Comparison of Hydronic Heating Systems in Multi-Residential Apartment Buildings

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Introduction

British Columbia is facing an electricity supply gap (Hoberg, 2010). The growth of energy demand is exceeding the rate of addition of new supply. Solutions to this problem are complicated as energy demand depends on many factors that have to meet the conflicting desires of multiple stakeholders. Energy demand can be broken up into three sections: industrial, commercial and residential. The results of this report mainly apply to residential sectors and are ultimately framed by slowing or reversing the growth rate of residential energy demand. The regulations that are in place and upheld by BC Hydro and the BCTC ensure a reliable and safe electricity grid but also caused a system that requires a large supply to meet a demand that only occurs a few hours every day. This “peak power” concept is tied to home energy use through shared social energy use patterns and has risen consistently over the past century and has been expanding significantly in the last 40 years. Recently, standards for residential buildings such as the LEED standard have set the bar for developers wanting to reduce the carbon footprint of the building and energy costs for tenants. The main obstacle now is providing enough incentive to encourage the principle agent to overcome typically higher capital costs for alternative methods.

1.1. Purpose

The purpose of this report is to compare the lifecycle costs between different methods of hydronic heating. A hydronic heating system will be investigate and a comparison will be made between meeting the energy demand through a hot water district heating system and a natural gas boiler. The heating system will be designed to meet the demand of two different

60-unit multi-story apartment complexes; one in North Vancouver and another located on the UBC South Campus. A life cycle analysis approach will form the basis of the comparison made.

1.2. Objective

The objective of this report was to conduct the following:

1) Characterize the hydronic heating system required to meet the heating demand of a 60-unit residential apartment complex
2) Provide a comparison between a hydronic heating system through costs and lifecycle impacts.
3) Explore the impacts of the REAP standard on building developers and homeowners

1.3. *Background*

This project was developed through the efforts of Adera. In their efforts to uphold their "green" track record, multi-year winner of "Best Builder Georgie" award and "Built Green BC Builder of the Year" award (Adera 2010), Adera is continuing the trend with two projects: Seven35 and Altima projects located in North Vancouver and on UBC South Campus, respectively. The main interests of concern are capital costs and life cycle impacts, of secondary concern but still important are the resulting life cycle energy costs. The heating load for each building was developed by Troy Glasner using the HOT2000 building energy modeling software. Adera wishes to obtain a sense of where BC sits in North America and globally from a green perspective.

1.4. *Literature Review*

An apartment unit's heat demand can be characterized by a given room temperature. Heat demand occurs by maintaining this temperature against loses to the outside via conduction, convection and radiation. The rate of heat loss depends on several factors such as the insulation quality of the walls and windows, the outside temperature and even wind speed.

1.4.1. General Hydronic System Overview

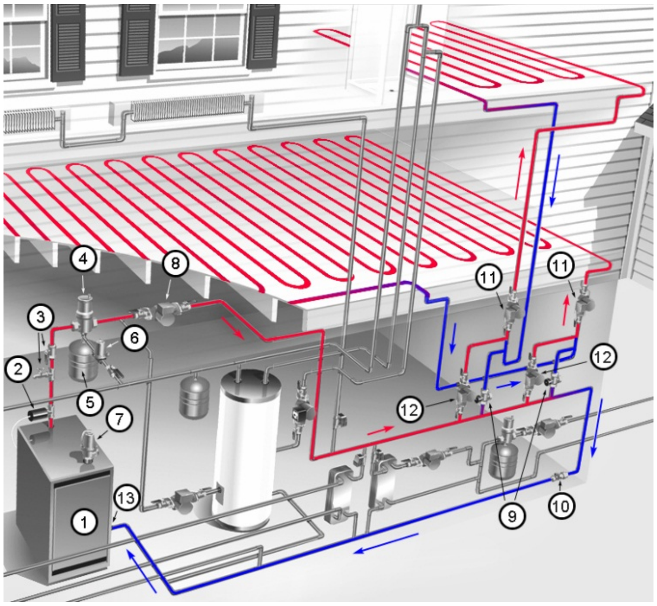
BC Hydro outlines a hydronic system for a home as including multiple types:

