Carbon dioxide-equivalent: a factor taking the potency of a specific GHG into account and comparing it to the GHG effect of CO2
COP	Coefficient of Performance
DDC	Direct digital control; a centralized, computerized control technology employed in building control
DE	District energy
DHW	Domestic hot water
DHWT	Domestic hot water tank
EGS	Engineered Geothermal Systems
F	Fahrenheit
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GJ	Gigajoule, an energy unit; 1 GJ is 1 billion Joule; 1 J = 1 Ws (Watt second) 1 GJ = 3.6 MWh = 0.94 mm BTU ; to convert GJ to MWh, multiply by 3.6, to convert MWh to GJ divide by 3.6 1 GJ is equal to slightly more than the energy content of two propane cylinders like the ones used on most gas bar-b-ques. 1 GJ is equal to the energy content of 28 litres of gasoline (at 20°C)
GST	Goods and Service Tax
ha	Hectare; the area in a surface of 100 x 100m; 1 ha = 2.47 acre
HDR	Hot Dry Rock

HVAC	Heating ventilation air conditioning, an umbrella term for heating installations
kg	Kilogram; 1 kg = 2.2 lb
kilowatts (kW)	Kilowatt; power or capacity measurement unit; 1 kilowatt (kW) = 1,000 W
km	kilometre; 1 km = 1,000 metres = 0.621 miles
kPa	kiloPascal; 1 kPa = 1,000 Pa = 0.15 PSI
kW_{el}	kilowatt electrical, indicating electrical power – rather than thermal capacity
kW_{th}	kilowatt thermal, indicating thermal power – rather than electric capacity
lb	Pound, 1 lb= 0.45 kg
LHV	Lower Heating Value: a measure of the calorific content of a fuel. Other than the Higher Heating Value (HHV), this is the energy released after subtracting the latent heat released when condensing the steam contained in the flue gases. For biomass, this value is more representative than the higher heating value as there are no condensing boilers on the market that could make use of the energy contained in the steam.
LPG	Liquefied Petroleum Gas
m	metre
m.c.	Moisture content
m.c. (dry basis)	Percentage of water in relation to the mass of the bone-dry biomass (i.e. without the water contained in the biomass)
m.c. (wet basis)	Percentage of water in relation to the mass of the bone-dry biomass and the water contained in the biomass
m^2	square metre; 1 m^2 =
m^3	cubic metre
m^3	Cubic meter; 1 m^3 = 1,000 litres
mg/sm^3	Milligram per standard cubic meter; a unit of concentration of a pollutant in fluegases, corrected to 101 kPa and 20°C
mm	millimetre; 25.4 mm = 1 inch
mmBTU/h	million BTU per hour, an imperial unit used for boiler capacity; 1 mmBTU/h = 273 kilowatts (kW)
MoE	Ministry of Environment
MW	Megawatt; power or capacity measurement unit; 1 MW = 1,000 kilowatts (kW) = 1,000,000 W
MW_{el}	Megawatt electrical, indicating electrical power – rather than thermal capacity
MWh	Megawatt hours; energy measurement unit; 1 MWh = 1,000 kilowatts (kW)h

MW_{th}	Megawatt thermal, indicating thermal capacity, rather than electric power
N_2	Nitrogen
NO_x	Oxides of nitrogen, primarily NO and N2O
NPV	Net Present Value; the current value of an investment that future income is worth
O&M	Operation and maintenance
OECD	Organization for Economic Co-operation and Development
ORC	Organic Rankine Cycle
PEX	Polyethylene, crosslinked; an oxygen-proof piping material used for heating
PID	Piping and instrumentation diagram
PLC	Programmable Logic Control, an electronic device for controlling machinery
PSI	Pounds per square inch; 1 PSI = 6.9 kPa
PST	Provincial Sales Tax
t	Metric tonne; 1 tonne = 1,000 kg =2,204 lb
ton	Imperial or 'short' ton 1 ton = 0.91 tonne
W	Watt
yr.	Year