District Feasibility Assessment for Ground Source Heat Pump System

Prepared for:

Otter Tail Power Company & Bemidji State University

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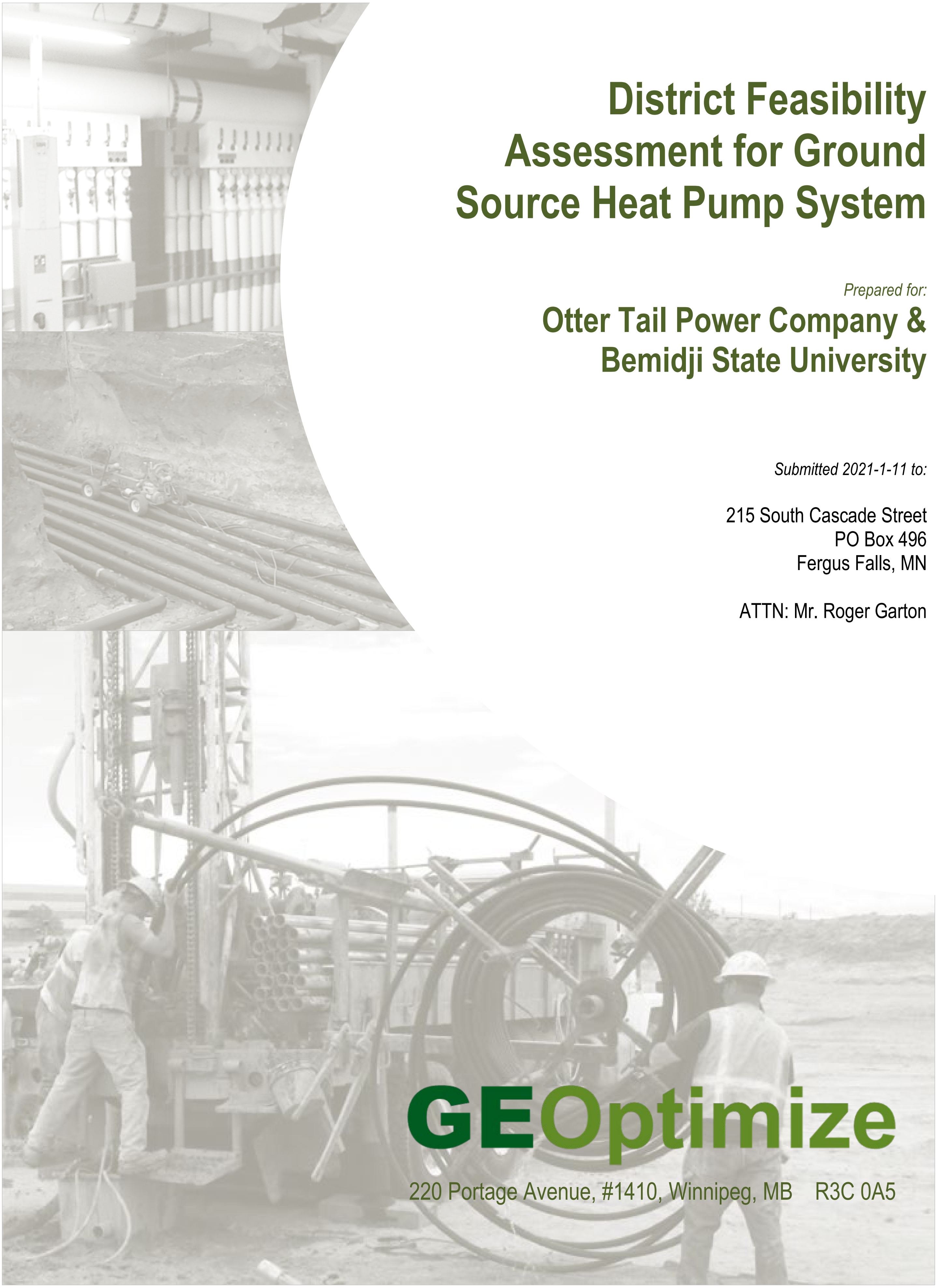

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Executive Summary

Bemidji State University (BSU) is a public state university located in Bemidji, MN with over 5,400 students and 23 buildings on campus with 1,450,000 ft^2 of floor area. BSU has embarked on a plan to achieve carbon neutrality by 2050. GEOptimize was retained to determine the feasibility of installing a district ground source heat pump (GSHP) system in the facility and comparing it to continuing to operate with the current central plant natural gas heating and electric cooling system.

To quantify the individual buildings space heating and cooling loads, previously constructed building energy models using Trane Trace 700 V6.3.4.0 were used. Based on the various buildings subdivided space usage, hourly energy loads from the existing energy models were scaled either up or down depending on the floor area difference and aggregated to create a new building energy profile. This method was applied to each of the 23 buildings in this analysis. The aggregated modelled energy loads were calibrated to the current energy bills to within 7% accuracy.

Individual energy load profiles were then optimized by using energy efficiency measures of lighting upgrades and energy recovery ventilators (ERV's). ERV's transfer energy from exhaust air to pre-heat or pre-cool incoming outdoor ventilation air which reduce the heating and cooling load in the buildings. More efficient lighting and lighting controls reduce cooling load as less energy is added to the space and also increase heating loads. These efficiency measures allow for a reduction in overall space heating and cooling while balancing the energy loads. This results in a reduced capital cost for ground heat exchangers (GHX) and reduced energy consumption.

The energy load profiles were used to model the size and performance of the GHX using the Ground Loop Design (GLD) 2016 software and thermal properties from the soil profile on campus. A horizontal directionally drilled (HDD) GHX was determined to be the most cost effective due to abundant land area on the campus and relatively low-cost drilling rates. Additionally, one vertical GHX and two water well heat exchangers were utilized in this study. Based on various interviews with the BSU staff and information sharing, a building priority list was developed to portion the capital cost required to begin the project. A modular construction process was applied by utilizing energy transfer pipe technology.

An energy transfer pipe moves energy from one building that is rejecting heat to the system (cooling) to another building that is extracting energy from the system (heating) and can be thought of as a conveyor belt. It consists of a single uninsulated plastic pipe with connections to buildings and GHX modules that allow for thermal energy storage and either heat extraction or heat rejection. Discretionary heating or cooling loads such as wastewater heat exchangers, surface water heat exchangers, and snow melt systems can be integrated to help manage the energy transfer pipe temperatures and reduce the capital costs while increasing the efficiency of the system. The energy transfer pipe system is an opportunistic technology that can take advantage of unique features of the site and buildings on the campus.

Based on the methodology described, in depth financial calculations were performed for each construction step based on the GHX cost, distribution piping cost, incentives, and energy cost savings. Two in depth analyses were performed, one with efficiency measures applied to the buildings and one without. The analysis without efficiency measures was deemed unfeasible due to a 40% greater GHX cost.

The total incremental cost for the district GSHP system including efficiency measure upgrades is $10,006,269 with annual energy cost savings of $450,275 once the project is complete (Table 1). Since the construction process is split into steps, this allows for compounding energy savings as more buildings are added to the energy transfer pipe.

The environmental impact from carbon dioxide (CO_2) emissions was one of the main driving factors for this study. Based on the current natural gas and electricity consumption as well as the CO_2 emissions intensity for the electrical grid (1.69 lbs/kWh), the estimated current annual CO_2 emissions from BSU is 14,102 metric tonnes (MT). Electrifying the campus would eliminate 98% of on-site CO_2 emissions due to the elimination of burning natural gas for heating. The estimated reduction in total CO_2 emissions considering the carbon intensity of electricity, once the full campus retrofit is complete including efficiency measure upgrades is 42% to a total of 8,181 MT's annually. Additionally, BSU can purchase $5,700 worth of RECs to offset the CO_2 emissions from their campus electricity consumption.

Table 1: Estimated capital and energy costs broken into recommended construction steps.

	Construction Steps	GHX Cost	Cooling Equipment Cost	ERV Cost	Lighting Upgrade Cost	Incentives	Incremental Capital Cost	Energy Cost Savings
A	Deputy Hall	$440,748	$297,000	$157,312	$0	$184,800	$710,260	$30,304
B	Bangsburg Hall + Phase 1 ETP	$333,382	$235,950	$173,756	$86,878	$147,876	$682,090	$25,877
C	Bensen Hall	$100,188	$141,900	$106,684	$53,342	$99,503	$302,611	$17,344
D	Hobson Memorial Union	$228,648	$158,400	$153,512	$76,756	$118,932	$498,384	$34,596
E	Heating Plant	$23,184	$47,850	$40,634	$20,317	$34,814	$97,171	$5,967
F	Chet Anderson Stadium	$0	$7,500	$900	$450	$5,162	$3,688	$90
G	PE complex + Phase 2 ETP	$854,496	$503,250	$218,855	$121,586	$256,071	$1,442,116	$32,711
H	Gillett Wellness Center	$577,080	$448,800	$171,530	$0	$212,300	$985,110	$28,942
I	Sattgast Hall	$312,480	$275,550	$142,029	$0	$151,800	$578,259	$9,983
J	AC Clark Library	$30,000	$178,200	$142,924	$0	$117,700	$233,424	$11,046
K	Central Receiving + Phase 3 ETP	$144,556	$34,650	$16,160	$8,080	$21,609	$181,837	$2,739
L	American Indian Resource Center	$79,380	$31,350	$20,776	$10,388	$20,240	$121,654	$2,837
M	Bridgeman Hall	$84,420	$85,800	$0	$33,772	$59,458	$144,534	$9,884
N	Decker Hall	$94,500	$75,900	$29,424	$29,424	$50,193	$179,055	$7,655
O	Memorial Hall	$130,000	$151,800	$0	$53,893	$117,301	$218,392	$23,322
P	Walnut Hall	$153,720	$138,600	$114,334	$0	$73,700	$332,954	$15,190
Q	Cedar Hall	$124,740	$92,400	$78,266	$39,133	$56,988	$277,551	$15,145
R	Birch Hall	$196,560	$145,200	$0	$62,184	$90,586	$313,358	$24,066
S	Linden Hall	$214,200	$146,850	$135,130	$67,565	$94,723	$469,022	$25,274
T	Oak Hall	$406,980	$280,500	$257,100	$128,550	$182,678	$890,452	$47,304
U	Tamarack Hall	$278,460	$206,250	$176,820	$88,410	$128,628	$621,312	$34,215
V	Pine Hall	$160,020	$117,150	$100,528	$50,264	$73,095	$354,867	$19,452
W	Hagg-Sauer Hall	$265,860	$240,900	$0	$0	$138,592	$368,168	$26,335
	Total	***$5,233,602***	***$4,041,750***	***$2,236,674***	***$930,992***	***$2,436,749***	***$10,006,269***	***$450,275***

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AHU	Air handling unit
BAS	Building automation system
BSU	Bemidji State University
CHP	Combined heating and power
CO_2	Carbon dioxide
COP	Coefficient of performance
EER	Energy efficiency ratio
ERV	Energy recovery ventilator
ETP	Energy transfer pipe
GHX	Ground heat exchanger
GLD	Ground loop design
GSHP	Ground source heat pump
HDD	Horizontal directionally drilled
HDPE	High density polyethylene
HVAC	Heating, ventilation, and air conditioning
LEED	Leadership in Energy and Environmental Design
MT	Metric ton
OTPCO	Otter Tail Power Company
REC	Renewable energy credit
TC	Thermal conductivity
TD	Thermal diffusivity

1. Introduction

BSU is a public state university located on the shores of Lake Bemidji and was founded in 1919 with the first class consisting of 38 students. Since then, BSU has grown to over 5,400 students with over 23 buildings on campus.

BSU has embarked on a plan to achieve carbon neutrality by 2050. The Sustainability Office on campus is devoted to sustainability efforts which is funded by a student 'green fee' of $7.50 a semester. Among their many initiatives towards sustainable, green energy, BSU is considering the installation of a district GSHP system as a potential strategy to reduce on site emissions from fossil fuels and energy consumption.

Currently, the 23 buildings included in this analysis are cooled with 2 chillers and heated with 3 high pressure steam boilers (Table 2). Additionally, the campus uses 1 low pressure boiler in the summer for domestic hot water. Electricity is supplied by OTPCO and natural gas is supplied by Minnesota Energy Resource and Constellation Energy Company.

Table 2: Equipment installed in existing central energy plant.

		Year Installed	Capacity	Primary Use
Heating	Low-Pressure Hot Water	1990	---	Summer / DHW production
	High-Pressure Steam	1990	23,000 pounds / hour	Stage 1 heating
	High-Pressure Steam	1990	23,000 pounds / hour	Stage 2 heating
	High-Pressure Steam	2008	43,000 pounds / hour	Peak heating (Dec-Feb)
Cooling	Chiller 1	1997	500-Ton	Alternating years
	Chiller 2	2008	550-Ton	Alternating years

The building name, occupancy and space usage breakdown that can be seen in Table 3, is based on current data. Additional information was gathered during several phone interviews and video conferences with the building operators. This information was used to diagnose optimum construction steps and methodology that offer the best business investment value by minimizing capital cost while maximizing the reduction of operating costs and greenhouse gas emissions.

Table 3: Building breakdown by occupancy, total area, and space usage (SU).

Site Name	Occupancy	Current SF	SU 1	SU 1%	SU 2	SU 2%	SU 3	SU 3%	SU 4	SU 4 %
Deputy Hall	12 months	78,656	Office	95%	Computer Center	5%				
Bangsberg Hall	9 months	86,878	Educational Laboratory	55%	Classrooms	25%	Office	10%	Theater/Auditorium	10%
Bensen Hall	9 months	53,342	Classrooms	70%	Office	20%	Workshop	10%		
Hobson Memorial Union	9/Office 12	76,756	Dining	45%	Office	20%	Common Areas	16%	Workshop	10%
Central Maintenance Building	12 months	20,317	Workshop	60%	Warehouse	20%	Parking	15%	Office	5%
Chet Anderson Stadium		19,911	Sports Arena	100%						
Physical Education Complex	12 months	121,586	Gymnasium	31%	Fitness	21%	Workshop	15%	Locker Rooms	13%
Gillett Wellness Center	12 months	85,765	Gymnasium	38%	Fitness	26%	Locker Rooms	16%	Office	10%
Sattgast Hall	9 months	107,598	Educational Laboratory	45%	Classrooms	20%	Workshop	15%	Office	10%
AC Clark Library	9 months	71,462	Stacks and Reading	75%	Computer Center	25%				
Central Receiving	12 months	8,080	Maintenance/Repair	50%	Warehouse	45%	Office	5%		
American Indian Center	9 months	10,388	Office	33%	Theater/Auditorium	25%	Classrooms	15%	Workshop	10%
Bridgeman Hall	9 months	33,772	Educational Laboratory	50%	Classrooms	40%	Office	10%		
Decker Hall	12 months	29,424	Classrooms	55%	Educational Laboratory	45%				
Memorial Hall	9 months	53,893	Office	45%	Classrooms	25%	Computer Center	15%	Common Areas	15%
Walnut Hall	12 months	57,167	Dining	41%	Storage	25%	Office	19%	Kitchen	14%
Cedar Hall	9 months	39,133	Dorm Rooms	60%	Common Areas	34%	Dining	5%	Apartments	1%
Birch Hall	9 months	62,184	Dorm Rooms	60%	Common Areas	34%	Dining	5%	Apartments	1%
Linden Hall	9 months	67,565	Dorm Rooms	54%	Common Areas	31%	Workshop	10%	Dining	5%
Oak Hall	9 months	128,550	Dorm Rooms	51%	Common Areas	29%	Workshop	15%	Dining	4%
Tamarack Hall	9 months	88,410	Dorm Rooms	60%	Common Areas	34%	Dining	5%	Apartments	1%
Pine Hall	9 months	50,264	Dorm Rooms	60%	Common Areas	34%	Dining	5%	Apartments	1%
Hagg-Sauer Hall	9 months	82,478	Classrooms	55%	Theater/Auditorium	20%	Office	15%	Workshop	10%

2. Utility history

The electricity and natural gas bills were collected from OTPCO, Constellation, and Minnesota Energy Resources for 2019-2020. Table 4 shows the campus monthly natural gas consumption in therms, electricity consumption in kWh and respective costs. The campus operates on one main electricity meter and one main natural gas meter. Since electricity and natural gas is not sub-metered to any of the buildings, accurate information is unavailable for each of the buildings.

Table 4: Monthly electricity and natural gas consumption with cost for 2019-2020.

Month	Gas Use (Therms)	Gas Cost ($)	Electricity Use (kWh)	Electricity Cost ($)
Jan	183,658	$74,685	928,800	$77,315
Feb	163,501	$64,975	928,800	$77,223
Mar	137,936	$52,725	860,400	$70,837
Apr	104,972	$38,164	716,543	$57,251
May	18,373	$7,483	526,800	$46,151
June	13,662	$5,180	752,400	$65,125
July	12,956	$4,936	936,540	$72,161
Aug	14,445	$5,584	1,031,760	$78,269
Sept	91,740	$12,708	954,240	$81,164
Oct	92,776	$34,349	913,800	$73,890
Nov	117,139	$48,238	937,680	$69,434
Dec	175,666	$72,871	907,620	$67,667
Total	**1,126,823**	**$421,898**	**10,395,383**	**$836,486**

The annual natural gas consumption is approximately 1,126,823 therms and 98% of the total natural gas consumption is estimated to be used for space heating. Therefore, space heating currently costs BSU $413,460 annually and they currently pay, on average, $0.39 / therm. Winter heating loads drive consumption from November through March with a peak usage shown in January at 183,658 therms. The total annual electricity use for 2019-2020 is 10,395,383 kWh costing BSU $836,486. Electricity consumption is relatively constant year-round with a drop in usage from April-June due to summer break. This reduces the number of students and lighting in the buildings which in turn reduces space cooling and electricity usage. When classes begin in August, the electricity usage rises to its peak due to high occupancies from starting semester activities. The percentage of space cooling out of the total electricity usage is estimated at 20% based on similar values from previous projects. Therefore, currently BSU spends roughly $167,297 annually on space cooling and pays $0.081 / kWh. The current total campus heating and cooling cost is estimated at $580,757.

2.1. Efficiencies

The primary benefit for using a steam boiler system is the amount of heat released as it condenses to water (986 Btu / lb). It is relatively safe, nontoxic and non-flammable. The disadvantages of using a steam district system are the heat losses in the distribution system that reduce efficiency by 15-20% according to Leadership in Energy and Environmental Design (LEED). Other heat losses on a steam boiler system can be attributed to steam traps, valve stems, blowdown, and flash losses. There is also reduced efficiency in the shoulder seasons when a high-capacity boiler is operating to meet a low heating requirement. To determine whether the natural gas usage in the system is normal relative to the climate, a regression analysis between monthly heating degree days and an average therms/day was performed and can be seen in Figure 1.

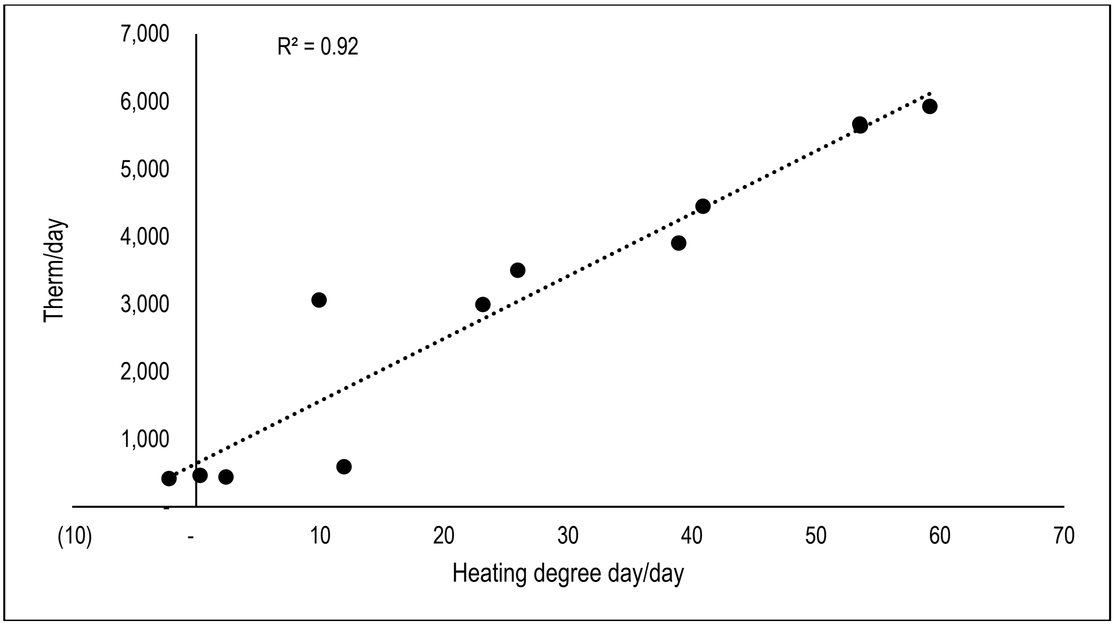


Figure 1: Regression between average monthly heating degree day/day and therms/day.