- Radiators
- Baseboards
- Hot water/forced air fan and coils
- Radiant Floors

This report will focus on radiant floor type hydronic systems. Generally, a hydronic system will require the following equipment(Hydro 2005)

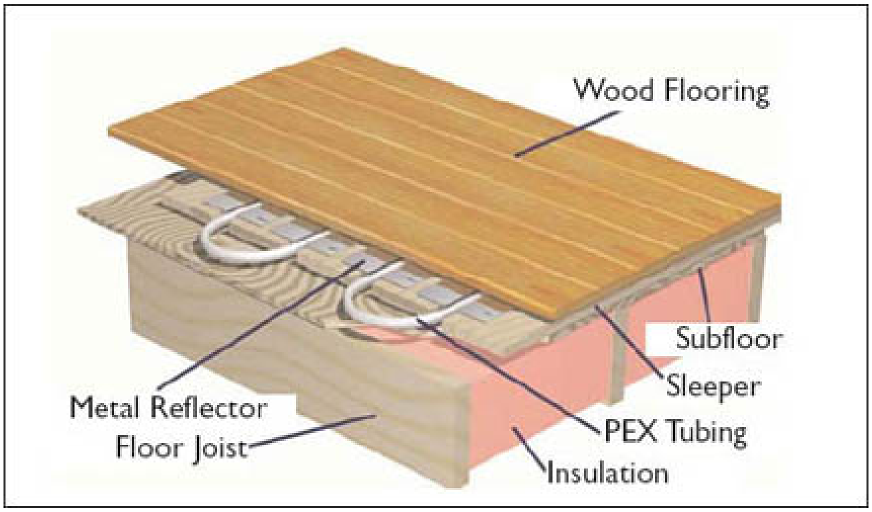
- Boiler
- Circulator
- Zone valves
- Expansion tank and air elimination devices
- Heat transfer device (radiant floor)
- Piping and distribution network (including mixing valves, controls and insulation)

Any hydronic heating system will follow these steps: water is heated in a natural gas or electric boiler. From the heating device, the water is distributed to multiple heat transfer points, i.e. in-floor tubes within the floors of each unit, then, is returned to the boiler to be re-heated. Hydronic systems are generally closed-loop system but several distribution types exist including one-pipe series loops systems, one-pipe system with diverting tees, two pipe-direct return systems and two-pipe reverse return systems. Below is an illustration showing how a radiant floor would be installed in a home. The principle is similar for a multi-story apartment building.



http://www.bellgossett.com/homeowners/HT-Radiant-Heat-Loop-How-does-it-work.asp

More specifically, an apartment's hydronic heating system would be split into three sections: Boiler room, distribution network and heat transfer point. In the boiler room would contain a natural gas boiler, pressure reducing valve (regulate city pressure vs building pressure). The distribution network would include all the piping required to distribute the heated water to each room as well as the necessary air removal systems (compression and expansion tanks and air control fittings) and circulators (small centrifugal pumps). Each unit would require a zone valve that allows for custom control of heating profile. The heat transfer point is the actual radiant floor assumed to occupy the total room area as provided in the HOT2000 building energy modeling software. Below, is an illustration of how a in-floor radiant tube system would be installed.



Three types of in-floor installation exist:

1. Slab-on-grade system – Tubing attached to wire mesh or clipped into Styrofoam insulation. At “Grade” level so slab must be insulated from exterior side of floor to edges.
2. Thin Slab system – used when above subfloor, either covered in lightweight concrete or self leveling gypsum, or sandwiched between subfloor and finished floor. The latter method required underlayment panels to hold tubes in place as well as improve heat transfer (aluminum transfer plates)

3. Dry or “plate” system – underside of subfloor “below-deck or joist space dry system”. In colder climates extra insulation required to prevent heat dispersing into basement

The next section will investigate commercial sources of in-floor radiant heating technology.

1.4.2. Sources of in-floor heating technology

The Canadian Mortgage and Housing Corporation (CMHC) estimates the cost for a licensed mechanical contractor to install a hydronic radiant floor heating system to be $6 - $8 per square foot(Corporation 2010). Having the space heating demand met by a hydronic system would mean a mechanical air ventilation system would be required. CMHC sets the lifespan of hydronic system at 30 years minimum.

