Study and Evaluation of Operating Experiences with Existing Geothermal Heat Pump Systems in North Dakota

Final Report

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Abstract

A Geothermal Heat Pump (GHP) system is a type of energy system that typically consumes electricity to provide cooling and heating in buildings. A GHP may be considered as a "green" system, mainly because of its use of geothermal energy that, as a type of renewable energy, has enormous potential for reducing CO_2 emission and fossil fuel consumption. Therefore, in the U.S., tax credits or incentives have been provided by governments or local utility companies to further support the installation and usage of geothermal energy devices. However, many factors determine the performance of GHP systems, such as control strategy, part/full-load efficiency, the age of system, and whether or not regular maintenance services are provided. Any of these factors could have significant impacts on the normal operation of GHP systems and the achievement of expected energy and energy cost savings.

The objectives of this project are to study and evaluate the operational performance of the existing GHP systems currently used in buildings located in North Dakota. Major emphasis is given to the reasons for installing geothermal systems, the data on capital costs and annual energy performance, the discussions of operating difficulties with the systems, as well as owner satisfaction to date. The results of this project are expected to 1) be regarded as a reference and used by the state to review its incentive or tax credit program for the geothermal application and then adjust or revise it if necessary; 2) help owners to identify and solve operating difficulties, improve their buildings' performance and their satisfaction; and 3) be used as a reference by building designers/contractors in North Dakota for geothermal heat pump applications in order to establish the confidence of design teams and the acceptance of potential end users.

This study has successfully accomplished by fully evaluating 24 target buildings that are located in North Dakota and equipped with GHP systems. The major findings are summarized below.

The major reasons for installing geothermal systems in these 24 buildings include "lower cooling and heating bills", "energy efficiency", and "environmental concerns". Although some of the building owners are expressing more concerns about energy and environment, instead of "Money", these building owners are only limited to non-profit organizations, such as colleges or schools. "Lower cooling and heating bills" is still the top concern for commercial buildings.

For these 24 buildings, about 75% of the building owners are very satisfied with their GHP systems in terms of noise, cost, and indoor comfort, about 71% of the investigated GHP systems have not had serious operating difficulties, and about 85% of the respondents (building owners) would like to suggest this type of system to other people. These survey results indicate the reliability and applicability of GHP systems in North Dakota as well as the potential for a broader statewide application.

On average, the energy savings of these 24 buildings is about 23%, compared to conventional air-conditioning systems, which is a reasonable number for buildings equipped with GHP systems. The corresponding energy cost savings, however, is relatively low (12%), due to the extremely low natural gas price in North Dakota. The low energy cost savings may cause the loss of attraction of building owners/developers to GHP systems, who would rather consider to use conventional systems that usually have low capital costs but consume more energy and fossil fuels, which will

be against the original intention of the state or local governments about energy efficiency and environmental protection, e.g. the purpose of the State Energy Program (SEP) in North Dakota. Compared to the national median (energy use and energy cost of similar buildings nationwide), the overall performance of the actual GHP systems used in North Dakota is slightly better, i.e. about 8% energy savings and 5% energy cost savings on average.

The estimated simple payback period (the use of the current GHP system against conventional air-conditioning system) is long, which is between 9 and 20 years or even goes to infinity (for the buildings where there is no energy cost savings identified compared to conventional systems). Additionally, according to the feedback from the building owners/end users, most of the investigated buildings did not receive any incentives for the installation and use of GHP systems. Therefore, the financial support either from governments or utility companies, or both, may improve the cost effectiveness of installing and using GHP systems, and may encourage the installation of GHP systems and contribute to making use of geothermal energy.

In summary, currently in North Dakota, one of the biggest barriers to the wide application of GHP system is the high capital and/or replacement costs. How to reduce capital costs and improve cost effectiveness of installing and using this type of system are the keys. Financial support from local governments and/or utility companies would give a much needed shot in the arm to the popularity of GHP system in North Dakota.