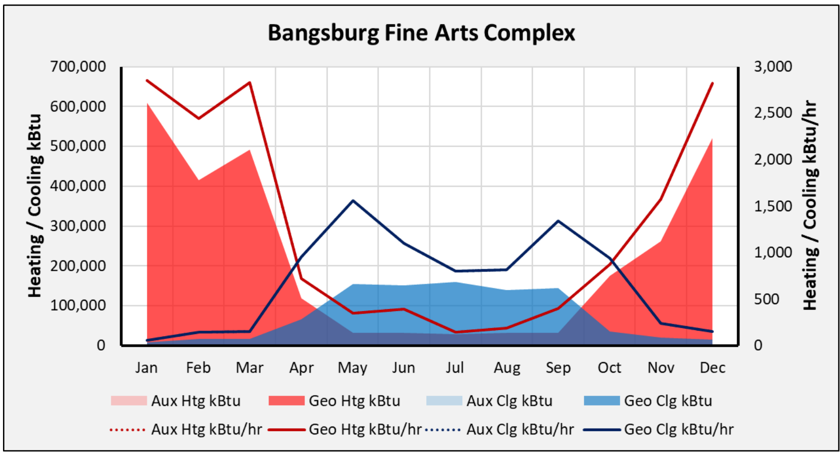
The coefficient of determination (R^2) is 0.92 which shows that the amount of natural gas consumed is consistent with the amount of heating required which therefore leads to confidence in the efficiency of the system. Although the amount of heating delivered is consistent with the amount of heating required, LEED recommends a minimum 15% reduction in efficiency from distribution losses. Since the boiler efficiency was determined as 88% after information gathering with the building operators at BSU, the total system efficiency for space heating is assumed to be 73%. For the space cooling, an estimated energy efficiency ratio (EER) of 10.2 for the chillers is used.

3. Methodology

3.1. Space heating and cooling block loads

To quantify the individual buildings space heating and cooling loads accurately with limited data, previously constructed building energy models (using Trane Trace 700 V6.3.4.0) from an energy model database using Bemidji weather data were used to extract monthly peak heating and cooling loads and monthly heating and cooling energy loads for the space usages seen in Table 3.

The existing energy models incorporated ASHRAE 90.1 (2013) building envelope u-factor standards for the roof, walls, and windows. The energy loads from the existing energy models were scaled to match the floor area of each building. For example, the Bangsburg Fine Arts Complex is an 87,778 ft^2 building comprised of 55% educational laboratory (48,278 ft^2), 25% classrooms (21,945 ft^2), 10% office space (8,778 ft^2), and 10% theatre space (8,778 ft^2). The existing energy model hourly load sets used were scaled and aggregated accordingly to match the square footage per space usage for the Bangsburg Fine Arts Complex represented in Figure 2. This method for obtaining hourly heating and cooling loads was replicated for the 23 buildings in this analysis. The aggregated energy loads for all the buildings on campus were calibrated to within 7% of the annual energy bills from BSU.



	Bangsburg Fine Arts Complex			
	Geo Cooling		Geo Heating	
	kBtu	kBtu/hr	kBtu	kBtu/hr
Jan	9078	57	608468	2850
Feb	16039	146	415332	2441
Mar	16020	150	490750	2828
Apr	66143	953	119318	724
May	154344	1557	31845	346
Jun	151287	1097	31905	390
Jul	159520	798	28890	148
Aug	138437	813	31331	192
Sep	144961	1341	32008	402
Oct	35431	942	174488	874
Nov	20686	242	261498	1573
Dec	14319	153	519745	2823
	926,267	**1557**	**2,745,577**	**2850**
	Tons	130	Tons	237
	EFLH	595	EFLH	964

Figure 2: Monthly peak and total cooling and heating load based on hourly calculations for the Bangsburg Fine Arts Complex.

3.2. Energy efficiency measures

Several iterations of the energy models were created and used for the analysis described in Section 3.1. In addition to the standard ASHRAE 90.1 energy model outputs, two efficiency measures were applied to manipulate and ultimately reduce the heating and cooling loads. The first efficiency measure that was applied was an exhaust air energy recovery ventilation system (ERV). This efficiency measure was applied to buildings without an existing ERV. ERV's use exhaust air to pre-heat or pre-cool incoming outdoor ventilation air as seen in Figure 3 and can have substantial savings on energy usage and costs.

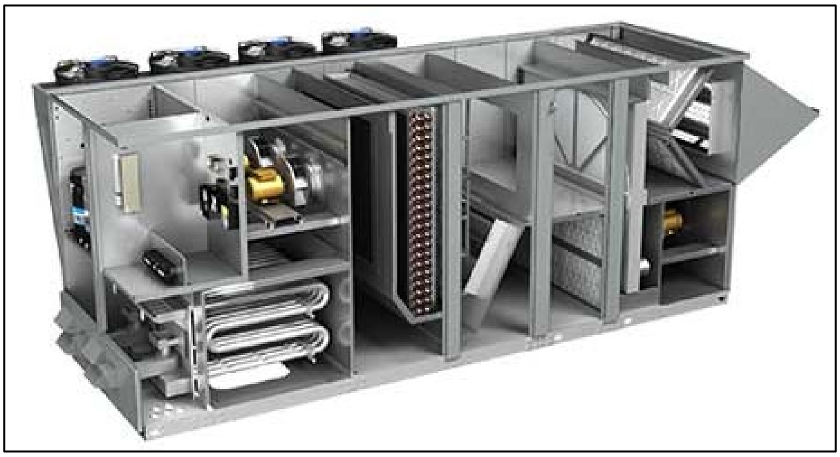
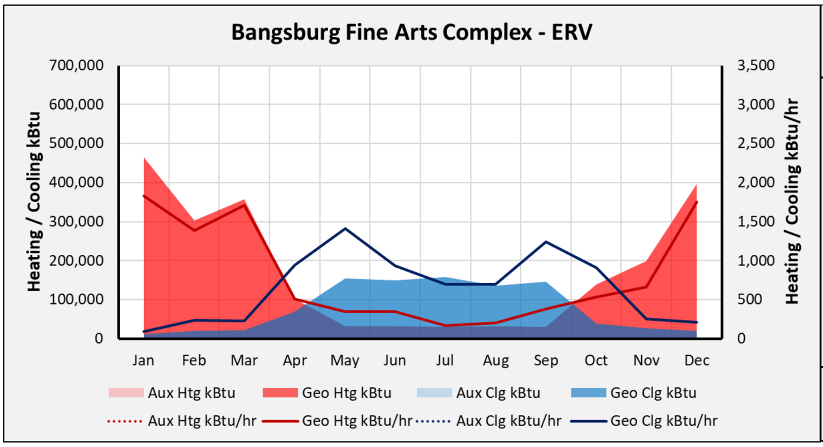


Figure 3: Energy recovery ventilation system

ERV's reduce the peak and annual heating load in a colder climate like Bemidji. When an ERV was applied to the Bangsburg Fine Arts Complex, the peak cooling and heating loads reduced by approximately 10% and 36%, respectively, compared to the standard building model (Figure 4). Similarly, the annual heating energy load was reduced by 24%. An ERV was applied to every building included in the analysis and they not only increase the energy savings, but significantly reduce the GHX size required due to the increase in balance between heating and cooling loads.

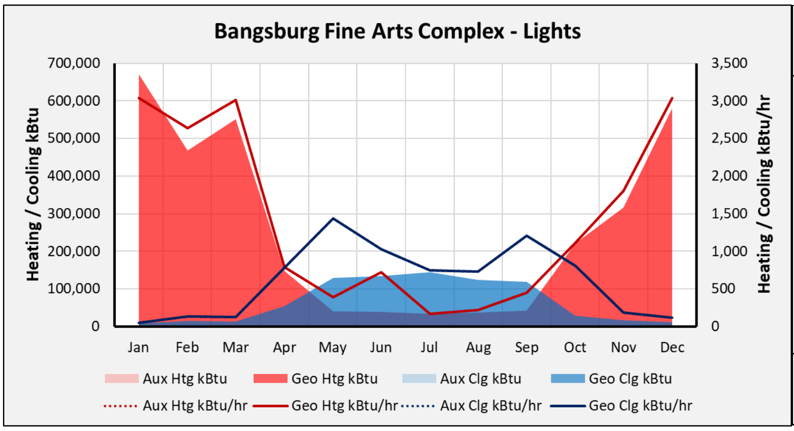


	Bangsburg Fine Arts Complex - ERV			
	Geo Cooling		Geo Heating	
	kBtu	kBtu/hr	kBtu	kBtu/hr
Jan	12169	96	465154	1826
Feb	20691	233	303284	1389
Mar	21304	226	357031	1709
Apr	69349	943	102258	511
May	155058	1407	31898	348
Jun	149653	930	32007	344
Jul	157717	700	29784	171
Aug	136546	699	31807	202
Sep	145587	1242	30101	381
Oct	38694	905	139928	531
Nov	26817	255	199151	664
Dec	19899	213	396232	1747
	953,484	1407	2,118,635	1826
	Tons	117	Tons	152
	EFLH	678	EFLH	1,160

Figure 4: Bangsburg Fine Arts Complex energy profile with ERV.

The second efficiency measure applied in this analysis was upgraded lighting. This efficiency measure was applied to buildings without a recent lighting upgrade. The lighting intensity in a building is typically measured in W/ft^2 and the lower the lighting intensity, the lower the cooling load. Lighting intensity can be reduced by installing LED lights, occupancy sensors and daylight sensors. Daylight sensors measure ambient light levels and adjust lighting levels when outdoor ambient light is sufficient. This takes into consideration seasonal changes in the day/night cycle.

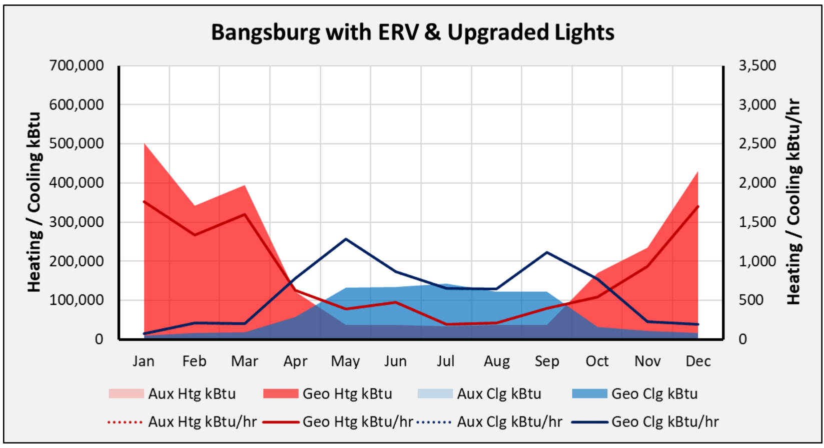
For this analysis, an assumed lighting intensity of 1.2 W/ft^2 was used for buildings without recent lighting upgrades and 0.6 W/ft^2 for a hypothetical retrofit or an existing building on campus that recently underwent a retrofit such as Deputy, Walnut and Sattgast Halls, the A.C. Library and the Gillette Wellness Center. Although, lighting upgrades can have a large impact on cost savings, the total energy reduction for both heating and cooling is typically low.The greater impact is seen in the impact on the energy balance, with a reduction in cooling load and a corresponding increase in heating loads. For example, the Bangsburg Fine Arts Complex, a decrease in lighting intensity from 1.2 to 0.6 W/ft^2, the peaking cooling load was reduced by 8% and peak heating load increased by 7% (Figure 5). Annual cooling loads decreased by 10% while annual heating loads increased by 15%.



	Bangsburg Fine Arts Complex - Lights			
	Geo Cooling		Geo Heating	
	kBtu	kBtu/hr	kBtu	kBtu/hr
Jan	7724	48	670732	3039
Feb	14251	136	467838	2637
Mar	13881	130	550888	3009
Apr	53719	781	148471	788
May	129241	1438	40436	393
Jun	134861	1025	39240	726
Jul	144322	745	33979	171
Aug	124301	734	37005	221
Sep	118700	1211	42463	446
Oct	28106	809	221759	1117
Nov	16970	188	315468	1806
Dec	12113	120	580652	3040
	798,187	1438	3,148,931	3040
	Tons	120	Tons	253
	EFLH	555	EFLH	1,036

Figure 5: Bangsburg Fine Arts Complex energy profile with lighting upgrades.

When combining an ERV and lighting upgrades, this allows for an amplified effect on the decrease of energy savings and GHX size. As seen in Figure 6, the peak cooling load reduces by 18%, the peak heating load reduces by 38%, the annual cooling load decreases by 11% and the annual heating load decreases by 14%. For each individual building, the reductions appear respectable, but when the efficiency measures are applied to a district system, the reductions are compounded and substantial.



	Bangsburg - ERV & Upgraded Lights			
	Geo Cooling		Geo Heating	
	kBtu	kBtu/hr	kBtu	kBtu/hr
Jan	9838	76	501240	1761
Feb	17450	209	341155	1334
Mar	17752	204	394308	1595
Apr	58377	780	122954	625
May	132689	1281	37881	389
Jun	133439	863	37592	479
Jul	142013	651	33990	193
Aug	122187	644	36541	211
Sep	121632	1112	37272	396
Oct	31537	770	169445	543
Nov	22421	225	235173	938
Dec	16452	191	430631	1700
	825,787	**1281**	**2,378,185**	**1761**
	Tons	107	Tons	147
	EFLH	645	EFLH	1,351

Figure 6: Bangsburg Fine Arts Complex energy profile with ERV and lighting upgrades.

3.3. GLD numerical modelling

To determine the size of the GHX required for the space heating and cooling loads developed in Section 3, GLD (V10.0.43) software was used to calculate the size and performance of the GHX by calculating long-term ground temperature trends and heat pump entering water temperatures. GLD is used to calculate the size, configuration, and long-term performance of several different types of GHX. For this analysis we analysed vertical and HDD configurations.

Initially, a vertical GHX was designed due to the construction familiarity for local contractors. For a vertical GHX, the following inputs are required.

- The local thermal conductivity (TC),
- Thermal diffusivity (TD) and
- Ambient ground temperature

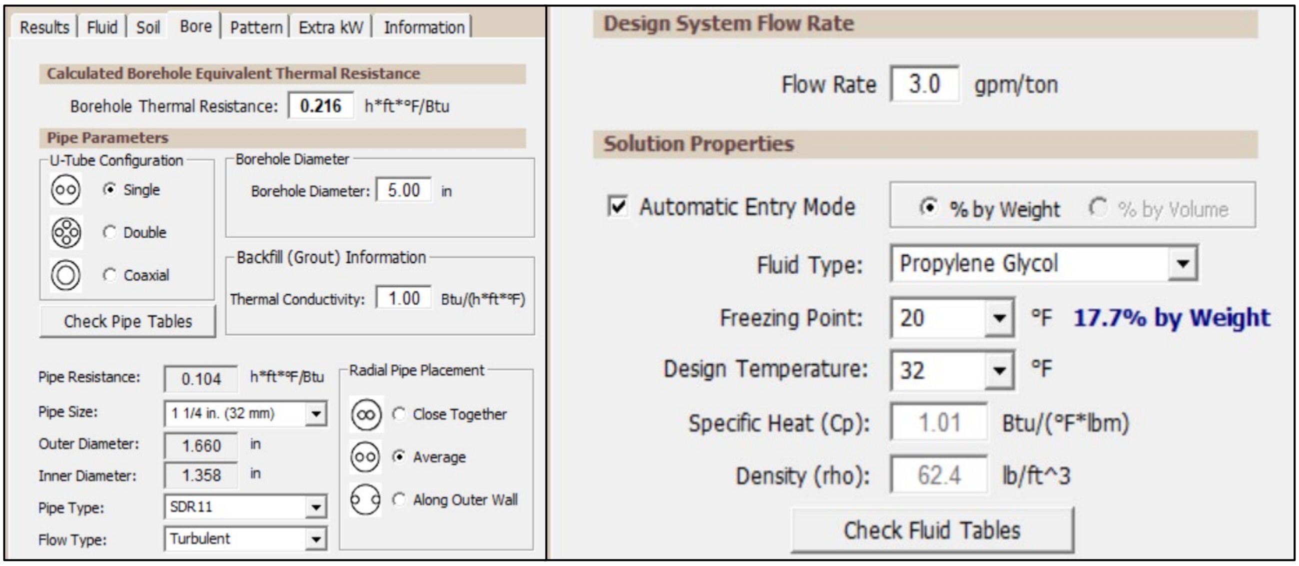
To estimate the TC and TD, soil stratigraphy information was gathered from water well logs in the Minnesota Well Index (https://mnwellindex.web.health.state.mn.us/). Data from a well drilled on the BSU campus was found and the stratigraphy with estimated TC and TD can be seen in Table 5. Along with the TC and TD, the undisturbed ground temperature was estimated at 49°F based on the average annual air temperature for the location. Other required inputs include:

- Pipe size and type,
- Borehole diameter,
- Thermal conductivity of grout installed between the GHX pipe and soil, can be seen in Figure 7.

Based on the geology found in the Bemidji area, horizontal directionally drilled GHX's can typically be installed at a cost between 10% and 15% less than a vertical GHX of similar capacity.

Table 5: TC and TD calculated from water well lithology and depth.

Depth		Layer	Lithology	Weighted TC	Weighted TD
Start	End			Avg	Avg
0	30	30	Sand 80 lb 10%	0.11	0.06
30	32	2	Clay 100 lb 10%	0.00	0.00
32	88	56	Sand 100 lb 20%	0.36	0.21
88	103	15	Sand 120 lb 15%	0.12	0.07
103	154	51	Clay 100 lb 20%	0.15	0.10
154	156	2	Sand 100 lb 15%	0.01	0.01
156	228	72	Clay 120 lb 15%	0.28	0.16
228	241	13	Sand 120 lb 15%	0.10	0.06
Depth	**241**			**1.14**	**0.67**



Calculated Borehole Equivalent Thermal Resistance

Borehole Thermal Resistance: 0.216 h*ft*°F/Btu

Pipe Parameters

U-Tube Configuration: ● Single ○ Double ○ Coaxial

Borehole Diameter: 5.00 in

Backfill (Grout) Information — Thermal Conductivity: 1.00 Btu/(h*ft*°F)

Pipe Resistance: 0.104 h*ft*°F/Btu

Pipe Size: 1 1/4 in. (32 mm)

Outer Diameter: 1.660 in

Inner Diameter: 1.358 in

Pipe Type: SDR11

Flow Type: Turbulent

Radial Pipe Placement: ○ Close Together ● Average ○ Along Outer Wall

Design System Flow Rate

Flow Rate 3.0 gpm/ton

Solution Properties

☑ Automatic Entry Mode ● % by Weight ○ % by Volume

Fluid Type: Propylene Glycol

Freezing Point: 20 °F **17.7% by Weight**

Design Temperature: 32 °F

Specific Heat (Cp): 1.01 Btu/(°F*lbm)

Density (rho): 62.4 lb/ft^3

Figure 7: Typical vertical ground heat exchanger pipe parameters along with solution properties and design system flow rate.

There are several advantages of an HDD GHX. These include:

- Lower capital costs,
- Minimal site disturbance, (horizontal boreholes can be installed under existing paved parking areas)
- The proximity of the horizontal GHX piping to the atmosphere allows dissipation of excess heat to the atmosphere in winter and warm outdoor air temperatures and rainfall can add energy to the GHX during the summer, eliminating the potential for long-term temperature degradation

Similar to the vertical GHX methodology, the same well log was used to calculate the TC and TD but to a shallower depth of 32 ft which yielded a TC of 0.83 Btu/h·ft·°F and TD of 0.46 ft^2/day. Because of the impact of outdoor air temperatures on the shallow boreholes, the regional air temperature swing and coldest/warmest day of the year is needed. In Bemidji, the regional air temperature swing is 33°F and the coldest/warmest day of the year is February 4th and August 5th, respectively. The piping configuration was modelled as 3 sets of u-tubes stacked vertically to a depth of 30 ft, 20 ft, and 10 ft. 1 ¼" SDR 11 pipe was used for the u-tubes. A visual representation can be seen in Figure 8. These sets of U-tubes are installed adjacent to each other in rows with a separation of 10 ft.

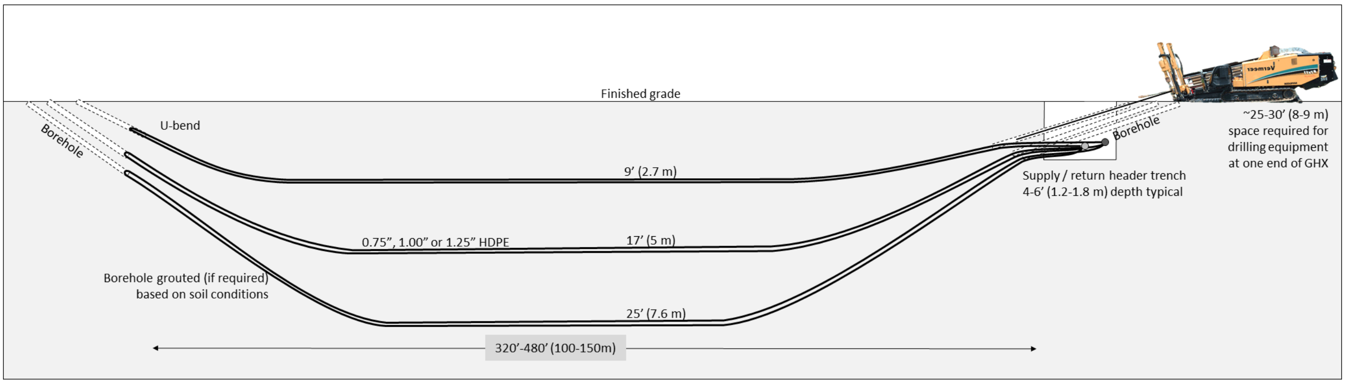


Figure 8: Visual representation of horizontal directionally drilled boreholes.

3.4. Building order selection

The campus consists of 23 existing buildings built between 1919 and 2009. Some of the buildings have had renovations as recently as 2016 while others have had few renovations since 1966. To minimize capital cost expenditures, it is more cost-effective to consider the installation of a geothermal heat pump system at a time the existing equipment is scheduled for replacement rather than replacing equipment before end of life.