Anderson Radiant Heating (ARH) is a Californian company that specializes in in-floor hydronic systems. The company’s FAQ website states that cost of a in-floor radiant heat system costs between $6 - $12 per square foot. Since the boiler and operating equipment cost make up the bulk of the total, the square foot costs decrease with larger systems. ARH installs systems in smaller homes as well as large units. The apartments considered in this report benefit from economies of scale. The layout of the piping network underneath the floor depends on the orientation but is installed in a serpentine manner which allows for the hottest water to border the exterior perimeter first where the highest heat losses occur(Heating 2007).

Figure 1 ARH Piping Layout

Having an even slab-temperature is extremely important, uneven heating can cause uncomfortable “hotspots” to occur and increase occurrence of cracks and leaks. The size of the pipe is decided by thickness of the slab containing the pipes. The size of pipes used range from 3/8” – 1” and it is recommended that the slab have a minimum thickness of 1-1/4” to 2” respectively(Heating 2007). Though un-even slab temperature is avoided, there is no significant effects of thermal expansion and contraction of the piping because of the moderate operating temperatures(Heating 2007). Wherever the piping is not encased in the slab it is encouraged that the piping be surrounded by 6” of insulation. ADH preferred piping material is type “L” hard copper tubing. The primary benefit is the cost effectiveness of the raw material compared with the efficiency and evenness of heat transfer.

1.4.3. Green building standards

According to the British Columbia Housing and Construction Standards, green building standards are worth achieving because they can have a positive effect on energy consumption.

Green buildings standards also tack BC Hydro's supply gap problem from a different angle. By encouraging home-owners to adopt green building practices their power demand can be met more efficiently and allow for more comfortable living spaces(Standards 2010). Several green rating systems exist including: LEED, EnerGuide, Green Globes, CASBEE, BREAM and Built Green.

1.4.3.1. BC, North Van., UBC Building standards

The province of British Columbia made changes to the BC Building Code in 2008 to increase energy efficiency in single family homes and row houses. Buildings in BC follow the EnerGuide rating system established by National Resources Canada (NRCan).

North Vancouver's Lonsdale Energy Corporation (LEC) uses natural gas to heat and circulate hot water to a number of buildings. The North Vancouver Bylaw 7575 states that any new building larger than 1000 ft^2 must be connected to the district heating system unless deemed too costly by the city(2010). The LEC system is designed to meet both space heating and domestic hot water heating demands and provides 76°C water while expecting 43°C maximum temperature in the return line(2010).

UBC has made it a priority to be a leader in sustainable design and research with some of the most stringent greenhouse gas emission targets in the world. Reduce GHGs by 33% from 2007 levels by 2015 and by 67% below 2007 levels by 2020 and eliminate 100% of GHG emissions by 2050(2010). While UBC's South Campus falls under the Residential Environmental Assessment Program (REAP) it is not a part of UBC's 2050 GHG reduction goals. REAP is based on seven categories: Sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environment quality, construction and innovation and design process. The REAP system awards points based on how well a developer reaches the goals of each of the seven categories. Ideally, it is hoped that the implementation of a hydronic heating system would earn credits under the energy and atmosphere category by lowering fossil fuel consumption.

1.4.4. LCA

Robert Ries *et al* conduct a life cycle assessment of residential heating and cooling systems in different regions in the United States. Ries *et al* divide the life cycle of the process into distinct phases: extraction of raw materials, manufacturing and transportation of the system components operation and disposal. Ries *et al* breaks down the main equipment into weights basic materials (steel, aluminum, copper etc) and the estimate lifespan. The operating energy consumption of the homes was determined by the DOE-2 buidling energy simulation software(Ries 2008) which is similar to the HOT2000 software used in this report.

The life cycle analysis conducted for this report will fall into two sections: a quantitative analysis of the life cycle costs over a 20 years lifetime and a quantitative description of the life cycle impacts. The life cycle costs will be defined in terms of the net present value (NPV) of the capital and operation and maintenance costs. The life cycle impacts will discuss the merits of each system in terms of greenhouse gas emission and fuel emissions.