A building retrofit order was determined based on building type, location, and the heating, ventilation, and air conditioning (HVAC) condition ranking seen in Table 6. Additional information was provided by the University indicating the residence buildings should be converted last due to the availability of capital funds which adjusted the building order selection.

Table 6: Building ranking based on current HVAC condition and years remodeled.

Building	Year Completed	Remodel	Remodel	Remodel	Remodel	HVAC condition (10 = new; 0 = replacement necessary)
Bangsberg Fine Arts Complex	1971					1
Deputy Hall	1919	1928	1949	1979	1981	1
Chet Anderson Stadium	1938	1989				1
Bensen Hall	1950	1986				2
Physical Education Complex	1959	1967				2
Hobson Memorial Union	1967	1972				3
Walnut Hall Food Service	1969	1991				3
Cedar Hall	1959	1991				4
Heating Plant & Garage	1926	2020				5
Gillett Wellness Center	1989					6
Sattgast Hall (original)	1962	1989				6
A.C. Clark Library	1966	1999				7
Central Receiving	1979					7
American Indian Resource Center	2001	2009				8
Birch Hall	1952					8
Bridgeman Hall	1964	2004	2006			8
Linden Hall	1959	1964	2007			8
Oak Hall	1965	1966				8
Tamarack Hall	1969	2010				8
Decker Hall	1957	1964	1979			9
Memorial Hall	1940	2016				9
Sattgast Hall (south addition)	2009					9

3.5. Energy reduction calculations

To quantify the projected reduction in CO_2 emissions and operating costs, the existing energy consumption seen in Table 4 was used as the baseline. Based on conversations with the building operators, the percentage of space heating from natural gas usage is 98% with a heating system efficiency of 73%. For the space cooling, the percentage of electricity consumption was estimated at 25% with a coefficient of performance (COPc) of 3 (EER of 10.2) for the chillers.

Based on the percentages and efficiencies, a current district space cooling load of 26,638,169 kBtu and heating load of 80,612,882 kBtu was determined (Table 7). Using the energy models discussed in Section 3.1 and the current district space cooling and heating load, the aggregated modelled energy loads were calibrated to match the current district loads within 5%.

Once the individual building energy loads were established, the energy savings were calculated based on the difference in efficiencies. With a GSHP, the heating COP was determined at 4.5 based on a 40°F source side temperature and a 110°F load side temperature. For cooling, a COPc of 5.1 (EER of 17.4) was determined based on an 80°F source side temperature and a 45°F load side temperature. The resulting energy cost savings and CO_2 emissions reduction is discussed more thoroughly in Sections 7 and 8.

Table 7: Annual energy use broken into space heating and cooling energy.

Heating		Annual Use (Therms)	Annual kBtu Heating Load	Annual Heating kBtu Delivered
Campus Gas Consumption		1,126,823		
% Gas Used for Space Heating	98%	1,104,286	110,428,605	
Central Boiler Efficiency (%)	73%	806,129		**80,612,882**
Cooling		**Annual Use (kWh)**	**Annual kBtu Cooling Load**	**Annual Cooling kBtu Delivered**
Campus Electricity Consumption				
% Electricity used for Space Cooling	25%		8,867,262	
Central Chiller Efficiency (EER)	10.25			**26,638,169**

For the energy savings from an ERV, the heating energy consumption was reduced by 39.6% based on the energy model estimates and the cooling energy consumption was increased by 5.9%. To determine the energy savings from the lighting upgrades, a reduction in lighting intensity from 1.2 to 0.6 W/ft^2 was assumed. Based on the floor area of each building applied with the lighting upgrades and an average annual lighting operating hours of 4271, the energy savings were determined. The annual lighting operating hours was determined from a lighting audit conducted on a similar type college campus.

4. GSHP system integration

A GSHP system is comprised of three components:
- Distribution system
- Heating and cooling equipment
- The GHX

4.1. Distribution system

In the existing BSU campus buildings, the distribution system and ductwork that distributes heating and cooling throughout the buildings are already in place. Air handling units (AHU's) currently provide heating with steam boilers connected to steam converters and cooling with electric chillers. Implementing a GSHP system into each building will most likely require the upgrade of the existing AHU's hot and chilled water coils. Water to water heat pumps will be required to supply hot and chilled water to the coils. These heat pumps will not replace the boilers and chillers in the central plant but will need to be located in the buildings that they serve.

As buildings are connected to the GSHP system, the capacity of the boilers and chillers in the existing central energy plant can potentially be reduced.

Additionally, the load side entering water temperature has a large impact on the energy savings and efficiency of the system. For example, when designing the entering heating water for the AHU's for 130°F versus 110°F, this not only reduces the efficiency of the system by 25%, but also decreases the size of the GHX by approximately 10%.

For new buildings, water to water heat pumps offer more flexibility in designing distribution systems as they are not tied to the temperatures supplied by the central plant. Low temperature heating and high-temperature cooling systems can be considered such as a radiant floor system that heats with 85-90°F water and cools with 65°F chilled water.

It is critical to design the system in the most efficient manner to maximize the capital and operating cost savings. The capital cost for the replacement of heating and cooling coils are not considered in this study due to the anticipated end of life retrofit. Although the cost of coils was not considered, the cost of coils designed for 110°F water is not significantly greater than the cost of coils requiring 130°F water.

4.1.1. Exhaust air energy recovery

Recovering energy from air exhausted from the building provides significant reductions in kWh consumption and kW demand regardless of whether a GSHP system is installed or not as shown in Section 3.2. The cost of installing an ERV is typically around \$2 / ft^2 of building. Installing an ERV system requires the installation of ductwork between the location of exhaust fans and the appropriate ERV equipment installed with each AHU. They can also be integrated with an existing system inexpensively by using less intrusive design methods.

The cost of heat pump equipment and the GHX required for a GSHP system is directly related to the energy loads of the building. Since energy loads are reduced as other energy efficiency measures are implemented in the facility, the reduced cost of a GSHP system helps offset the cost installing an ERV. Additionally, in some cases, an ERV can reduce the capacity needed for the heat pump equipment.

4.2. Heating and cooling equipment

The implementation of a GSHP system will require mechanical room space to house water to water heat pump equipment, circulation pumps and GHX supply/return pipes. Hot and chilled water piping will be required from the mechanical room space to the existing AHU's. To accommodate the heat pump equipment, circulation pumps and other mechanical equipment, an external modular mechanical room seen in Figure 9 is an option that can be considered for buildings with inadequate space for an internal mechanical room .

Installing high efficiency heat pumps versus a low efficiency heat pump can decrease the ground loop size by 5% and for cooling dominant buildings up to 10%. Additionally, high efficiency heat pumps will allow for greater energy savings and reduced CO_2 emissions. The main difference between a high and low efficiency heat pump is the EER and COP. The EER is the ratio output of cooling energy delivered to input electrical energy to run the heat pump whereas the COP is the same ratio for heating. A high efficiency heat pump typically has an EER of 20 and COP of 4.7 whereas a low efficiency heat pump has an EER of 12 and COP of 3.7. The higher the EER and COP, the more cost savings, and less CO_2 emissions.

Figure 9: External modular mechanical room to house water to water heat pumps, and circulation pumps can possibly be located near the campus buildings.

4.3. GHX

One of the main components of a GSHP system is the GHX. It consists of plastic pipe buried in the ground adjacent to a building. The total campus footprint is approximately 160 acres. Within the campus footprint, there is available space for a HDD GHX under the Bangsburg parking lot, Chet Anderson Stadium field, soccer complex, PE parking lot, BSU athletic field, Maple parking lot, Birch parking lot and Tamarack parking lot. Based on the methodology discussed in Section 3.4, the HDD GHX has been designed to be a step-by-step type installation based on building priority.

Rather than retrofitting the entire campus simultaneously which would require large amounts of capital, Table 8 shows the order of buildings to be retrofitted when funds are available. Since the land area is limited, it was determined that the scenario without installing efficiency measures would not be feasible. If efficiency measures are not installed, the GHX size increases by an average of 40%. All GHX installations will be HDD except for steps I where a vertical GHX will be installed. Also, steps J and O will utilize a water well heat exchanger. The total campus GHX length is estimated at 387,345 ft and will cost approximately $4,808,140, when efficiency measures are added to each building.

Table 8: Building priority list with size and cost of incremental ground loop required to heat and cool each building with efficiency measure upgrades.

	Building Priority List	Incremental GHX Length (ft)	Estimated Installation Cost
A	Deputy Hall	36,729	$440,748
B	Bangsburg Hall	10,313	$123,756
C	Bensen Hall	8,349	$100,188
D	Hobson Memorial Union	19,054	$228,648
E	Heating Plant	1,932	$23,184
F	Chet Anderson Stadium	0	$0
G	PE complex	61,383	$736,596
H	Gillett Wellness Center	48,090	$577,080
I	Sattgast Hall	26,040	$312,480
J	AC Clark Library	Water Well System	$30,000
K	Central Receiving	3,885	$46,620
L	American Indian Resource Center	6,615	$79,380
M	Bridgeman Hall	7,035	$84,420
N	Decker Hall	7,875	$94,500
O	Memorial Hall	Water Well System	$130,000
P	Walnut Hall	12,810	$153,720
Q	Cedar Hall	10,395	$124,740
R	Birch Hall	16,380	$196,560
S	Linden Hall	17,850	$214,200
T	Oak Hall	33,915	$406,980
U	Tamarack Hall	23,205	$278,460
V	Pine Hall	13,335	$160,020
W	Hagg-Sauer Hall	22,155	$265,860

HDD GHX's are a non intrusive type of drilling with only a 5'x 5' trench adjacent to the drill rig required as seen in Figure 8. Although the HDD GHX is fairly unintrusive, available land area is still required for the pipe to be buried under. Based on the various lengths of GHX in Table 8, six key drilling areas have been identified as Bangsburg parking lot, Chet Anderson Stadium field, soccer complex, PE parking lot, BSU athletic field, Maple parking lot, Birch parking lot and Tamarack parking lot as seen in Figure 10. The total aggregated land area required for the GSHP retrofit with efficiency measures is 1,254,410 ft^2. Note that the capital costs associated with each GHX, include the connections to the energy transfer pipe (ETP) from the GHX. This is shown in a detailed breakdown for location and per building in Table 9.

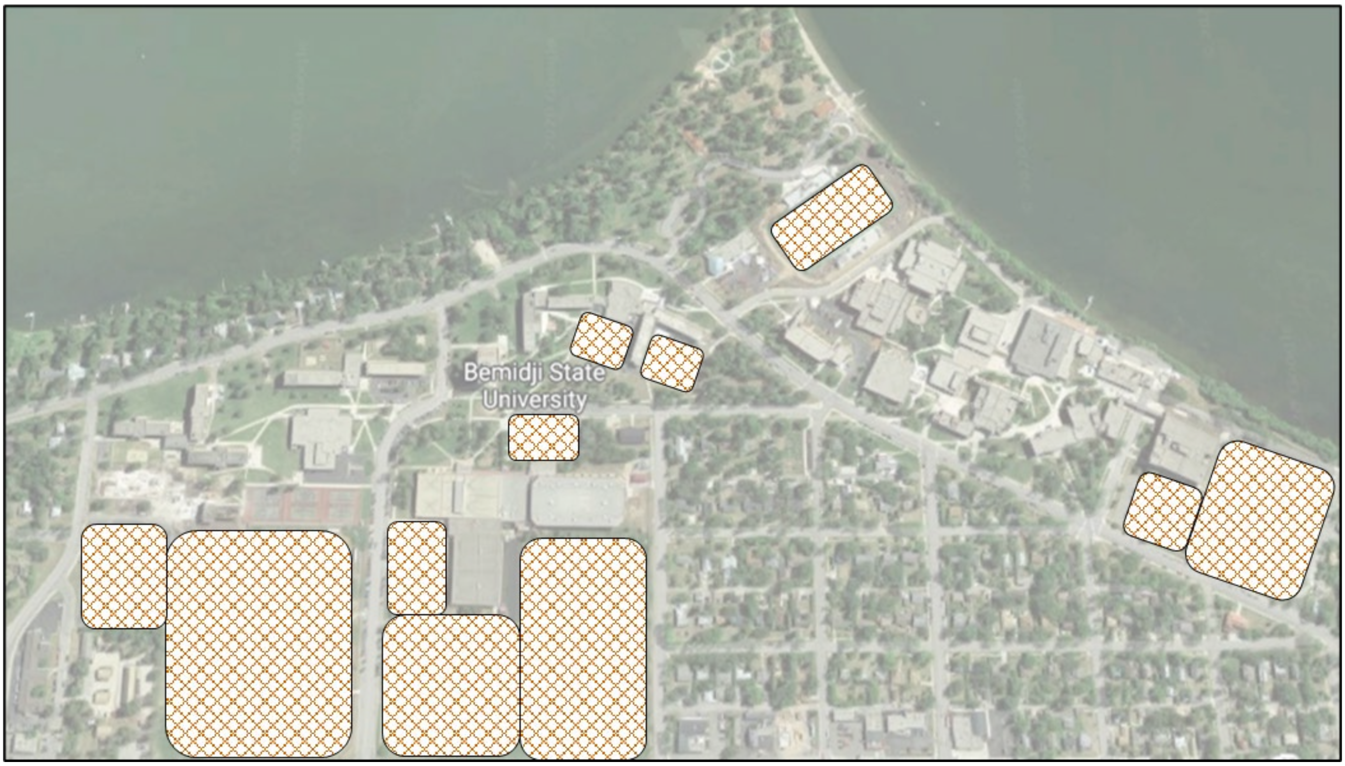


Figure 10: Key drilling sites for the HDD GHX

Table 9: Building priority list with incremental land area and location required to heat and cool each building with efficiency measure upgrades.

	Building Priority List	Incremental Land Area (ft2)	Location
A	Deputy Hall	116,400	Bangsburg Parking Lot
B	Bangsburg Hall	5,400	Bangsburg Parking Lot
C	Bensen Hall	39,700	Bangsburg Parking Lot
D	Hobson Memorial Union	86,510	Chet Anderson Stadium
E	Heating Plant	6,580	Chet Anderson Stadium
F	Chet Anderson Stadium	0	Chet Anderson Stadium
G	PE complex	204,750	Soccer Complex
H	Gillett Wellness Center	160,020	Soccer Complex
I	Sattgast Hall	50,000	Adjacent to Sattgast Hall
J	AC Clark Library	100	Adjacent to A.C. Library
K	Central Receiving	13,090	BSU Athletic Field
L	American Indian Resource Center	22,135	Chet Anderson Stadium
M	Bridgeman Hall	23,400	Maple Parking Lot
N	Decker Hall	26,075	Soccer Complex
O	Memorial Hall	100	Adjacent to Memorial Hall
P	Walnut Hall	42,630	Maple Parking Lot
Q	Cedar Hall	34,580	Maple Parking Lot
R	Birch Hall	54,600	Birch/Linden Hall Parking Lot
S	Linden Hall	59,570	Tamarack Parking Lot
T	Oak Hall	112,805	BSU Athletic Field
U	Tamarack Hall	77,560	BSU Athletic Field
V	Pine Hall	44,275	BSU Athletic Field
W	Hagg-Sauer Hall	74,130	BSU Athletic Field

4.3.1. Water wells

Groundwater can provide a constant energy source / heat sink when it is available. BSU is on the shore of Lake Bemidji and groundwater moves readily through the spaces between particles of sand and gravel beneath the ground. Groundwater in this area is at a constant temperature of approximately 47°F.

When the fluid temperature in the ETP is above or below the groundwater temperature, energy can be transferred to or from the system. Groundwater can be circulated through a heat exchanger connected to the ETP similar to the connections of the solar thermal and snowmelt seen in Figure 19.

Groundwater can be drawn from a supply well, circulated through a heat exchanger connected to the ETP and returned to the ground via a return well. Alternatively, a heat exchanger can be installed directly in a water well. Inducing flow across the heat exchanger by drawing water from a water bearing zone at one depth and returning it into a water bearing zone at a different level above a heat exchanger installed inside the water well. Fluid from the ETP is circulated through the heat exchanger in the well, transferring energy to or from the system[1]. Installing the heat exchanger within the well casing allows the transfer of energy between the ETP and the aquifer without physically removing water from the ground, reducing the risk of contamination.

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[1] DARCY Systems is a firm located in Minneapolis that manufactures the heat exchangers designed for installation in the well casing.

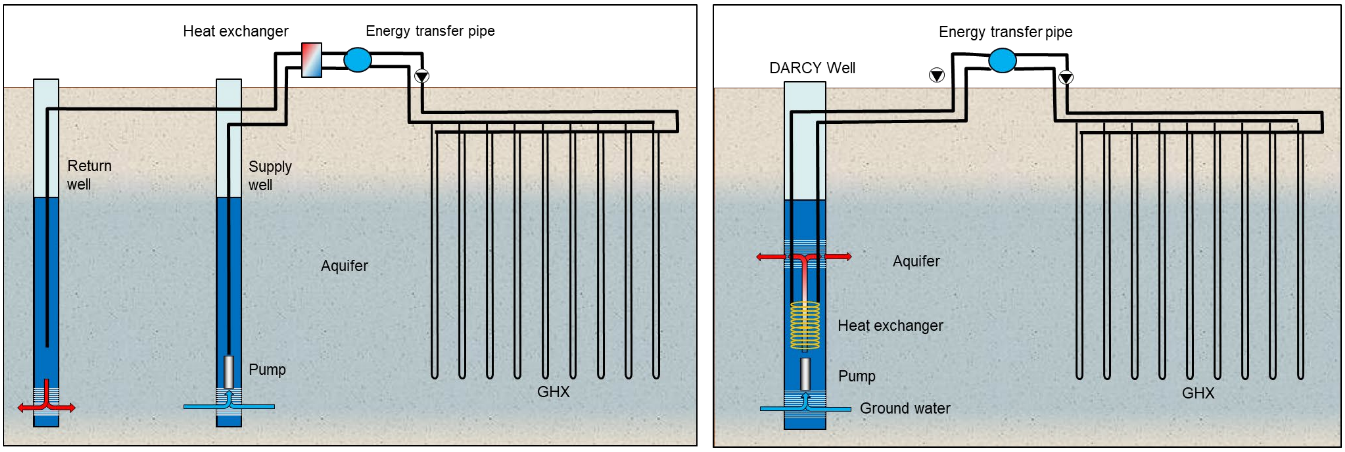

Figure 11: Transferring energy between the ETP and an aquifer can be accomplished with supply / return well pair and a heat exchanger in a mechanical room or with the installation of a heat exchanger located in the well casing.

4.3.2. Surface water heat exchanger

Surface water heat pump systems could be an alternative or additive technology to support the HDD GHX system. They utilize surface water bodies such as lakes, reservoirs, and rivers as heat sources and heat sinks. Closed-loop surface water heat pumps use submerged heat exchangers to extract or reject heat from the surface water body. Heat transfer between the heat exchanger and the lake is typically due to natural convection. Since the BSU campus is on the shore of Lake Bemidji, this allows for the opportunity of utilizing a surface water heat exchanger in Lake Bemidji to control the temperature of the energy transfer pipe.

For a surface water heat pump system, the heat exchanger coils are often made of high-density polyethylene (HDPE) pipes, but some projects use titanium alloy or galvanized steel tube heat exchangers which can have a higher cost and corrosion problems. There are two main configurations of surface water heat exchangers:

- HDPE slinky type (Figure 12)
- Stainless steel plate (Figure 13)

Figure 12: HDPE slinky surface water heat exchanger being sunk to the bottom of a pond.

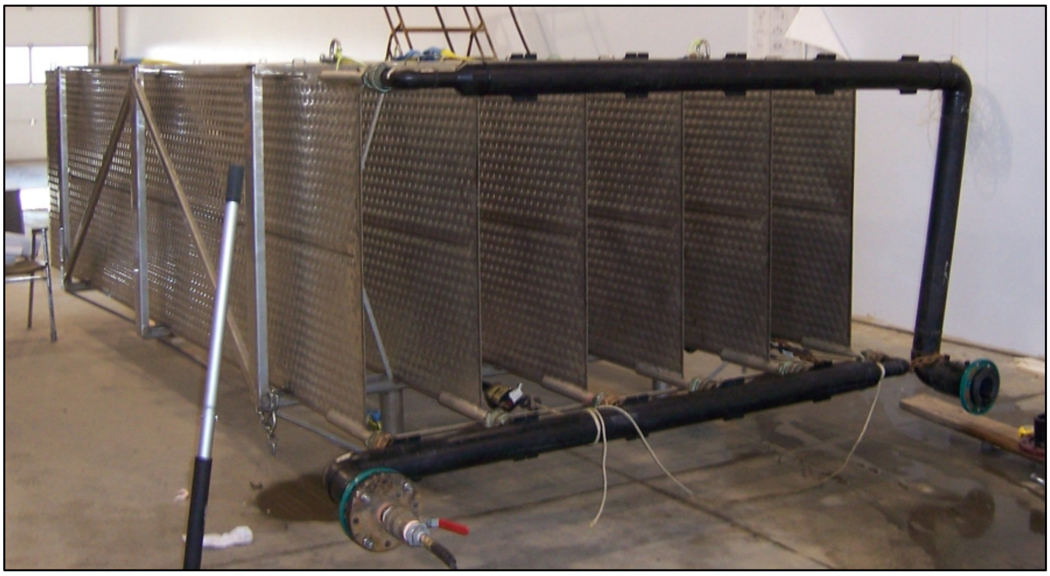

Figure 13: Stainless steel plate surface water heat exchanger.

Depending on the location and occupancy of the BSU campus shoreline on Lake Bemidji, the installation would need to be coordinated to minimize risk of propeller contact from recreational boats. This could ultimately cause a system failure from a broken pipeline. If installed properly, this technology has the potential to not only reduce the capital costs from the reduced size of the GHX field, but also reduce the annual operating costs and CO_2 emissions due to increased efficiencies.