2. Information Sources

The data used for this report is divided into three sections: building models, energy demand and energy supply. The energy demand is based off the HOT 2000 building envelope modeling engine and the Infloor radiant heat system defined by InFloor Heating. This section will describe the limitations and assumptions made by the models and provide the basis for capital and life-cycle costs. Ultimately, the energy demand will characterize the space heating load for the apartment complex. The energy supply data sources will describe the two methods of supplying the energy: using a high temperature district water heating system defined by the LEC and using a high efficiency natural gas boiler. In both cases, the energy used will be used in a heat exchanger to meet the required temperature difference between the supply and return water temperature for the hydronic system.

2.1. Building Models

The building models for this report encompass two locations. The first one on marine drive in the city of North Vancouver and subject to the bylaws and regulations of that city and the second on UBC South Campus, subject to the regulation and guidelines of UBC's principles.

2.1.1. North Vancouver Seven35

The Seven35 residential complex is a 60-unit apartment located at 735 West 15th Street in North Vancouver, BC. HOT2000 characterizes the heating demand as 96,700 kWh/yr.

2.1.2. UBC South Campus Ultima (Spirit)

The Spirit residential complex is a 60-unit apartment on the UBC South Campus. HOT2000 characterizes the heating demand as 138,000 kWh/yr.

2.2. Heat Demand Characterization

The heat demand is defined by the assumptions and limitations of the HOT2000 building envelope thermal model and the efficiency and effectiveness of the heat distribution system, the hydronic heating system. The hydronic heating system investigated in this report is the system defined by InFloor radiant heat.

2.2.1. Infloor Radiant Heating

InFloor hydronic systems are designed for a 20 C drop between supply and return temperatures. Excessive insulation on the tubing will impede heat transfer. The maximum water temperature in-tube is 65 C. The amount of water required for the system is dependent on the supply temperature and the desired room temperature. Hydronic heating system has a high response time because of the heat capacity of water and the joining material (E.g. cement or aluminum). Infloor provides a table that links the heat loss of a room to the water flow rate with a 20F degree drop between supply and return.

2.2.2. HOT 2000 Modeling

The HOT2000 energy modeling software was used to characterize the building energy load. The software breaks down an apartment into units of similar type and quantifies the heat loss through the building envelop given the material R-values and solar gain of windows. The model incorporates weather data to provide a realistic model of heat loss throughout the year. Ultimately, HOT2000 determines the heat load to be met by the heating system, in this case an in-floor hydronic heating system.

The HOT 2000 (H2K) building modeling software was used to characterize the multi-unit residential building. H2K estimates the heating requirement of a building by modeling the heating envelope and estimating heat loss through air leakage and other factors. Two H2K models were received from Adera. One was a model of the Seven35 building and the other was a model of the SPIRIT building. A copy of the planned UBC building was not ready but the SPIRIT model is a close approximation for the purposes of this study. The heating requirements for the Seven35 and Spirit buildings are 96,700 kWh/yr and 138,300 kWh/yr respectively.

The Spirit building has been modeled as a set of 20 units with a total of 1445 m^2. The Seven35 building has been modeled as a set of 10 units totaling 507 m^2. Neither comprises all the units in the building. Therefore, assuming an average unit size of 72.25 m^2 and 50.7 m^2 the total floor area for the spirit and seven35 building is 4335 and 3043 m^2 respectively. The total floor area is important as it serves at the available heat transfer area for the hydronic heat transfer surface area.

2.3. Heat Supply Characterization

2.3.1. LEC

The Lonsdale Energy Corporation provides energy services to a community of customers through a network of underground pipelines that link suppliers with consumers. LEC claims a district energy system reduces capital costs by reducing building space dedicated to mechanical systems like boilers and water treatment systems and increased efficiency by waste stream recycling. The LEC heating system is made up of a series of mini-plants containing gas-fired condensing boilers rated at 90% efficient and able to provide 800-900 kW of energy. The system has a capacity for 15 boilers and able to provide 15 MW of hot water to 30 buildings, roughly 3 million ft^2 of building area.

LEC claims environmental benefits of reducing NOx emission by 64% and CO_2 emission by 21% compared to conventional heating practices. Boilers are rated at 95 % AFUE. Distribution system uses hot water in thin-walled steel pipe insulated with PUR insulation. Total capital cost of system at a 2003 estimate is $ 8,133,800

Buildings served by LEC will require a 2m X 3m space for an energy meter station including a heat exchanger typically located in a building mechanical room. LEC requirements dictate that both the space heating and domestic hot water must be heated by LEC system. DHW is to be heated to a minimum 760 C under all load conditions. Maximum return water temperature of 590 C. Also the system will provide 925 C to the customer side of the heat exchanger.