5. District system configuration

A traditional district system consists of a central energy plant that produces steam or hot water and / or chilled water that is delivered to the buildings connected to the system. Conventional systems burn fossil fuels (gas, oil, propane, or coal) and deliver hot water at approximately 160°F or greater, or steam. Chilled water is produced with conventional water-cooled chillers. GSHP systems can and have been used in place of conventional fossil fuel boilers and water-cooled chillers.

An alternative approach that works well with a GSHP system is often referred to as an "energy sharing system". An energy transfer pipe (ETP) moves energy around a single continuous pipe loop. Buildings connected to the ETP add energy to it when they are being cooled and remove energy from it when they are being heated, much like parcels added to or removed from a conveyor belt.

The two district system design approaches are described in the following sections.

5.1. Central energy plants

A traditional district heating system is based on a large central heating / cooling plant that produces hot and / or chilled water that is distributed to buildings connected to it. The schematic design of a central plant district heating / cooling system is illustrated in Figure 14. The capacity of the central plant and the hot and chilled water distribution system must be designed to meet the peak heating and cooling loads of all buildings that will potentially be connected to it.

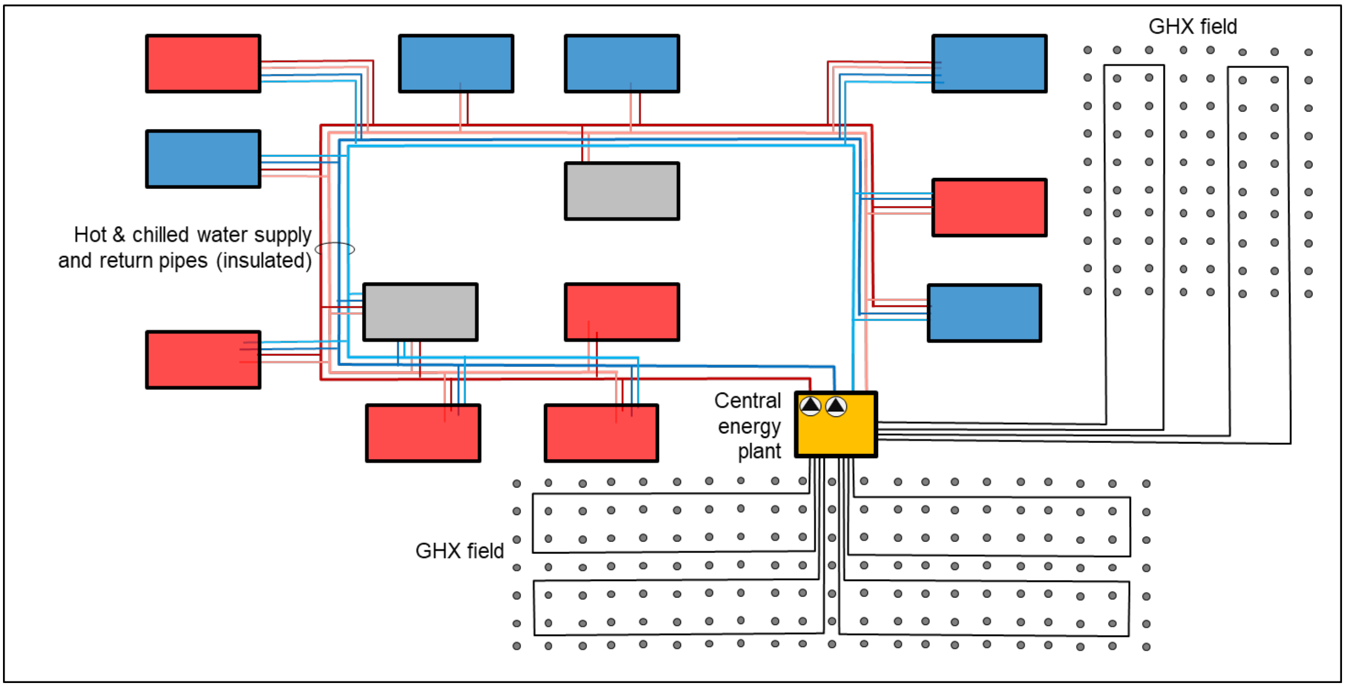

Figure 14: With a central energy plant all boreholes are connected to the heat pump in the central plant.

5.1.1. GHX connections to central energy plant

Energy is transferred to or from the GHX at a single, central location, at the large heat pump in the central energy plant. All boreholes are connected to the central energy plant and, depending on the land area available near the central plant building, may significantly increase the cost of connecting the GHX to the system and can have an impact on construction cost.

5.1.2. Distribution piping

When all heating and cooling is distributed from a central energy plant, the hot and chilled water distribution system is sized to meet the peak heating or cooling capacity of the entire system. The flow rates shown for the buildings seen in Figure 16 indicate a flow rate of 1,700 gpm at peak heating load for the buildings. With numerous connections to GHX modules to the single ETP shown in Figure 16, the peak flow rate required is reduced to 300 gpm. This flow rate can be accommodated with an ETP 8" in diameter.

To meet the peak system heating load from the central energy plant, the pipe must deliver 1,700 gpm to the buildings. This will require a pipe approximately 12-14” diameter to supply heated fluid to the building and a similar size pipe to return water to the central energy plant. In comparison, the single ETP requires a peak flow rate of 300 gpm that can be accommodated with a single 8” diameter pipe.

To achieve the peak flow rate of 1,700 gpm used in this example, a 15 hp pump will be required. In comparison, a 2 hp pump will be required to achieve the peak flow rate of 300 gpm. This will have an impact on both capital cost as well as long term energy cost.

In a system with a central energy plant heating water is delivered to the buildings at approximately 120°F and chilled water is delivered at approximately 45°F. Hot water piping buried in the 47°F ground will require insulation to prevent heat loss and will have to be insulated. Hot and chilled water piping that can be located in the utility tunnels will have to be insulated to prevent heat loss to the space and avoid condensation on the chilled water piping. In contrast, the water temperature delivered to the buildings connected to the single ETP can range between 35°F and 85°F without minimal impact on the heating and cooling delivered to the building. Insulation is not required for the buried portions of the single ETP.

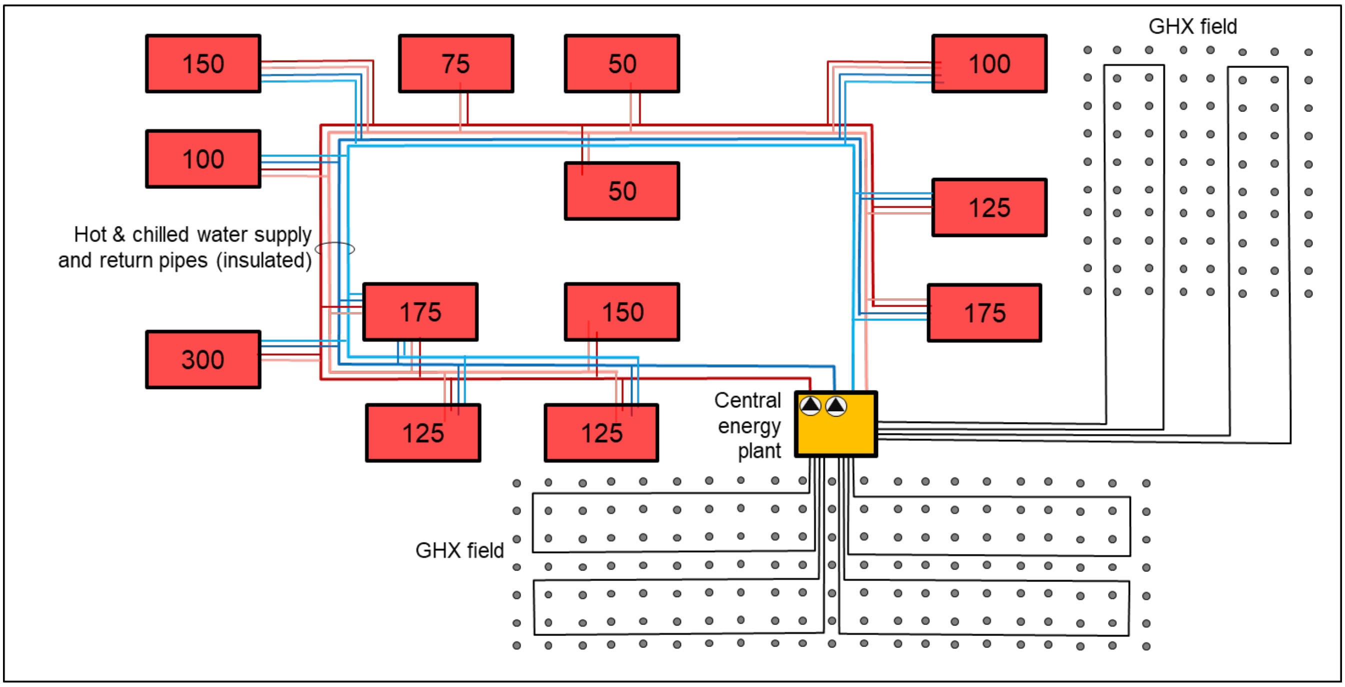

Figure 15: Hot and chilled water is delivered to all connected buildings. The pumps and piping system is designed to accommodate the total flow of 1,700 gpm during peak loads and the piping must be insulated to minimize heat transfer to and from the ground.

5.2. Energy sharing system

Buildings and GHX modules are connected to a single continuous pipe loop, or ETP. Water (or water mixed with antifreeze) is circulated around the ETP. Buildings connected to it add energy to the fluid in the ETP when the building is cooled, raising the temperature a few degrees, and remove energy from it when heating, lowering the temperature a few degrees.

When a building adds heat to the ETP and the building adjacent to it removes the same amount, the temperature of the fluid in the pipe after the second building is the same as the fluid temperature before the first building. Energy transfer between buildings recaptures and recycles heat that would otherwise be dissipated through cooling towers and reduces or eliminates the need for burning fossil fuels to heat the buildings.

When more heat is removed from the pipe than is being added, the temperature in the ETP drops. To continue operating efficiently, heat must be added to the pipe. GHX modules connected to the ETP at regular intervals along the length of the pipe add heat when the temperature of the fluid drops too low by activating the GHX circulation pump. Some of the cold fluid from the pipe is diverted to the GHX module, extracts heat from the ground and is injected back to the ETP.

Conversely, when the heat added to the pipe increases the temperature in the pipe, the GHX modules are activated to dissipate heat to the ground. Typically, the temperature of the fluid in the pipe is maintained between 40° and 85°F. GHX modules are activated as the temperature of the fluid falls outside of that range.

The GHX modules store excess energy when it cannot be used in other buildings connected to the ETP and release the heat to the pipe when it is not available from other buildings.

The fluid temperature in the ETP operates at moderate temperatures, generally within 20-30°F of the ambient ground temperature (about 47°F in Bemidji). Insulation is not required on the pipe, and the temperature is well within the temperature parameters of HDPE pipe.

The size of the ETP is dictated by three factors:

- The flow required to meet the peak heating and cooling loads of the buildings connected to the ETP
- The temperature of the fluid circulating through the ETP
- The relative location of connections to buildings with connections to GHX modules

Figure 16 shows building connections to the ETP alternating with connections to GHX modules. Alternating connections of GHX modules and building(s) to the ETP allows reductions in both capital cost and long-term operating costs of the system.

Figure 16 shows 13 buildings connected to an ETP. The building connections are labeled with numbers 1 to 13. GHX module connections are found at regular intervals around the ETP after every 2nd or 3rd building. The GHX connections are labelled from A to F. A pump, labelled the energy transfer pump, circulates fluid continuously around the ETP. The buildings in Figure 16 are shown in red, indicating they require heating. Circulation pumps in each building are drawing fluid from the pipe, circulating the fluid through heat pumps in the buildings and injecting the fluid back into the ETP a few degrees cooler. In one section of the pipe (building connections 10-13) each building lowers the temperature a few degrees.

GHX-A is immediately downstream of Building-13. If the temperature at A is lower than desired, the pump on the GHX module is activated to divert some of the fluid through the GHX where it is warmed by the earth. The warmed fluid is pumped downstream to Buildings-1 and 2 and heat is again removed from the fluid. Immediately after Building-2, the fluid is diverted through GHX-B and re-warmed before it is pumped to Building-3. This process, with the fluid being cooled in the buildings and warmed at intervals around the ETP, is repeated continuously as fluid is circulated through the ETP.

When all buildings are being cooled in summer, the opposite occurs. As heat is rejected to the ETP, efficient operating temperatures are maintained by activating GHX pumps at intervals around the ETP, as shown in Figure 17.

5.2.1. System flow rates

Heat pumps require specific flow rates within specific temperature parameters to operate efficiently. Most heat pump manufacturers recommend:

- Flow of 2.5 to 3.0 gpm per ton of capacity
- Minimum temperature of 30-35°F to maximum of 80°F entering water temperature when heating
- Minimum temperature of 50°F to maximum of 90-100°F entering water temperature when cooling

The flow needed through the ETP must meet the flow requirements of the largest building peak load connected to it. For example (in Figure 16), if the peak heating load in Building-7 is 100 tons, the flow through the ETP must be approximately 300 gpm to deliver the required energy at a minimum temperature of 30-35°F.

To achieve this, the Energy Transfer Pump must circulate 300 gpm of fluid to the Building-7 connection. If the temperature of the fluid is less than the minimum temperature required, the pump for GHX-D is activated to add heat to the pipe. Fluid reinjected to the ETP at Building-7 is cooled as heat is removed by the heat pumps in the building, to be re-warmed before the Building-8 connection by diverting the flow through the ETP through GHX-E.

Note that the flow required through each building (or group of buildings) totals 300 gpm or less, and that the fluid can be diverted through a GHX module to collect energy from the earth to stay within the operating parameters of the heat pumps connected to it. Because of the GHX connections to the ETP at regular intervals around the ETP loop, the temperature of the fluid can be maintained, while allowing a flow rate of 300 gpm to supply the energy required by heat pumps which traditionally would require a total flow of 1,700 gpm. This significantly reduces pumping energy required in the system and allows a much smaller pipe to deliver energy to heat pumps in the buildings.

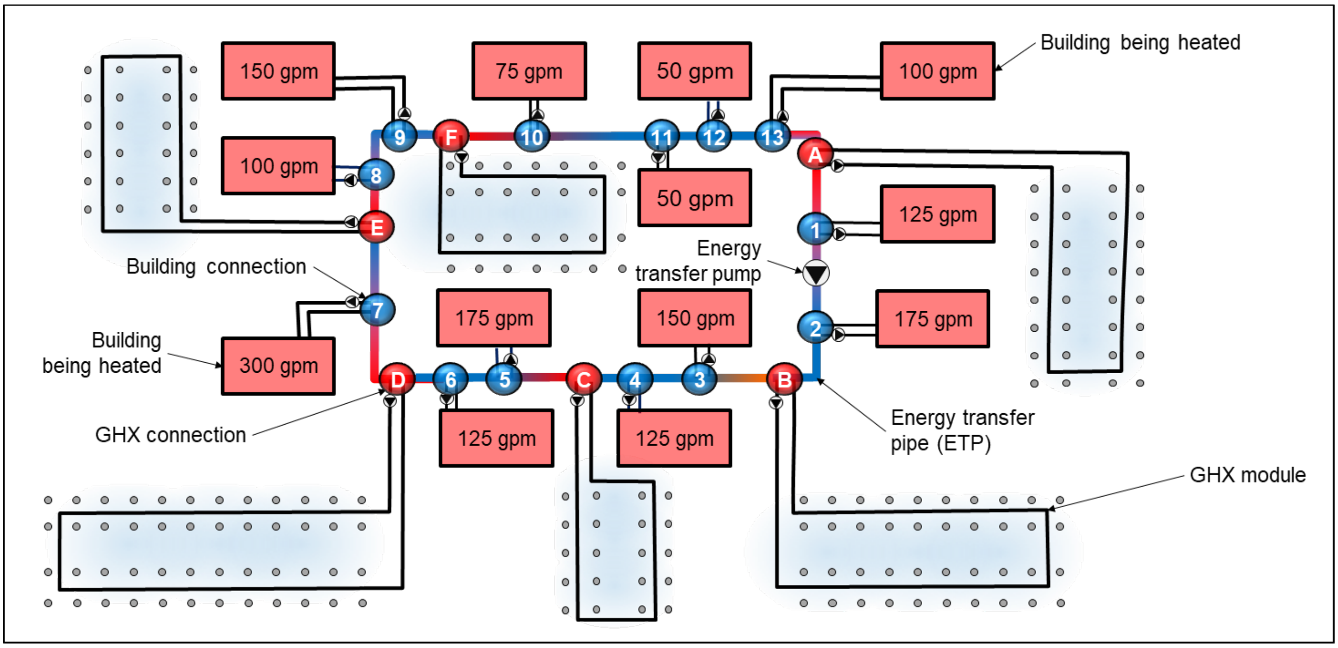

Figure 16: Buildings connected to the ETP removing energy from the ETP while energy from the GHX modules is injected into the pipe to maintain efficient operating temperatures.

The system operates in the same way when all the buildings in the system are cooling, with heat being rejected to the ground, as seen in Figure 17.

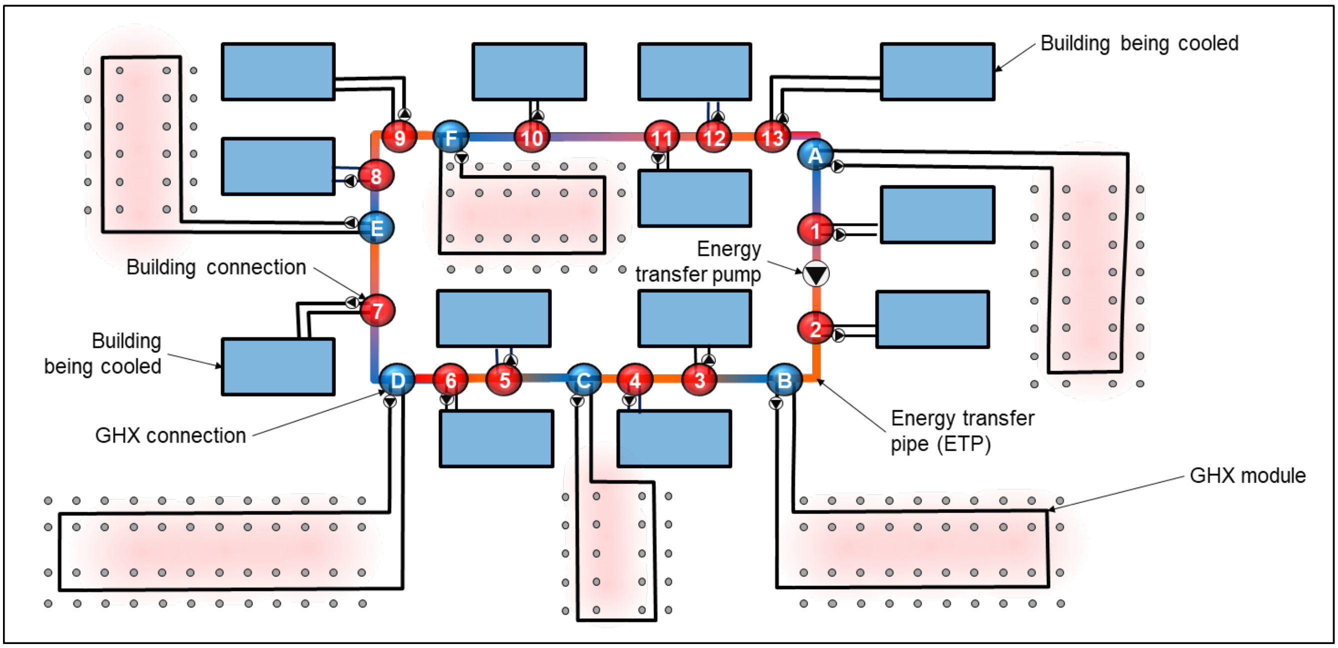

Figure 17: Buildings connected to the ETP injecting energy to the ETP while energy from the GHX modules is extracted from the pipe to maintain efficient operating temperatures.

Much of the year, however, the scenario seen in Figure 18 is more likely, with some of the buildings requiring more heating than cooling while others require more cooling. Building-1 in Figure 18 extracts heat from the pipe, while Building-2 rejects heat to it. The temperature of the fluid drops after Building-1, increases at Building-2, resulting in minimal temperature change. Energy does not have to be added or removed to the pipe at GHX-B to maintain efficient operating temperature for Buildings 3, 4 and 6.

Depending on the temperature decrease after Buildings 3, 4 and 6, GHX-C and / or GHX-D may be needed to add energy to the pipe from the ground. After Building-7 adds energy to the ETP, heat is rejected to GHX-E. Three of the GHX modules are not required in the scenario seen in Figure 18. The temperature in the pipe is maintained within the desired operating range by heat added to or removed from it by the buildings themselves. This allows a reduction in the size and cost of the GHX modules required and reduces pumping energy required to operate the system.

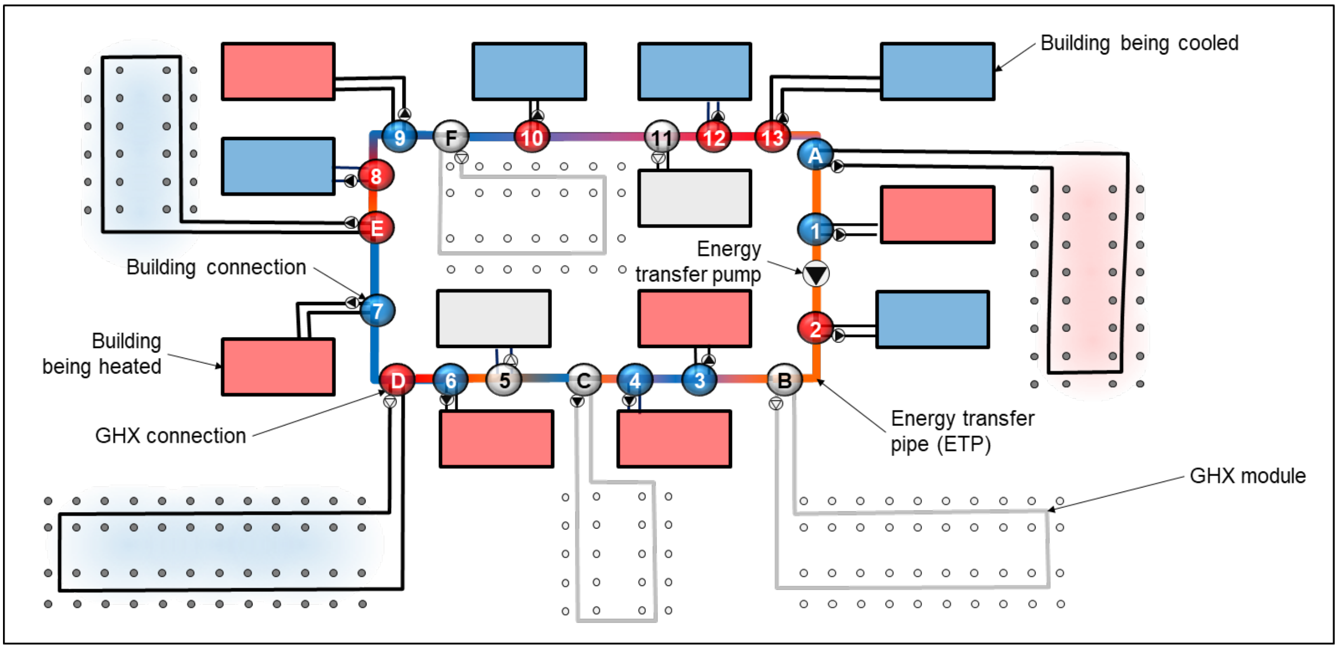

Figure 18: With some building heating and others cooling, energy is simply transferred from one building to the next, reducing the requirement for GHX modules

5.2.2. Addition of discretionary heating and cooling loads

GHX modules are the backbone of the energy resource for a district geothermal energy system primarily because of the energy storage capability of the earth. A range of other energy resources can be connected to the ETP. Resources that can be connected to the system can include:

- Fluid cooler to dissipate excess heat from the system
- Snow melt system on sidewalks, roadways
- Sport field irrigation systems
- Water wells
- Waste heat from combined heat and power systems
- Waste heat from data center
- Solar thermal energy
- Wastewater energy transfer
- Waste heat from refrigeration system (ice rinks, grocery stores)

Connecting waste energy resources, renewable energy sources, or heat dissipation devices to the ETP to operate in conjunction or in parallel with GHX modules connected to the system can reduce the size and / or cost of the GHX modules required on the system by balancing the amount of energy transferred to and from the GHX on an annual basis. Balancing energy loads to and from the ground avoid long-term temperature increase or decrease in the GHX and help maintain system efficiency over the long term. Figure 19 illustrates a snow melt system connected to the ETP between Building-3 and GHX-B which dissipates excess heat from the system. A combined heat and power system that can add waste heat to the system can also be added if required.

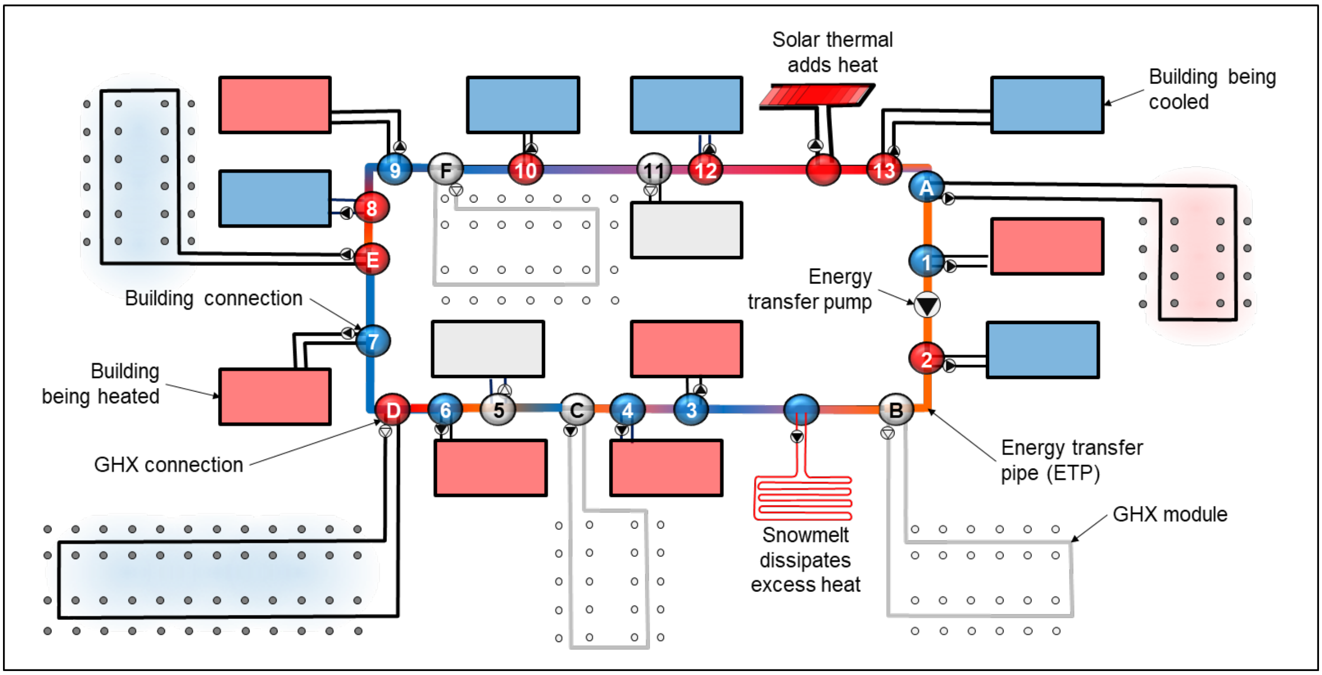

Figure 19: The addition of other heat sources and / or heat dissipation devices can reduce the size and cost of GHX modules required for the system while improving long-term system performance.

5.2.3. Expanding the energy sharing system

The installation of a district geothermal heat pump system for BSU is anticipated to take place over the next 20-30 years. Building mechanical and electrical systems as well as the building envelop components are typically replaced at the end their anticipated life to avoid replacing serviceable equipment prematurely. During the first few years it is expected that one or two buildings will be retrofitted with a GSHP system.

To minimize the initial cost of retrofitting a district energy sharing system on the campus the first buildings that are converted can be designed as free-standing GSHP systems, avoiding the cost of the ETP, controls and additional infrastructure (if desired). Figure 20 illustrates 2 of the 13 buildings retrofitted with a GSHP system, each with a GHX designed to meet its heating and cooling loads.

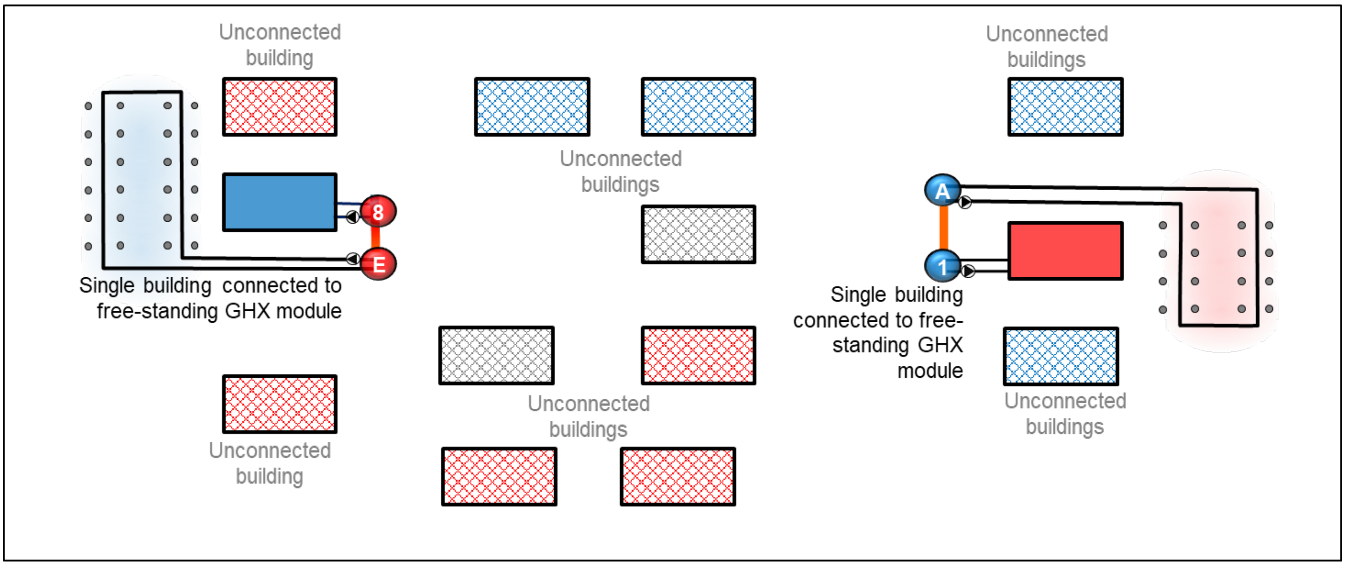

Figure 20: Initial buildings can be retrofitted with a GSHP system without connecting to a large integrated district energy sharing system.

As more buildings are retrofitted with GSHP systems connecting the buildings with an ETP facilitates the recovery of waste energy produced when cooling one building to improve the efficiency of heat pumps in a building requiring space heating or domestic hot water. Figure 21 shows 5 buildings connected to the ETP (Buildings 1, 2, 8, 10 and 11). Buildings 2, 8 and 10 are cooling and increasing the temperature of the fluid in the ETP, while buildings 1 and 11 are extracting heat from the pipe. Waste energy from one building provides energy for the next, reducing reliance on energy transfer to and from GHX modules.

Computer simulations indicate that the size and cost of GHX modules required for buildings taking advantage of energy transfer opportunities is reduced compared to that required for a separate GHX for each building as illustrated in Figure 20. Additional buildings are connected based on scheduled building renovations, upgrades, and budgets.

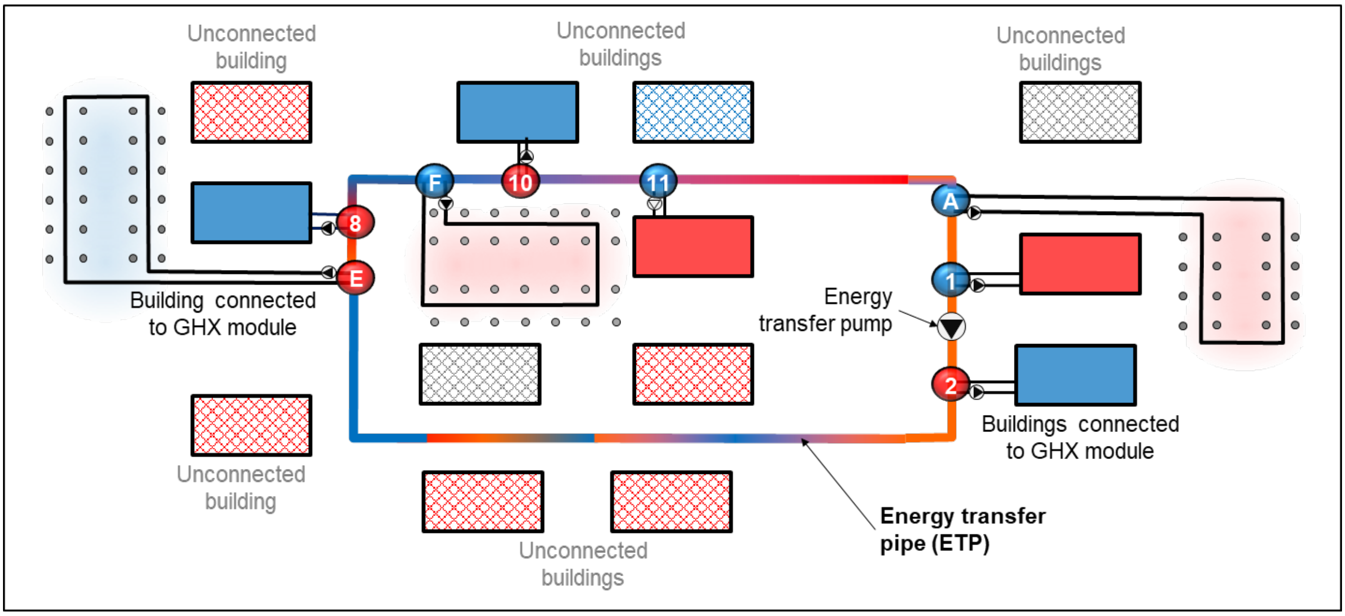

Figure 21: An energy transfer pipe connects five buildings to enable the transfer of energy from one building to the next.

Buildings being renovated are not necessarily located near one another and may be at opposite ends of the campus. It may be advantageous to create two district energy modules, each with a group of buildings, as seen in Figure 22. As the two district modules expand to include additional buildings, the modules can be linked with a pair of pipes that can facilitate the transfer of energy from one module to the other.

This can be beneficial when one district energy module consists of heating dominant buildings such as residences with large domestic hot water requirements and the other includes primarily cooling dominant facilities such as a data center. The energy transfer link seen in Figure 22 enables the transfer of heat across the campus, while enabling the expansion of the system to optimize the needs of the buildings on campus.

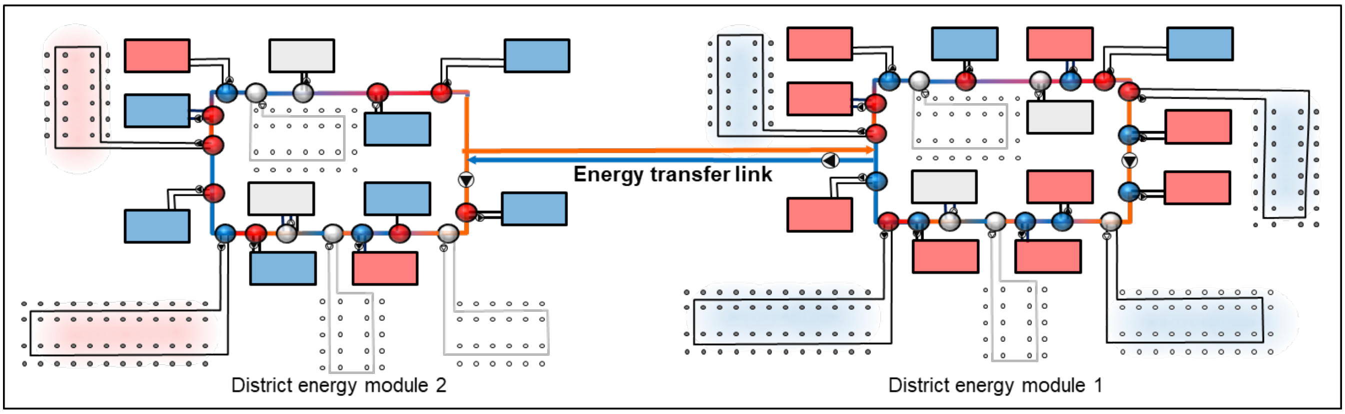

Figure 22: Illustrates the development of 2 separate district energy modules connected with and energy transfer link to transfer energy across the campus.

5.3. Summary

There are advantages to both district system configurations…a Central Energy Plant and the Single ETP distributed heat pump system. The following table summarizes the comparison between the two system approaches.

		Central Energy Plant	Single Energy Transfer Pipe
Mechanical system design	Pros	• Maintenance of a single central energy plant may be more efficient and cost-effective than maintenance of distributed mechanical systems in numerous buildings.	• Mechanical systems in each building can be designed specifically for the needs of the building to maximize system efficiency. Buildings designed to operate with radiant floor heating and chilled beam cooling system operate more efficiently with heat pumps than buildings operating at higher and lower temperatures required with air-handling units. • Buildings can be added to energy transfer pipe at any location without affecting system operation. • Significantly lower initial infrastructure cost as system can grow and expand as required. This approach adapts readily to changes in development plans over time. • Additional ground heat exchanger module may be required to accommodate additional building load but can be located adjacent to or under proposed new building.
	Cons	• Requires full planning of future system to ensure central plant has capacity to meet heating and cooling demands of completed development, even though development build out may not be completed for several years. • Requires higher initial construction cost for larger central energy plant and piping infrastructure. • System delivers same water temperature to all buildings. The building with that requires the highest water temperature determines that temperature. Cannot take advantage of distribution system that can heat with low temperature water	• Distributed mechanical rooms may increase maintenance costs and require mechanical room space in each building.
Distribution system design	Pros		• A single uninsulated pipe acts as an energy source and / or heat sink for heat pumps located in the buildings connected to it which results in lower initial capital cost. • Connections to the energy transfer pipe (ETP) at regular intervals allows energy transfer to or from the ETP before each building or group of buildings. This allows a significant reduction in flow rates through the ETP and a corresponding reduction in pipe size and the pump power required to circulate the fluid through the pipe (Figure 18). • Single energy transfer pipe operates at ground heat exchanger temperature and does not require insulation as delivery temperature to buildings is not critical. • Fluid in energy transfer pipe operates at typical ground heat exchanger temperature within the operating parameters of high-density polyethylene pipe used for the GHX piping. • Waste energy rejected to ETP from building operating in cooling mode becomes heat source for building downstream in heating mode or producing hot water.
	Cons	• Hot and chilled water supply and return pipe pairs are required from central plant to each building (Figure 15) • Distribution piping and circulation pumps must have the capacity to meet the combined peak heating and cooling loads of all buildings connected to system. • Ground temperatures typically range from 45-50°F in Bemidji. To minimize heat transfer to the soil the distribution pipe requires insulation increasing construction cost. • If hot water delivery temperatures are greater than 110-120°F, high-density polyethylene pipe cannot be used. Higher cost material will be required.	
Ground heat exchanger design	Pros		• GHX modules can be connected to ETP at numerous locations, allowing flexibility in GHX locations. • GHX modules are designed to fit the land area available, minimizing the piping connecting them to the ETP, reducing construction cost, pipe sizes and fluid volumes.
	Cons	• All GHX modules must be connected to the central energy plant. Depending on the land area available for construction on the GHX modules, piping connections may be long, increasing installation cost with increased pipe lengths and sizes as well as greater fluid volumes (Section 5.1).	

Integration with other energy sources / heat sinks	**Pros**		• Low-grade energy sources or cooling sources can be connected to ETP at any location. Renewable or waste energy resources can include solar thermal, waste heat from ice rink refrigeration system, combined heat and power, or wastewater energy recovery. Alternate heat sinks can include wastewater, sidewalk snow melt system and irrigation water (Section 5.2.2).
	Cons	• Waste and renewable energy resources often provide only low-grade heat. For a central energy plant system to take advantage of low-grade energy they must be connected directly to the heat pumps in the central plant. When energy resources are not located near the central energy plant long piping connections may make it challenging to connect to the central energy plant to take advantage of them.	
System expansion	**Pros**		• The capacity of a single ETP is easily expanded by adding buildings and / or GHX modules to the pipe at almost any point around the ETP (Section 5.2.3). • District energy modules can be linked to transfer energy from one district to another to take advantage of waste energy resources or to transfer energy to a heating dominant district from a cooling dominant district. This allows the transfer of energy across the entire system (Figure 22).
	Cons	• The expansion of the system is determined by the heating and cooling capacity of the central energy plant, pump sizing and the design of the distribution system of the original system. If the central energy plant and distribution piping system have been designed to accommodate the anticipated capacity more buildings can be connected to the system.	

6. System Implementation

The conversion of the BSU campus from a central energy plant fueled by natural gas for heating and water-cooled chillers for cooling the buildings can be accomplished over an extended period. Critical design principles to incorporate immediately or as soon as possible to insure GSHP feasibility remains cost effective in the future include:

- Implementation of ERV’s on any anticipated AHU upgrade
- Implementation of AHU coils with additional capacity to accommodate lower hot water temperature (110°F)
- Ensure mechanical room renovations include allocated space for anticipated heat pump equipment

For the GSHP installation, the existing utility / pedestrian tunnels can potentially accommodate the piping for the ETP. The tunnels are indicated in Figure 23, represented by the double red line. Piping that cannot be installed in the existing utility / pedestrian tunnels can be installed with little disturbance on site with horizontal directional drilling techniques.