LEC Charges explained. There are three charges encompassing the cost of LEC energy: Meter charges, capacity charges and commodity charges.

- The meter charge is a monthly fee of $491 for each service connection. The monthly fee aims to recover the capital cost and operating cost for the meter and heat exchanger installed in the building over a 20 year period.
- The capacity charge is 2.93 $/kw multiplied by the energy capacity as determined by a professional engineer. This charge aims to recover the capital and operating costs of the boiler plants and distribution system.
- Commodity charge relates to the amount of heat consumed measured in kWh. This is the only charge that varies on a monthly basis. As natural gas is the primary source of energy

for LEC the commodity charge is directly related to the price of natural gas set by Terasen Gas

2.3.2. Terasen Gas

The alternative to a district heating option would be to use a natural gas boiler and purchase natural gas directly from Terasen Gas. The natural gas would run a boiler that would be in conjunction with a heat exchanger to heat water from the city supply to the distribution temperature.

2.4. Life Cycle Analyses Methodology

The life cycle analysis conducted for this report will fall into two sections: a quantitative analysis of the life cycle costs over a 20 years lifetime and a quantitative description of the life cycle impacts. The life cycle costs will be defined in terms of the net present value (NPV) of the capital and operation and maintenance costs. The life cycle impacts will discuss the merits of each system in terms of greenhouse gas emission and fuel emissions.

Terasen Gas quotes Statistics Canada in reporting that the emissions associated using natural gas as a fuel are 48.5 kg/GJ (Terasen Gas) or 0.183 tonnes CO_2eq / MWh. A City of North Vancouver website states that "it is more than fair to compare its emissions with the levels generated by BC Hydro's natural gas plant" (City of North Vancouver). However, the BC Climate Action Toolkit website claims the yearly energy supplied and GHG emissions released are 4 5000 GJ/year and 2230 tonnes GHG/ yr respectively (BC Climate Action Toolkit). Taking a high level average, the GHG intensity of the LEC district energy is 0.198 t GHG / MWh.

It is interesting to note that the LEC GHG intensity is 8% higher than Terasen Gas. A possible explanation for this is that the Terasen Gas value is strictly associated with the fuel, whereas the LEC value represents the GHG emissions associated for the entire system.

3. Results and Discussion

This section of the report discusses the effectiveness of a hydronic heating system meeting the space heating load of two multi-residential apartments with different loads. Furthermore, two sources of energy for the hydronic system were investigated: high temperature water from a district heating system and a natural gas boiler.

With the space heating demand determined by the HOT2000 model, the amount of water used on days when heating is required can be determined. The hydronic system outlined by InFloor transfers heat using a 20 C differential between input and output flows. Ignoring the inefficiencies due to heat transfer resistance in the floorboards a volume of water can be determined. For simplicity sake, it is assumed that the return water temperature is equal to the ambient room temperature, 20 C. Thus the supply temperature required in 40 C. The energy supply system is then required to heat the city water supply, 10 C to the distribution temperature, 50 C. The energy supply system must consume enough energy to heat the total mass of water used in the hydronic system. The characterization of the heat exchanger is beyond the scope of this report however it is a reasonable assumption that a high efficiency heat exchanger is used. An In-floor type hydronic heating system would require a volume of water that could transfer enough energy to meet the space heating demand. Assuming that the system is run half the time, a specific volume of water can be determined that would have to be heated by the external energy source. Table 1, below shows the data and amount of water required to meet the heating demand of the two cases.

Table 1

	N.Van	"UBC"	
Total Heat Demand	112.9	136.5	kWh
Water supply	10	10	C
Water entry to Hydro	30	30	C
dT	20	20	K
Cp	4.18	4.18	J/kgK
m_water	0.123	0.149	kg/day

Two separate external energy sources are being investigated to heat the water in the hydronic system. One, a 90% efficient hot water distribution system run by LEC and a 95% efficient natural gas boiler using Terasen natural gas. If the space heating demand for a building is 100 kWh, then the LEC system and Terasen system would have to provide 111.1 kWh and 105 kWh respectively. Each system can be used to determine the fuel cost for each system and the sensitivity analyses can be performed. Table 2, below shows the range in fuel costs for high and low estimates of fuel costs. The LEC energy costs range from 40 to 80 $/MWh_th and the Terasen gas NG rates vary from 4 to 8 $/GJ to represent the best and worst case scenarios for prices over the next 50 years.