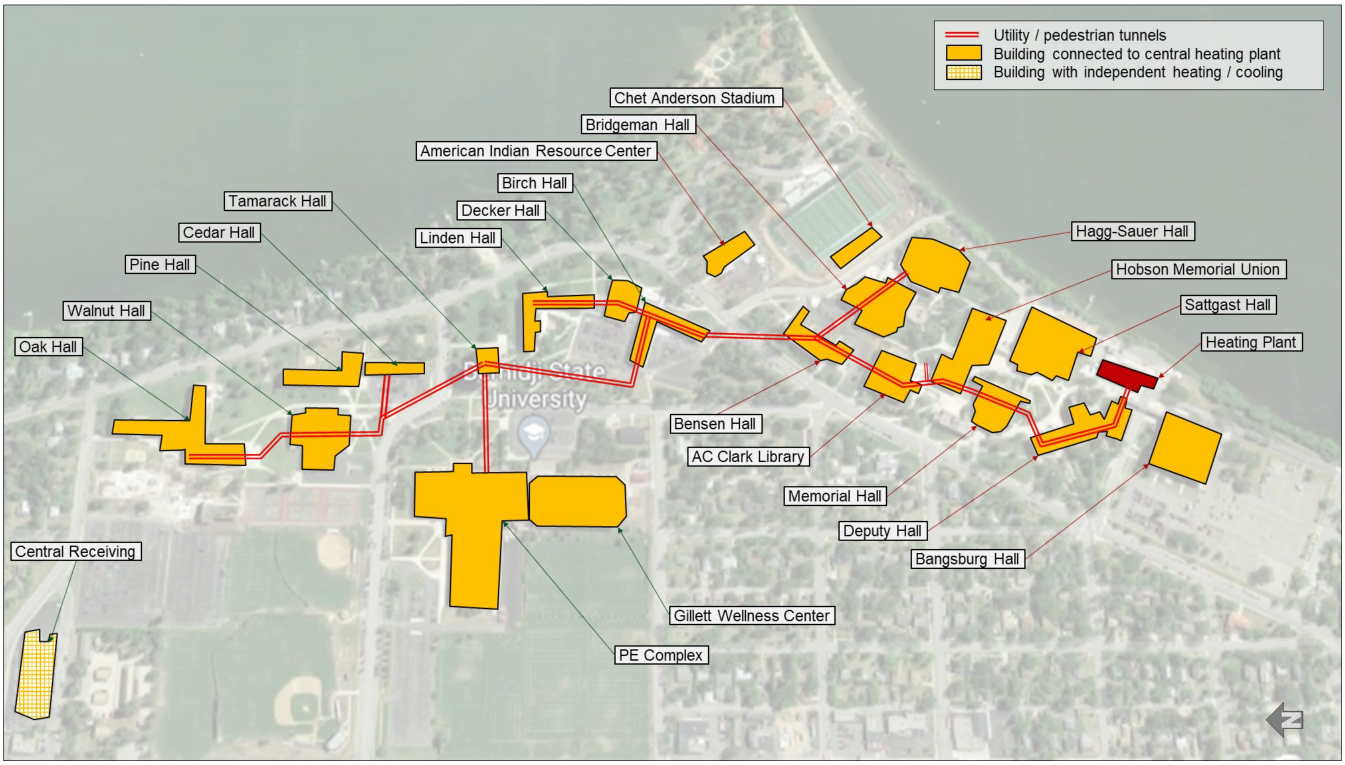

Figure 23: Campus buildings currently connected to the central energy plant with steam and chilled water piping in the utility / pedestrian tunnels and buried piping.

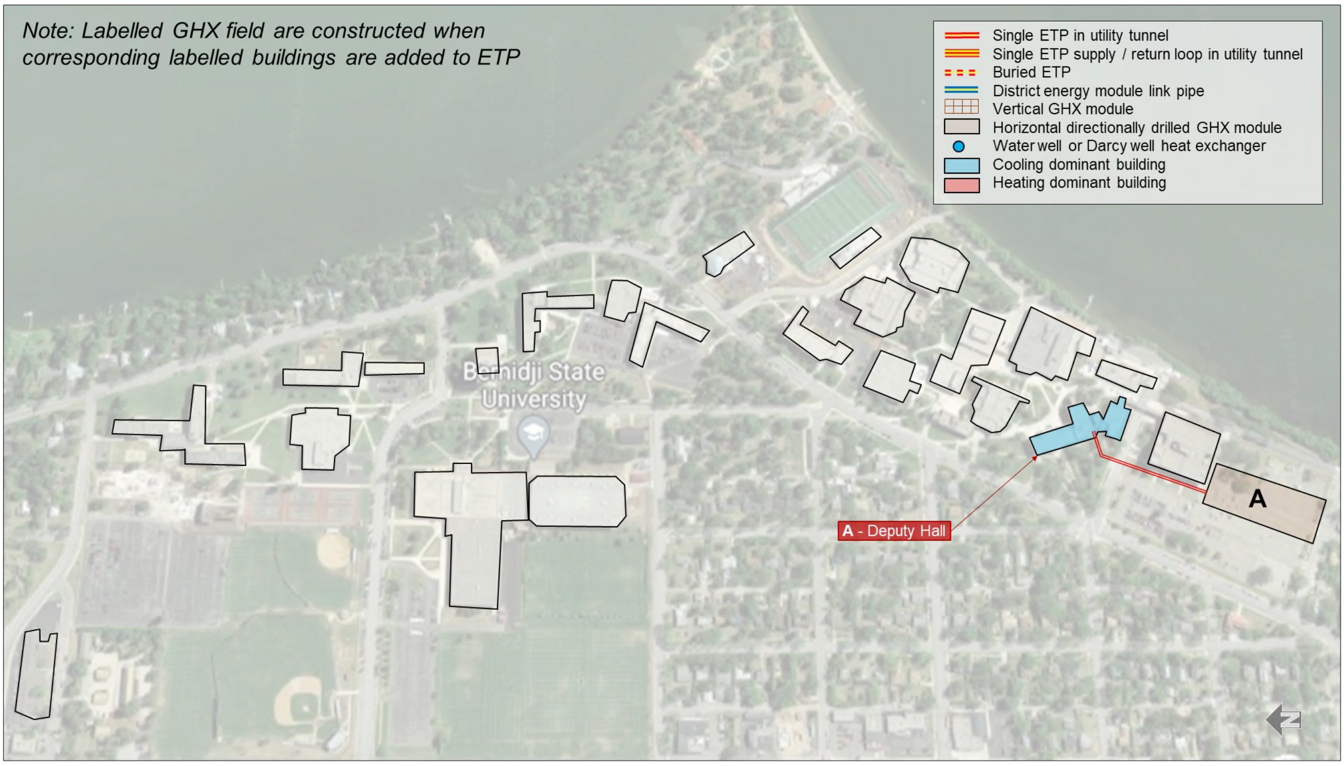

Figure 24: First step for the BSU geothermal conversion project.

Initial steps to reducing reliance on fossil fuels for heating can be taken with a retrofit of a GSHP system in Deputy Hall, with a HDD GHX located in the parking lot south of the Bangsburg Hall, as illustrated in Figure 24. Based on interviews with University personnel, Deputy Hall is one of the buildings most in need of mechanical system upgrades. Operation of the first building converted to a GSHP system provides an opportunity for facility operators to become familiar with a GSHP system.

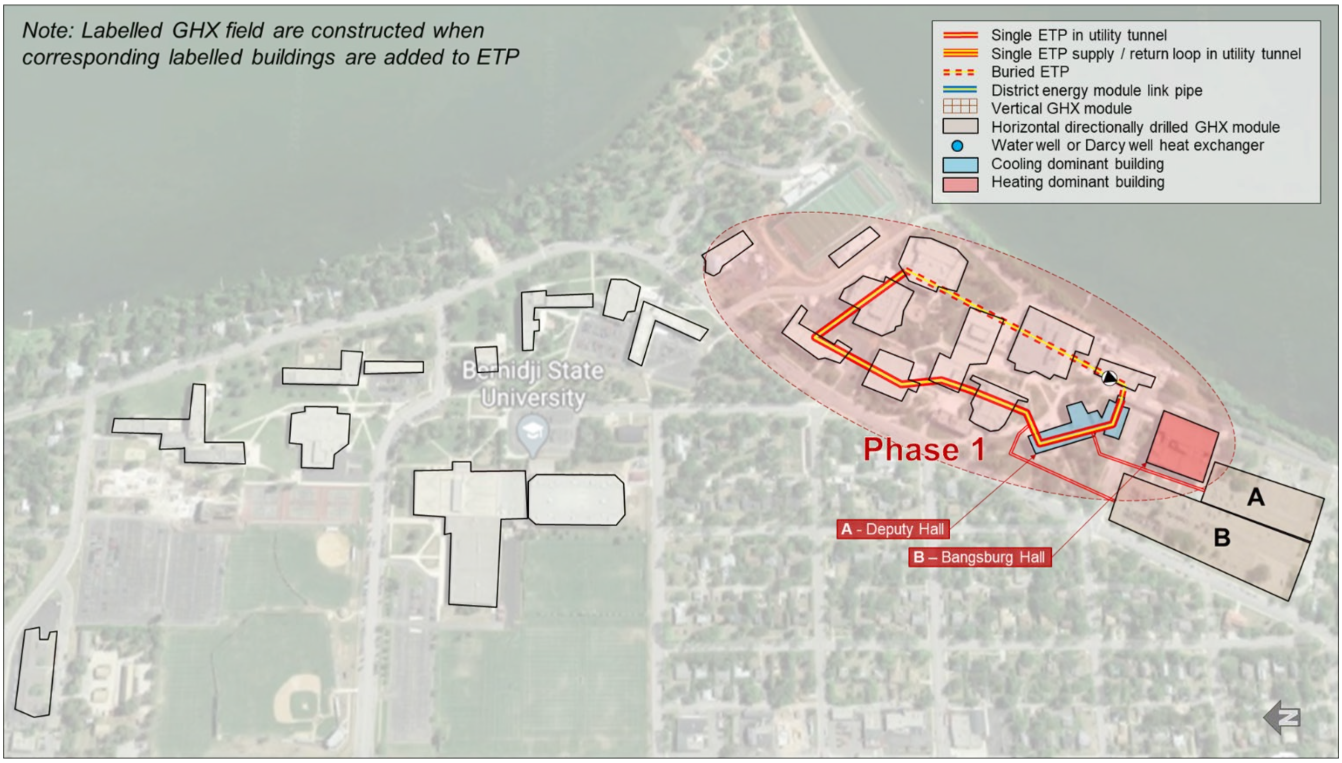

Figure 25: Phase 1 ETP installation.

Next, Bangsburg Hall is converted, where initial steps are taken to facilitate energy sharing from one building to the next by connecting them with an ETP. The ETP can be installed in the existing utility / pedestrian tunnels up to Hagg-Sauer Hall. From the Hagg-Sauer Hall to the Heating Plant, the ETP is installed with horizontal drilling techniques to complete the single ETP loop. In the following years Bensen Hall and Hobson Memorial Union Buildings are connected to the ETP along with additional GHX modules constructed in the parking area south of Bangsburg Hall and under the football field at the Chet Anderson Stadium. The construction of the ETP is seen in Figure 25.

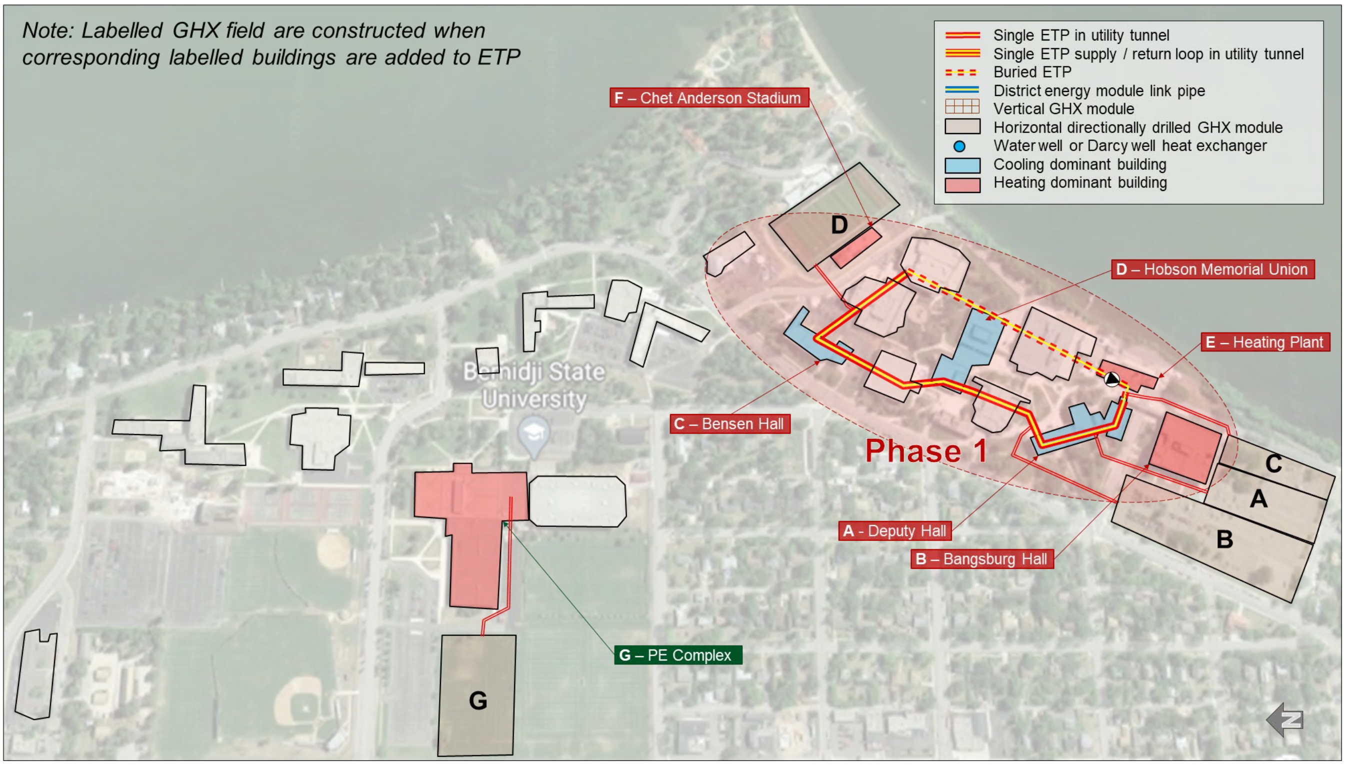

Figure 26: Initial steps for Phase 2 of the district geothermal energy system with the installation of an HDD GHX for the PE Complex.

Figure 26 shows the initial steps into the second phase of the district geothermal energy system with the installation of an HDD GHX for the PE Complex. Initially this facility will operate as a free standing GSHP system, unconnected to the ETP. Figure 27 shows the connection of the Gillett Wellness Center to the PE Complex along with the construction of an additional GHX module. Connecting the two mechanical systems is beneficial as the PE Complex is expected to be more heating dominant then the Gillette Wellness Center. Having the ability to share energy from one building to the other improves the energy balance to and from the GHX, reducing the size and cost of the GHX while improving system performance.

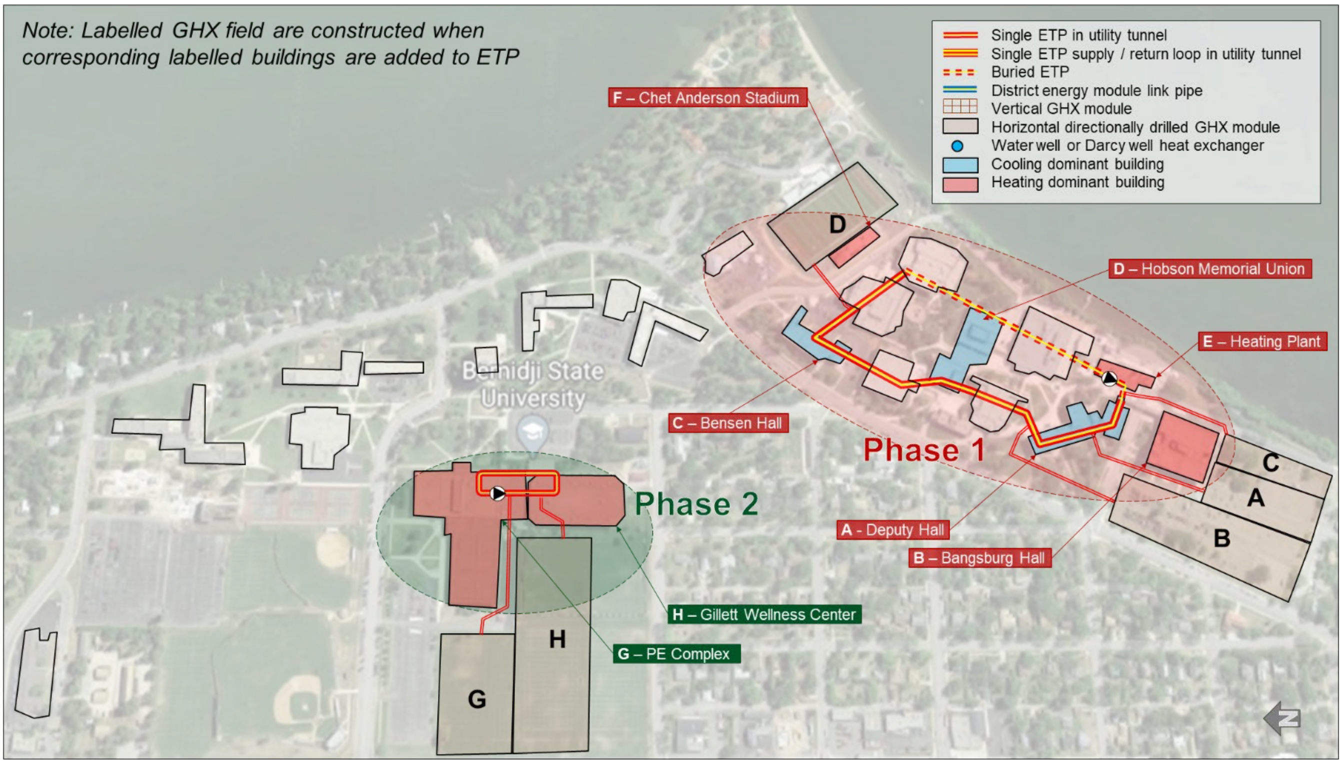

Figure 27: Phase 2 construction of the ETP connecting the Gillett Wellness Center with the PE Complex.

The PE Complex and Gillett Wellness Center are completed before several buildings in Phase 1 are connected to the ETP. As noted, the schedule is based on input from University staff and the need to upgrade the existing mechanical systems. After the Gillette Wellness Center and PE Complex are completed, several buildings in Phase 1 can be connected to the ETP. These include the Sattgast Hall and the AC Clark Library. Note that the site is somewhat constrained for construction of GHX modules in Phase 1.

Figure 28 indicates that a vertical borehole GHX may be required when Sattgast Hall is connected to the ETP and that a water well or Darcy Well system is added when the AC Clark Library is connected to the system. As noted in Section 5.2.1, it is important to connect GHX modules at intervals between building or building groups to reduce the flow rate needed through the ETP. Limiting the flow rate reduces the size of the ETP as well as the size of the energy transfer pump needed on the ETP. Connecting GHX modules at intervals between building connections reduces initial construction cost while reducing pump power needed to operate the system.

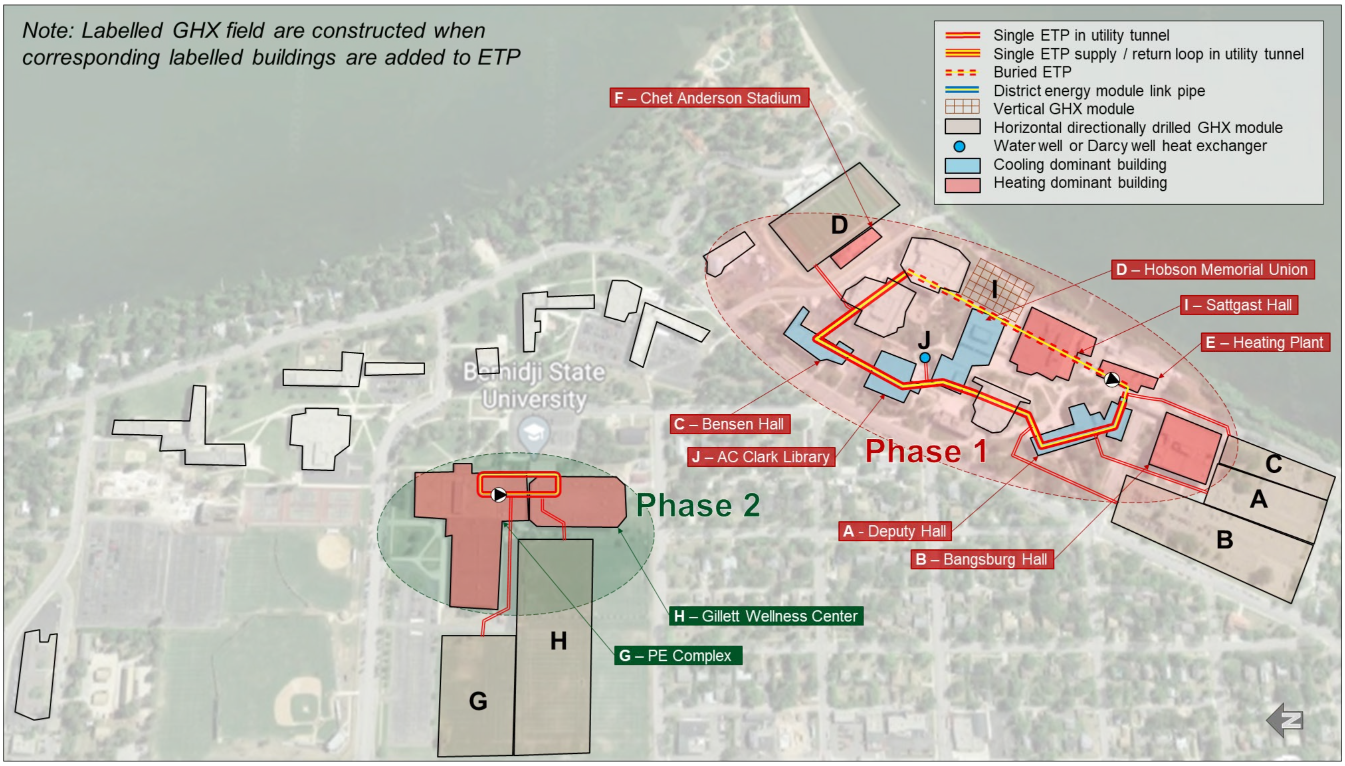

Figure 28: Sattgast Hall and the AC Clark Library connected to the Phase 1 ETP as well as a vertical GHX and water well heat exchanger.

The Central Receiving building is not connected to the existing central heating plant. When this building mechanical system requires renovation, it can be connected to the ETP for the third phase of the district geothermal energy system by extending the ETP to the Oak Hall building through the utility / pedestrian tunnels, as seen in Figure 29. After the ETP's in each of the three phases of the system are complete, district module link pipes are installed to take advantage of moving energy from one district module to another. The link pipes are also shown in Figure 29.

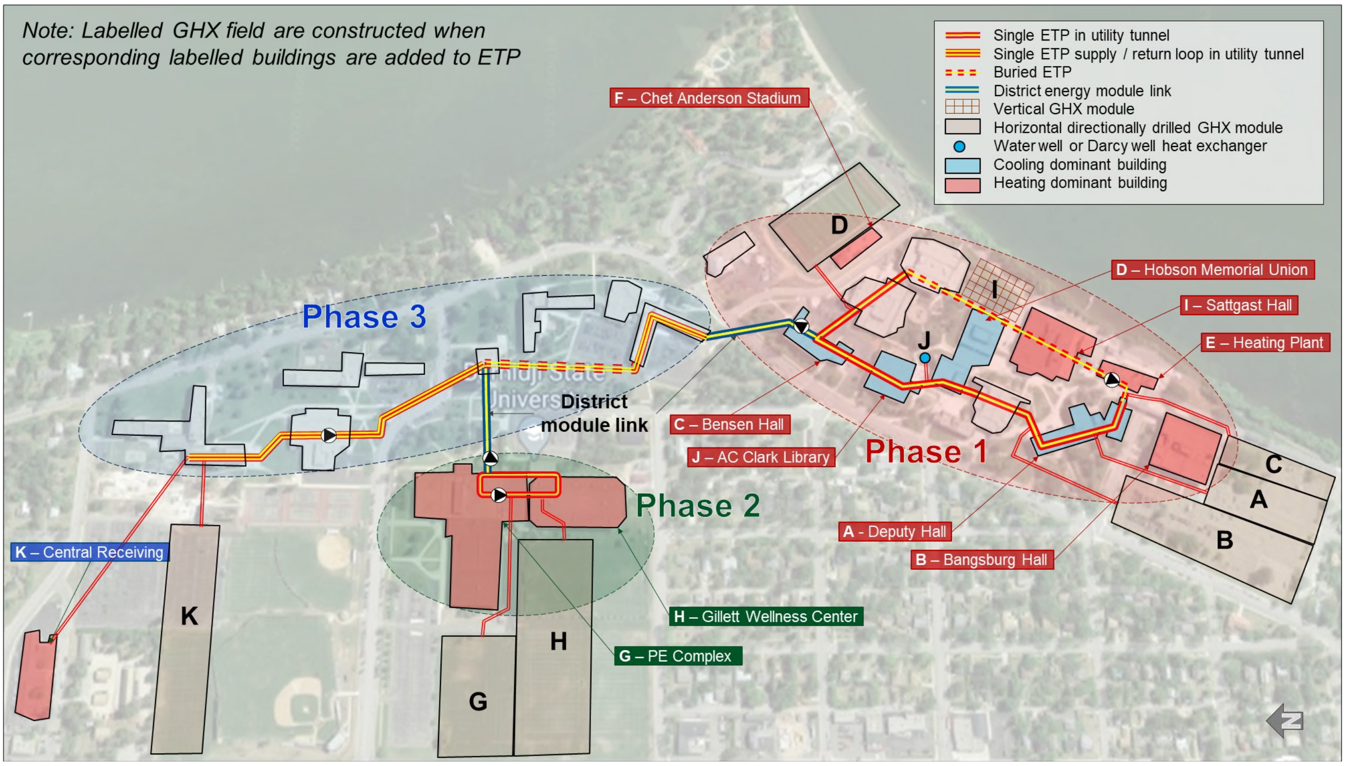

Figure 29: Initial phases of the Phase 3 ETP construction.

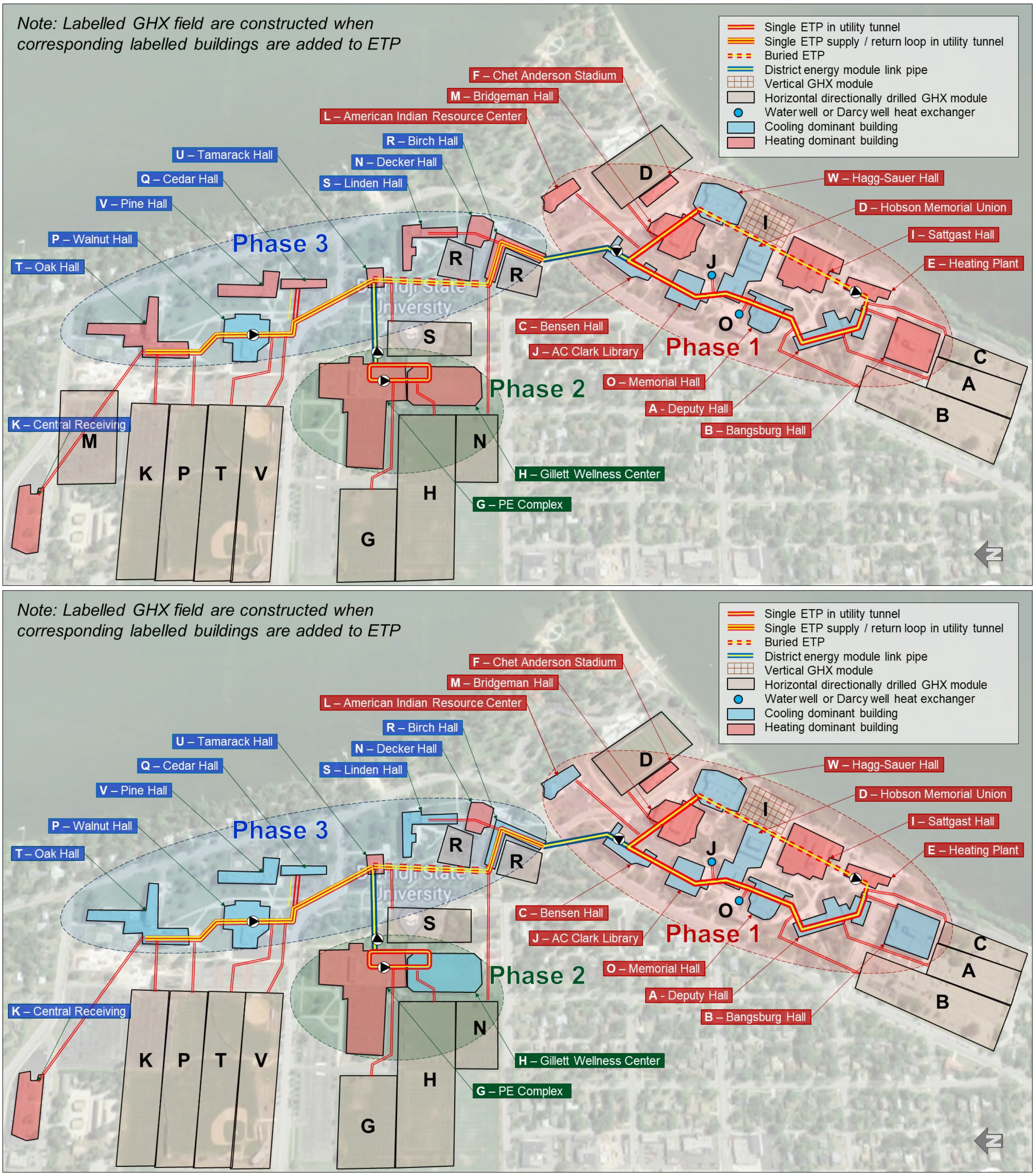

Figure 30: BSU geothermal district system roadmap.

When the ETP in each of the phases is complete, remaining buildings are connected to the ETP when they are scheduled for renovation. As additional buildings are connected to the ETP, additional GHX modules may be required to ensure the temperature of the fluid in the system can be maintained. Figure 30 shows the three proposed phases of the district geothermal energy system with all currently existing buildings connected to one of the three ETP's.

It is anticipated that the system will be constructed as buildings or building mechanical systems are renovated over the next 10-30 years. When new buildings are planned for the campus, they can be integrated into the system by connecting it to the nearest ETP. The additional GHX capacity that will be needed to meet the additional energy loads of a proposed building will be dependent on the past performance of the system.

6.1. Performance and monitoring

Energy to heat and cool the buildings on the campus as it currently operates is delivered from an external source…a gas pipeline and electrical grid. An external energy source can be considered as an infinite energy supply if the energy bill is paid. The utility delivers as much energy as needed to meet the heating and cooling loads of the building(s). The only consequence is the impact on the energy cost.

The operation of a GSHP and GHX is fundamentally different than the operation of a conventional system connected to an external energy source. The earth should be considered more as an energy storage medium than an energy source. As heat is extracted from the earth around the GHX piping, when the buildings are being heated, the temperature of the earth will drop. As heat is rejected to the earth while the buildings are being cooled, the temperature of the earth increases.

Typically, a GHX is designed to deliver heat transfer fluid to heat pumps in the system within a specific temperature range. Most commercially available heat pumps are manufactured to operate efficiently in the heating mode with fluid temperatures ranging between 30-35°F and a maximum temperature of approximately 75-80°F. When operating in the cooling mode, they are designed to operate efficiently at a minimum temperature of approximately 35-40°F and a maximum of 90-95°F. Outside of those temperatures the heat pumps operate much less efficiently and they will eventually quit operating.

The performance of a GHX is calculated based on the following parameters:

- Thermal properties of the soil / rock in which the heat exchanger piping is installed
- Ambient soil temperature
- The influence of groundwater flow across the GHX piping
- The configuration and layout of the GHX piping relative to the surface of the earth and to other GHX piping
- The amount of heat extracted from the GHX relative to the amount of heat rejected to the GHX
- The instantaneous peak heating and cooling loads

The factors on which the design and performance of a GHX is based are based on inexact knowledge and on conditions that change year to year.

- Geological conditions can vary on a site as large as the Bemidji campus.
- Calculated building energy loads are based on incomplete information
- Building use and occupancy schedules change throughout a typical year and may vary from one year to the next
- Weather changes from year to year
- The way a building is operated can change from year to year

With insufficient information about geological conditions and buildings and the variability of building use and occupancy, weather and building operation from year to year, the amount of energy that is transferred to and from the ground can vary significantly.

Changes during a single year generally create relatively small changes in the performance of a GHX because of the large mass of earth and rock the pipe is in contact with, as long as the GHX design is well matched with the geology, GHX configuration and calculated energy loads. Over the longer term, however, the cumulative change in temperature and GHX performance is the greater concern.

Installing an energy meter on each GHX module and each building connection to the ETP allows full monitoring of the energy loads to and from the GHX modules on an hourly basis. During the first year of operation the hourly energy loads are compiled in a remote server. The hourly loads are used to calculate the performance of the GHX module for the upcoming year (or years) into the future if the hourly energy loads remain the same. Continuous monitoring of the performance of the GHX and predicting the performance into the future provides the information needed to:

- Optimize the performance of the GHX into the future, ensuring the fluid temperatures delivered to the heat pumps stay within efficient operating parameters.
- Verify the capacity of the GHX and calculate more accurately how much additional GHX is required to meet the requirements when additional buildings are connected to the system.
- Validate the calculated heating and cooling energy loads of the buildings connected to the system.
- Verify and optimize the flow rates required to meet the requirements of the heat pumps connected to the system.

6.2. Discretionary loads

The ETP is designed to move energy, much like a conveyor belt. The primary purpose is to provide an energy source for buildings connected to it when they are being heated and to remove energy from them when they are being cooled. If too much energy is added to the "conveyor belt" …if the temperature of the fluid in the ETP is higher than desired…excess heat is diverted to the GHX module(s). When the temperature in the ETP falls too low energy is drawn from the GHX.

Energy can be transferred to and from the ETP from many other sources. If temperature control is not required for the alternate energy sources, these are referred to as "discretionary loads". Examples of discretionary loads can be used to add heat to the ETP include:

- Fossil fuel boilers
- Solar thermal panels
- Waste heat from combined heat and power plants
- Waste heat from refrigeration systems (ice rinks)
- Heat recovered from wastewater (sewer lines)

Discretionary loads that can be used to take heat from the ETP include:

- Fluid coolers and cooling towers
- Water used to irrigate sports fields
- Sidewalk and driveway snowmelt systems
- Water features (fountains)

6.2.1. Auxiliary gas boilers

Gas (or other fossil fuels) are often used to add energy to a GSHP system to supplement the heating capacity of a GHX. Boilers are sometimes considered when the energy loads of the proposed system indicate that more energy will be removed from the ground than will be rejected to the ground on an annual basis. Reasons to consider an auxiliary boiler can include:

- The land area available to build a GHX is cannot support the full loads of the building(s) connected to it
- The cost of installing the GHX is greater than the available budget
- Annual energy loads are very heating dominant (extract more energy from the GHX than is rejected to it), causing the temperature of the GHX to decrease in time

An auxiliary heat source can be added at any location around the ETP, like the snowmelt system or solar thermal connections seen in Figure 19 to maintain the temperature of the fluid delivered to the heat pumps in the buildings.

6.2.2. Wastewater energy transfer

The use of wastewater as a heat source/sink has been overlooked as an energy saving measure in modern day mechanical designs. Recent technologies have been developed for extracted and injecting heat into a wastewater line. Two new technologies include the *Sharc* wastewater system and the @*Source-Energy* pipe. The @*Source-Energy* pipe is a hollow concrete cylinder with a helical high-density polyethylene pipe embedded within the concrete pipe walls that has an outlet and inlet on each length of pipe, which are attached to a heat pump. Heat is captured from effluent in sanitary and storm sewer pipes, and from the adjacent ground. Since wastewater is constant at approximately 60°F year-round, energy for the district ETP can either be extracted or injected into the wastewater. This allows for complete control of the ETP and could drastically reduce the size/cost of the ground loops and ultimately increase the efficiency of the system.

Figure 31: Wastewater heat recovery system integrated with vertical GHX.

This type of system would be most effective connected to the student residence buildings due to the relatively high wastewater flow rate compared to other buildings on campus. A recent study in Germany determined that 917 kWh/day of wastewater energy can be recovered from student residences by using a heat exchanger and heat pump system. Not only could this system reduce capital cost for reduced ground loop size, but also improve the efficiency of the system which would therefore increase annual cost savings and decrease CO_2 emissions. Since typical concrete sewage lines last between 50 to 75 years and the student residence buildings at BSU were built from 1950-1970, the @*Source-Energy* pipe could be installed as a replacement to the existing sewage pipe. The cost difference between the @*Source-Energy* pipe and a conventional sewage pipe is assumed as negligible. Due to the anticipated reduction in operating costs from the heat extracted/injected to the @*Source-Energy* pipe; when BSU plans to replace the sewage pipes, it is strongly recommended to install the @*Source-Energy* pipe.

Another option is the *Sharc* system which can be installed where wastewater exits to the wastewater treatment plant and transfers heat from the wastewater to a holding tank connected to the ETP. The estimated cost of installing a *Sharc Energy Systems* wastewater energy transfer system in this development is estimated at approximately $1,000,000. The benefit to this system is that it can be tied into the existing sewage pipe system.

6.2.3. Heat Rejection

Cooling towers are expensive and relatively useless other than their function of dissipating heat. Installing an ETP allows for the flexibility to dissipate heat with alternative means that are more useful. Irrigation lines for football fields, soccer pitches, and baseball diamonds can be integrated into the ETP system with a water-to-water heat exchanger to get rid of excess heat from the ETP when overheating (Figure 32). This allows for further control of the ETP and a useful dissipation of heat. This alternative is only available on the Chet Anderson Stadium, BSU Athletic Fields, and Soccer Complexes during May to October which is a limitation.

Figure 32: Integration of energy transfer pipe with irrigation lines for football fields, soccer pitches, and baseball diamonds.

For the remainder of the year, snow melt systems can be utilized to act as a heat dissipation device that also reduces the need for paid snow removal. Piping is laid under sidewalks or parking lots and connected to the energy transfer loop (Figure 33). The piping can be installed when renovations are needed on the sidewalk or parking lots after years of deterioration. At this point, it would be worth installing snow melt systems if the economics make sense.

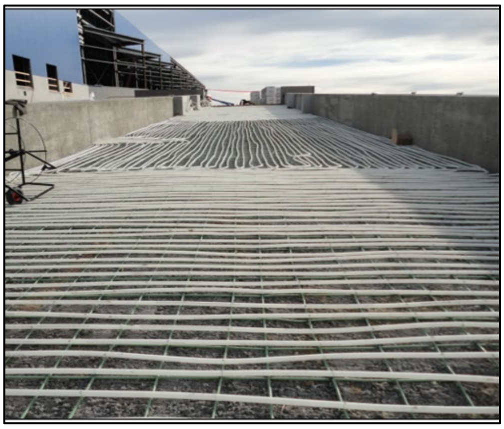

Figure 33: Integration of energy transfer pipe with piping under sidewalks and parking lots for snow melt.

6.2.4. Combined heat and power

Combined heat and power plants (CHP) burn fossil fuels or biomass to produce electricity. If 100 units of energy are consumed, the CHP produces approximately 30 units of electricity, 45 units of waste heat that is easily recovered, and 25 units of heat that is released to the atmosphere of exhaust gases, for an overall combined efficiency of approximately 75%. The waste heat of a CHP can potentially be connected to the energy transfer pipe and transferred to the buildings and / or GHX modules connected to the ETP.

7. Economics

For this analysis, the main consideration is the incremental costs of the GHX, distribution piping, and efficiency measure upgrades. For the costs of the heat pump supply and installation, the price per ton was assumed as $1,500. The advantage of a GSHP system is the gradual capital needed to retrofit one building at a time rather than spending a large amount of capital simultaneously for a boiler/chiller replacement for the entire campus.

The incentives were calculated by multiplying the building peak block load by 10% to account for installed heat pump capacity and building load diversity then multiplying by OTPCO incentive of $1000/ton of installed equipment capacity. The lighting reduction incentive was assumed to be $0.6 per watt/ft^2 saved. The incentives for the ERV's were not included but there is expected incentives based on the energy savings. The energy cost savings were calculated based on existing OTPCO rates and projected energy consumption as described in Section 3.5. The incremental costs and the additional energy costs savings have been broken into the recommended construction steps to allow for a modular build and higher probability of accepted funding.

For the scenario without efficiency measures, the economic projections were deemed unfeasible due to the 40% increase in GHX size and cost.

When efficiency measures are added to the buildings, the incremental capital cost is $10,006,269 which includes the projected costs of the ERV and lighting upgrades (Table 10). Since the efficiency measures decrease total energy usage, the energy cost savings are projected to be $450,275 annually with $202,575 attributed to the upgraded lights, $66,888 attributed to the ERV and $180,812 attributed to space heating and cooling once the project is complete. Although the ERV provides the lowest cost savings, it is required for an efficient GSHP system to create the high space heating and cooling cost savings. Based on these projections, the annual energy bill for BSU would decrease by 36%. Since the modular construction sequence allows for the accumulation of energy savings over each construction step, this allows for greater financial benefits.

Table 10: Estimated capital, energy costs savings and economic calculations broken into recommended construction steps with efficiency measure upgrades.

	Construction Steps	GHX Cost	Cooling Equipment Cost	ERV Cost	Lighting Upgrade Cost	Incentives	Incremental Capital Cost	Energy Cost Savings
A	Deputy Hall	$440,748	$297,000	$157,312	$0	$184,800	$710,260	$30,304
B	Bangsburg Hall + Phase 1 ETP	$333,382	$235,950	$173,756	$86,878	$147,876	$682,090	$25,877
C	Bensen Hall	$100,188	$141,900	$106,684	$53,342	$99,503	$302,611	$17,344
D	Hobson Memorial Union	$228,648	$158,400	$153,512	$76,756	$118,932	$498,384	$34,596
E	Heating Plant	$23,184	$47,850	$40,634	$20,317	$34,814	$97,171	$5,967
F	Chet Anderson Stadium	$0	$7,500	$900	$450	$5,162	$3,688	$90
G	PE complex + Phase 2 ETP	$854,496	$503,250	$218,855	$121,586	$256,071	$1,442,116	$32,711
H	Gillett Wellness Center	$577,080	$448,800	$171,530	$0	$212,300	$985,110	$28,942
I	Sattgast Hall	$312,480	$275,550	$142,029	$0	$151,800	$578,259	$9,983
J	AC Clark Library	$30,000	$178,200	$142,924	$0	$117,700	$233,424	$11,046
K	Central Receiving + Phase 3 ETP	$144,556	$34,650	$16,160	$8,080	$21,609	$181,837	$2,739
L	American Indian Resource Center	$79,380	$31,350	$20,776	$10,388	$20,240	$121,654	$2,837
M	Bridgeman Hall	$84,420	$85,800	$0	$33,772	$59,458	$144,534	$9,884
N	Decker Hall	$94,500	$75,900	$29,424	$29,424	$50,193	$179,055	$7,655
O	Memorial Hall	$130,000	$151,800	$0	$53,893	$117,301	$218,392	$23,322
P	Walnut Hall	$153,720	$138,600	$114,334	$0	$73,700	$332,954	$15,190
Q	Cedar Hall	$124,740	$92,400	$78,266	$39,133	$56,988	$277,551	$15,145
R	Birch Hall	$196,560	$145,200	$0	$62,184	$90,586	$313,358	$24,066
S	Linden Hall	$214,200	$146,850	$135,130	$67,565	$94,723	$469,022	$25,274
T	Oak Hall	$406,980	$280,500	$257,100	$128,550	$182,678	$890,452	$47,304
U	Tamarack Hall	$278,460	$206,250	$176,820	$88,410	$128,628	$621,312	$34,215
V	Pine Hall	$160,020	$117,150	$100,528	$50,264	$73,095	$354,867	$19,452
W	Hagg-Sauer Hall	$265,860	$240,900	$0	$0	$138,592	$368,168	$26,335
	Total	***$5,233,602***	***$4,041,750***	***$2,236,674***	***$930,992***	***$2,436,749***	***$10,006,269***	***$450,275***

The operator staffing required for a GSHP system is similar to a conventional steam boiler/chiller system. The incremental cost regarding maintenance and chemical water treatment of the existing boiler/chiller system was not included in Table 10, but is significant. BSU estimates that they currently spend $3,500 to $4,500 on boiler chemicals annually. The estimated annual cost difference for chemical water treatment between the existing system and anticipated GSHP system is $2,000 based on the reduced make-up water from a tighter system.