Table 2

	Sensitivity Analysis			
Purchase Rate	DE Hot Water [$/MWh]		Terasen NG [$/MWh]	
	40	80	14.4	28.8
North Van	$ 4,298.43	$ 8,596.86	$ 1,465.99	$ 2,931.98
UBC	$ 6,148.05	$ 12,296.11	$ 2,096.81	$ 4,193.62

A quote from Infloor Radiant Heating for installation costs of a hydronic system state the installation cost of a hydronic system at $275000. The lifecycle costs for a LEC heating system would entail a 20000$ capital cost, 500$ per year in operating and maintenance costs and a 5000$ replacement cost after 20 years. The lifecyle costs for a Terasen gas system would entail a 10000$ capital cost, 200$ per year in operating and maintenance costs and a 2500$ replacement cost after 25 years. The total lifetime on the system in 50 years. Using a high and low estimate for fuel cost, the net present value (NPV) of each option is outlined in Table 3, below.

Table 3

	North Van	UBC
HW high	($440,550)	($501,265)
HW low	($370,001)	($400,359)
NG high	($347,027)	($367,734)
NG low	($322,967)	($333,320)

From Table 3, it can be seen that the NPV of a hydronic system fed by a district hot water system is higher than a system fed by a natural gas system. The reason for this is that the fuel costs for the district system are more expensive than for the natural gas option. On a cost basis alone, it would be hard to rationalize that a district hydronic heating system would be better

Table 4, below, contains the yearly greenhouse gases directly associated with the fuel type used. The greenhouse gas emissions associated with the space heating of 74 m^2 home using baseboard heaters supplied with hydroelectric electricity is .310 t GHG emissions per year (Mazzi, 2010). Scaling this value to 60 units equals 18.6 tonnes of GHG emissions per year.

Table 4

	GHG emissions [t GHG/yr]	
	LEC DE	NG Boiler
UBC	19.17	17.78
North Van	27.42	25.42

From Table 4, it can be seen that the UBC complex has a comparable amount of GHG emissions with respect to Mazzi's results. Whereas the North Van complex is roughly 45% higher. It is worth noting that installing a hydronic system don't significantly reduce the greenhouse gas emission compared to the city average. It would appear that the cost and environmental benefits of installing a hydronic system are worth making the switch from conventional systems. However, there can be ancillary benefits to using alternative methods to home heating that could offset the cost of a hydronic system. The REAP system, for example, gives points for developers for adopting alternative methods. So while maybe cost ineffective, there is the possibility that spending more on an alternative heating system could score more points on the REAP system.

4. Conclusions and significance of project

This report investigated meeting the space heating demand of two 60 unit residential apartments by using hydronic heating. An in-floor system was used as the heat distributor in the unit and two energy sources were compared. A high temperature water distribution system offered by LEC and a high efficiency natural gas boiler with natural gas purchased from Terasen Gas. The significance of this project highlights alternative methods to home space heating which is less dependent on electricity. Residential energy use accounts for 18% of electricity demand. New building codes and standards are encouraging new ideas that not only reduce overall lifetime costs but reduce the environmental impacts of cities in society. This report hopes to highlight the potential effectiveness of using more efficiency heat transfer mediums to meet space heating demands

5. Recommendations for future work

The limitations of this work are many but it does provide a starting point for future work. The question “is a hydronic heat system the optimal home heating system” is not answered in this work. A comparison was made so that a developer could choose to make either system profitable. Every method of energy generation has environmental impacts and sometimes a higher cost is worth it if the benefits of the whole system are considered.

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Appendix A –Data for Calculations

Data for Net Present Value Calculations

Discount rate = 6 %

Lifetime = 50 years

Space Heating Demand calculation

	N.Van	"UBC"	
H2K Annual Heat Demand	32238.2	34582.8	kWh
Units Modeled	20	15	
Heat demand per unit	1611.91	2305.52	kWh