Once the steam boilers are offline and the campus is fully retrofitted, water consumption is expected to reduce drastically. Throughout the heating season, BSU uses 700,000 to 800,000 gallons of water per year with their steam boilers. Therefore, if we assume a cost of $5.55 per 1000 gallons (https://www.bemidjipioneer.com/news/government-and-politics/4739087-Water-rate-increases-among-changes-in-citys-2020-fee-schedule), BSU spends between $3,885 - $4,440 per year on water which would be eliminated if they switched to a GSHP system.

8. Environmental impact

The environmental impact from CO_2 emissions is one of the main driving factors for this study. Based on the current natural gas and electricity consumption as well as the CO_2 emissions intensity for the OTPCO grid (1.69 lbs/kWh), the estimated current annual CO_2 emissions from BSU is 14,102 MT. The on-site CO_2 emissions strictly from natural gas are estimated at

6,133 MT's. Electrifying the campus removes 98% of on-site CO_2 emissions and effectively eliminates all natural gas usage (Figure 34).

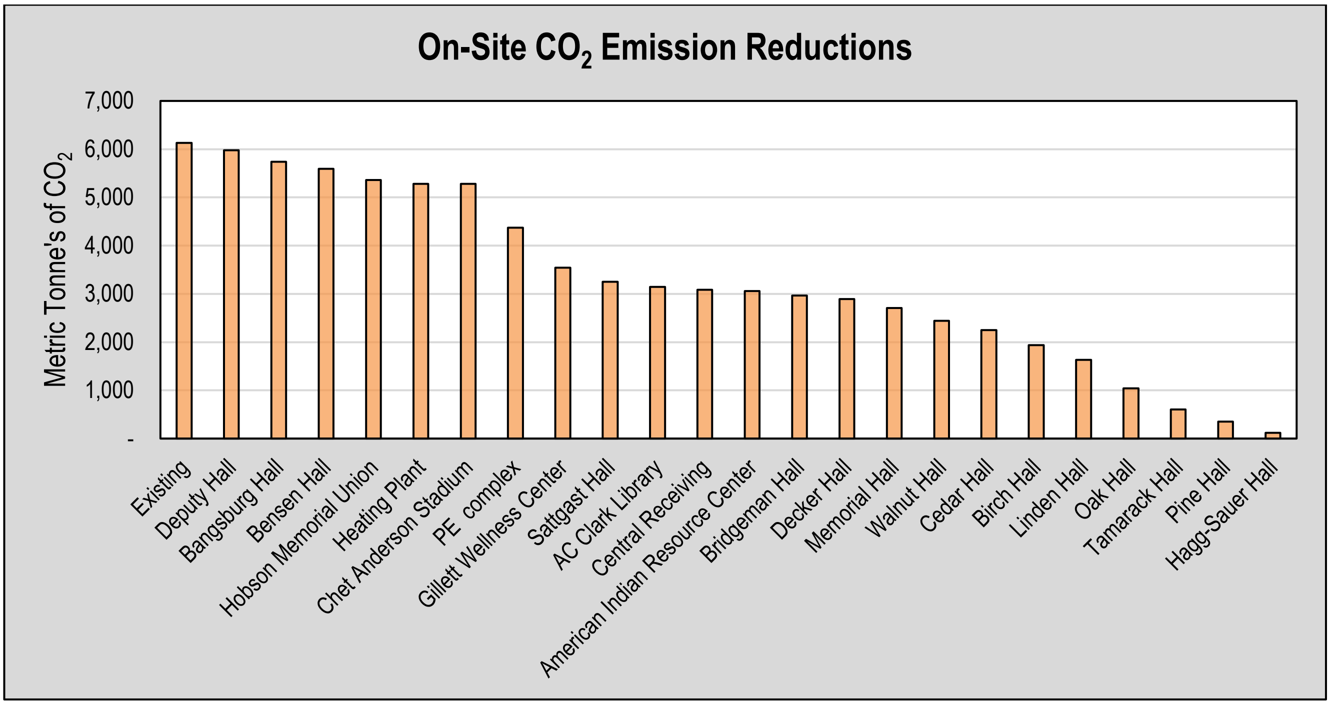

Figure 34: On-site CO_2 emission reductions per building construction step.

Based on the methodology described in Section 3.5, the estimated total reduction in CO_2 emissions including the carbon emission intensity from electricity once the full campus retrofit is complete is 42% to a total of 8,181 MT annually. The reduction in CO_2 emissions will be gradual as more buildings are retrofitted. Based on the buildings previously prioritized in Table 9, the step-by-step campus CO_2 emissions reduction can be seen in Figure 35. Since the district system is being electrified, as the OTPCO electrical grid decreases its carbon emission intensity, the annual CO_2 emissions will decrease proportionally.

Since BSU is electrifying their campus, this allows for multiple avenues to continue reducing CO_2 emissions. OTPCO will continue to reduce their CO_2 emissions from power generation by actively pursuing renewable energy technologies and possible future regulations (mandates or carbon tax) may push electric utilities toward more aggressive adoption of renewables. Another option for BSU is to purchase Renewable energy credits (RECs) which is the least costly way of purchasing green electric power in the marketplace. Lastly, the installation of self-generation renewable technologies could play a role in BSU's renewable energy goals if it is cost/space effective.

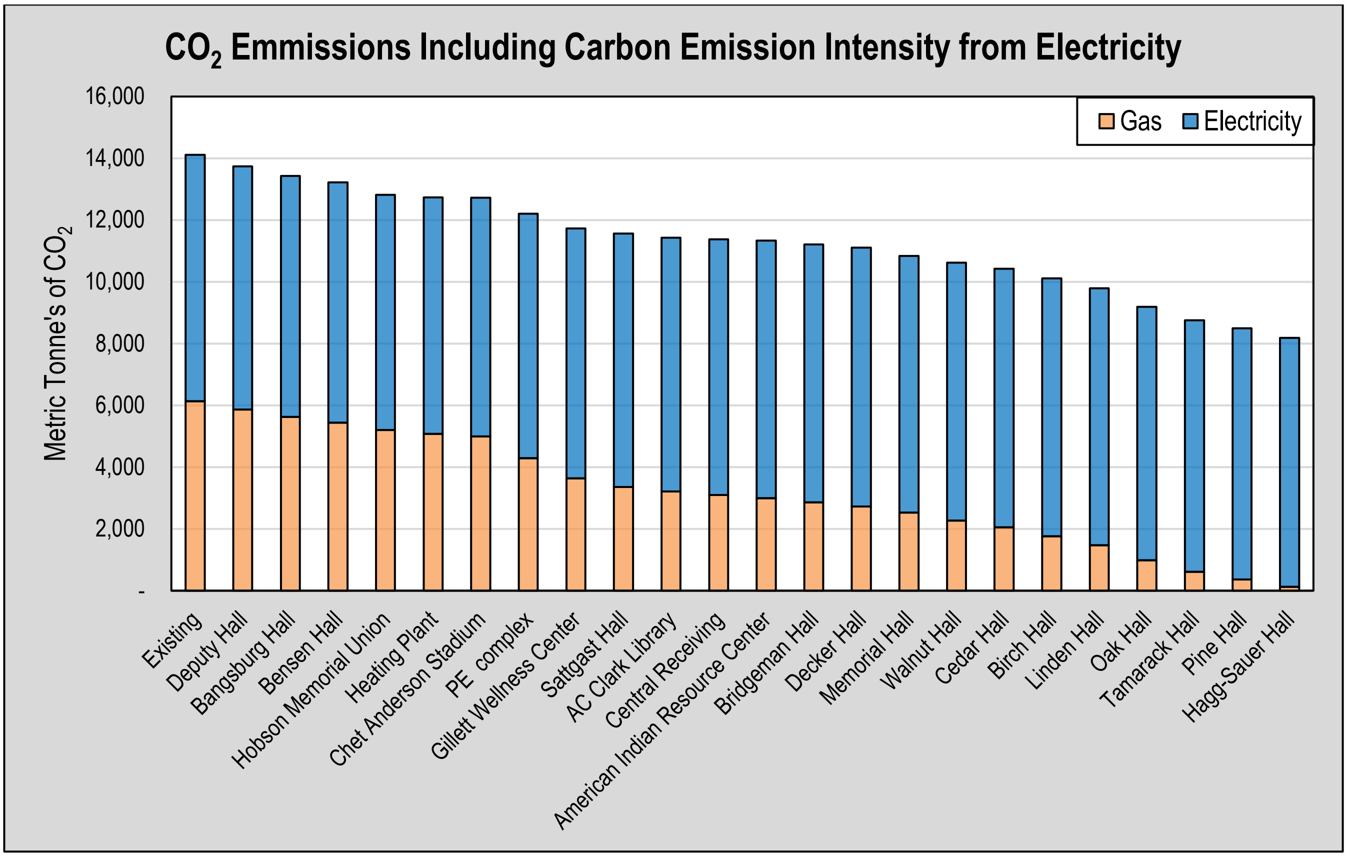

Figure 35: CO_2 reductions - buildings with efficiency measures.

8.1. Carbon Intensity

Currently, the OTPCO power grid is produced by coal-fired power plants that provide the largest share of the electricity generation at 46%. 38% is purchased from Midcontinent Independent System Operator, 14% is produced by wind power, 1% is produced by hydro power and 1% is produced from natural gas/oil. OTPCO currently has a carbon intensity of 1.69 lb/kWh and has committed to the continual reduction of their carbon intensity. OTPCO has recently commissioned a 150 MW wind farm and will be investing in a 50 MW solar plant in coming years. By 2022, their anticipated carbon intensity is projected to be 1.28 lb/kWh which is 24% lower than it currently stands as seen in Figure 36. OTPCO plans to add 250 MW of natural gas power in 2021 and 150 MW of wind power throughout the next decade. This investment will further reduce the carbon intensity and therefore decrease the offsite CO_2 emissions produced from BSU.

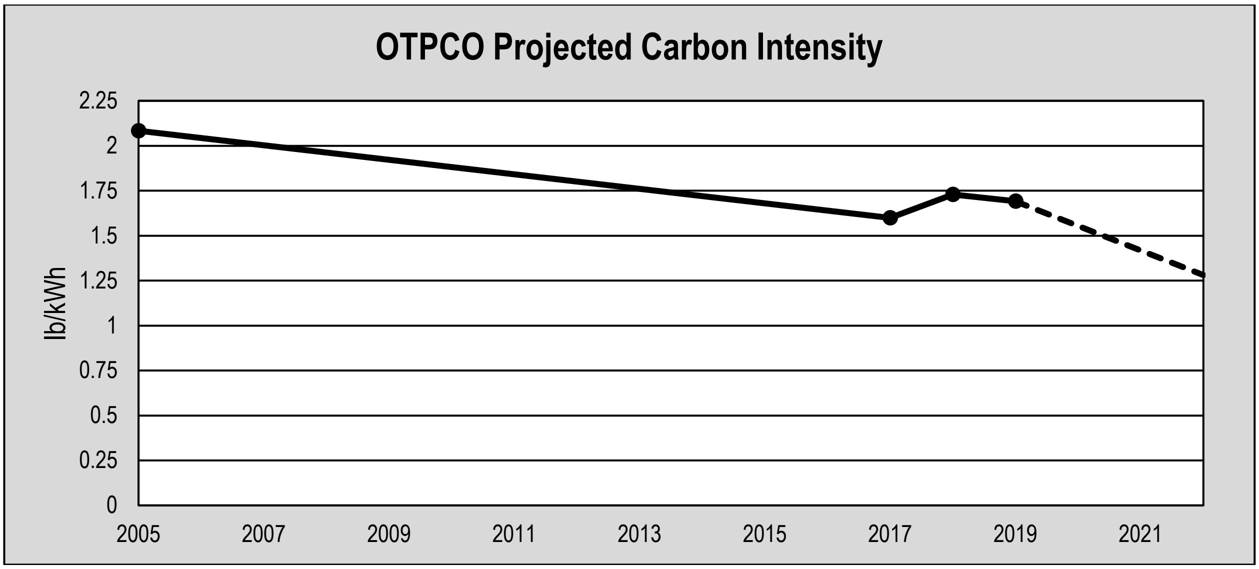

Figure 36: OTPCO projected carbon intensity through 2022.

8.2. Renewable Energy Credits

Renewable energy credits (RECs) are certificates that transfer the renewable energy portion of the electrical grid to the purchaser of the credit. A REC is produced when a renewable energy source generates one megawatt-hour (MWh) of electricity and delivers it to the grid. For example, if a wind power facility produces 5 MWh of electricity, they have 5 credits to either keep or sell. If BSU buys those credits, they are buying the “renewable” aspect of the electricity from the wind farm and can say that 5 MWh of their electricity use came from a renewable source. A REC that has been sold once cannot be purchased again and the exchange of RECs is tracked and recorded. All RECs are uniquely numbered and generally include information such as where they were generated, the type of renewable resource they came from, and a date stamp of generation.

Currently, OTPCO sells RECs at a cost of \$0.54/MWh. Throughout the construction process of converting the BSU campus from natural gas to electricity, the cost of REC’s to eliminate CO_2 emissions from electricity consumption varies (Figure 37). At the end of the anticipated GSHP retrofit project, BSU can purchase \$5,700 worth of RECs annually, to offset the CO_2 emissions from their campus electricity consumption.

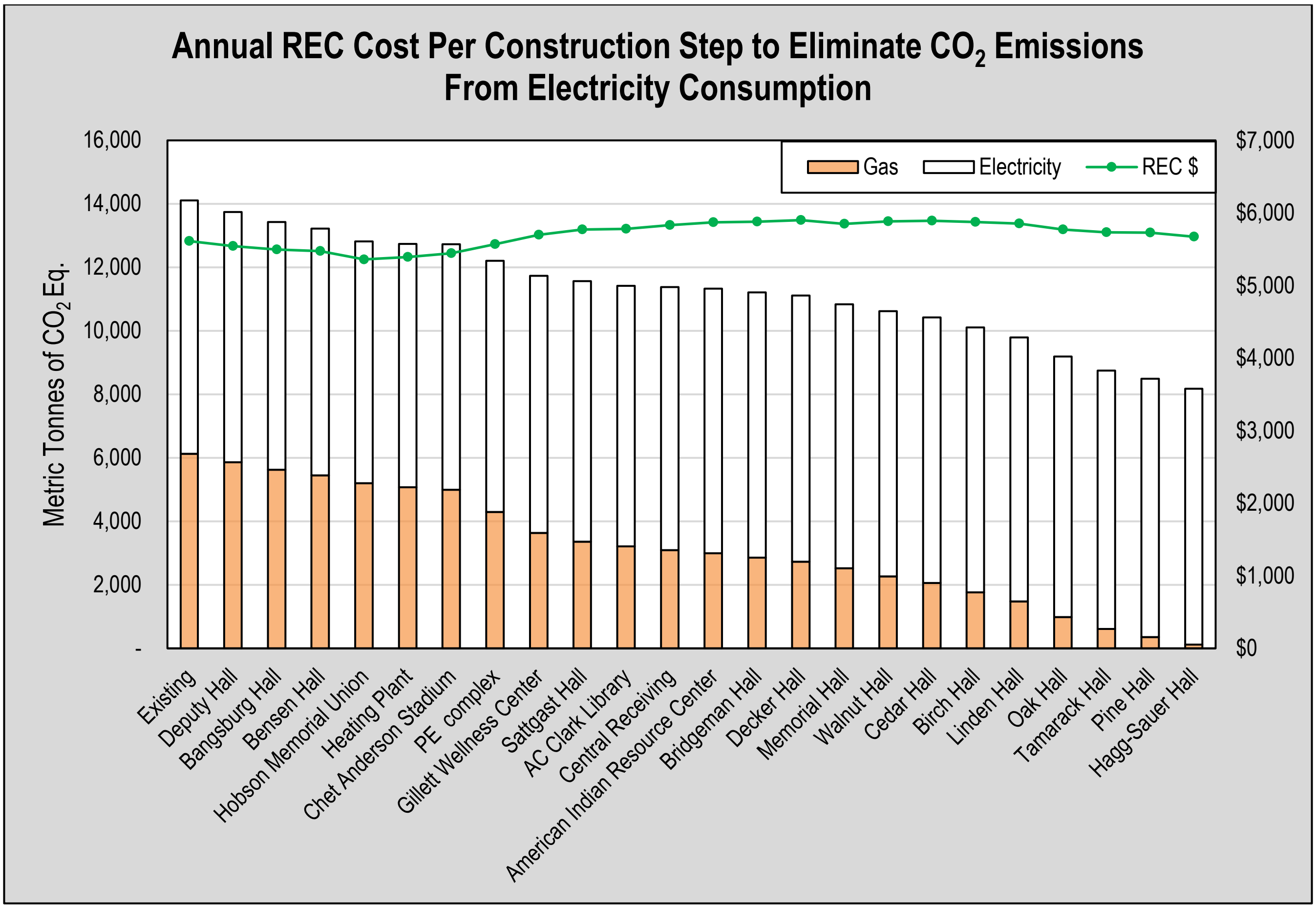

Figure 37: Annual cost of REC's to offset CO_2 emission from electricity consumption.

8.3. Carbon Tax

A carbon tax is not a matter of 'if', but a matter of 'when'. European countries such as Sweden, Switzerland, and Finland are leading the way with carbon taxes of 139, 101, and 77 USD/MT, respectively. The city of Boulder in Colorado became the first U.S. city to adopt a carbon tax in 2006 and since then has generated an average of $1.8 million per year. A 2017 study conducted by the U.S. Department of the Treasury estimated that a tax of $49/MT could raise roughly $2.2 trillion in net revenues over 10 years from 2019 to 2028 (https://www.treasury.gov/resource-center/tax-policy/tax-analysis/Documents/WP-115.pdf).

BSU is currently producing 6,011 MT from on-site natural gas heating annually. If a carbon tax of $40/MT is applied, this could cost BSU $240,440 annually. Since carbon taxes have traditionally targeted building owners for on-site emissions, converting the campus to electricity would effectively eliminate all on-site emissions. Over the lifetime of the GSHP system (25 year), if the carbon tax remains constant, this carbon tax savings totals approximately $6,011,000.

9. Closure

Converting the existing district heating and cooling system to a GSHP system is a step in the right direction for BSU and the State of Minnesota. A common misconception for geothermal systems is that they are risky and costly. To mitigate risk, a new technology has been developed that can monitor and predict the temperature of the ground based on the energy flowing into and out of it from sensors. Applying this system to the ground loops on campus would ensure a sustainable system for the anticipated lifespan.

Critical design principles to incorporate immediately or as soon as possible to insure GSHP feasibility remains cost effective in the future include implement ERV's on any anticipated AHU upgrade, implement AHU coils with additional capacity to accommodate lower hot water temperature (110°F), and ensure mechanical room renovations include allocated space for anticipated heat pump equipment.

The ETP is an opportunistic technology. Monitoring allows for assurance in optimal operation and the ability to determine whether adding discretionary loads could be lucrative rather than installing additional ground loop. Adding devices that can be used to divert energy away from a GHX like integrating into the irrigation system for fields or snowmelt systems can be more cost effective and useful than cooling towers. Incorporating surface water heat exchangers, wastewater heat exchangers or a Darcy Well system can also add or remove energy from a GHX in a cost-effective manner.

Working with BSU to provide the most cost-effective installation is the number one goal. Preliminary numbers show that installing a GSHP with efficiency measures is lucrative. The projected total incremental capital cost is $10,006,269 with annual energy cost savings of $450,275. The ETP allows for a modular type installation and the recommended construction steps allow for funding requests in smaller portions rather than a larger lump sum.

Electrifying the campus would eliminate 98% of on-site CO_2 emissions. Based on the analysis in Section 8, current greenhouse gas emissions are 14,102 MT annually and can be reduced to 8,181 MT based on the carbon emission intensity from electricity. As the OTPCO electrical grid becomes cleaner through increased production from renewable technologies, the reduction in CO_2 emissions will be proportional. Additionally, BSU can purchase $5,700 worth of RECs to offset the CO_2 emissions from their campus electricity consumption.

GEOptimize is prepared to work with local mechanical engineering firms, mechanical contractors, OTPCO, and BSU to provide and install an optimal system that maximizes CO_2 emissions reduction and energy consumption while minimizing capital cost. GEOptimize would be pleased to take this feasibility assessment a step further into detailed design to help shape a better future and set a benchmark for other establishments to reach for.