Nomenclature

AHU – Air Handling Unit

ASHRAE – American Society of Heating, Refrigerating and Air-conditioning Engineers

BAS – Building Automation System

BOD – Basis Of Design

BSC – Bismarck State College

CCEC – Cass County Electric Cooperative

COP – Coefficient Of Performance

DCV – Demand Control Ventilation

DOAS– Dedicated Outdoor Air System

DREC – Dickinson Research Extension Center

DX – Direct Expansion

EER – Energy Efficiency Ratio

EPA – Environmental Protection Agency

ERU – Energy Recovery Unit

EUI – Energy Use Intensity

GAC – Gorecki Alumni Center

GHP – Geothermal Heat Pump

HRU – Heat Recovery Unit

HVAC - Heating, Ventilation, and Air-Conditioning

LEED – Leadership in Energy and Environmental Design

LNWR – Lostwood National Wildlife Refuge

LREC – Langdon Research Extension Center

MAU – Makeup Air Unit

MMBTU – Million British Thermal Units

N.D.C.C. – North Dakota Century Code

NDSU – North Dakota State University

NECE – National Energy Center of Excellence

OPR – Owner's Project Requirement

SEP – State Energy Program

UND – University of North Dakota

UTTC – United Tribes Technical College

VAV – Variable Air Volume

VSD – Variable Speed Drive

WSC – Williston State College

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Executive Summary

Research Objectives and Needs (Chapter 1&2)

In this project, a study and evaluation was undertaken through on-site surveys and computer simulations for buildings that are located in North Dakota and equipped with Geothermal Heat Pump (GHP) systems, in order to evaluate whether these buildings, as the recipients of the incentives and/or tax credits, are operating as anticipated and designed, and whether the energy savings of these buildings, which were predicted at the building design stage, are over- or under-estimated, compared to the actual data in the survey. Specifically, this project was designed to

- be regarded as a reference and used by the state to review its incentive or tax credit program for the geothermal application and then adjust or revise it if necessary;
- help building owners to identify and solve operating difficulties, improve their buildings' performance and their satisfaction;
- and be used as a reference by building designers/contractors in North Dakota for GHP applications in order to establish the confidence of design teams and the acceptance of potential end users.

Research Design and Development (Chapter 3)

As proposed, this study was accomplished through four steps, i.e. 1) Preliminary preparation; 2) On-site visit and investigation; 3) Computer simulation; and 4) Data analysis and discussion. In this study, 24 buildings were selected and evaluated, which are located in North Dakota and equipped with GHP systems. These investigated buildings include 9 college buildings, 6 school buildings, 2 churches, 3 commercial buildings, 2 public buildings, and 2 residential buildings, which were selected considering several factors, such as the building locations and types, the ages of GHP systems, and the richness and availability of the received information and documents of each building. Building information and data were collected through on-site visits and surveys. Computer simulations were carried out to identify potential energy and energy cost savings compared to conventional HVAC (Heating, Ventilating, and Air-Conditioning) systems that were typically determined based on ASHRAE Standard 90.1 – Appendix G. In-depth analysis was conducted on the collected building information and data along with the results of computer simulations, e.g. the estimation of simple payback period, in order to find out the trend of the development and application of GHP system in North Dakota and to evaluate the cost effectiveness and applicability of GHP systems as well as to identify the role of North Dakota's incentive/tax credit program in the decision of using a GHP system.

Research Results and Outcomes (Chapter 4)

As the outcome of this project, this final report includes the case studies of 24 target buildings, each of which covers the following aspects:

- Building background including the basic building information;
- System description including a brief description regarding the existing GHP system;
- System performance
- Project cost analysis including the information on system investments and operational

expenses, a cost comparative analysis between existing and conventional systems, as well as a simple payback period calculation;

- ❖ A basic summary information of each target building, including the parameters of the building and the GHP system, the building cost data, operating difficulties, owner satisfaction, and/or suggestions.

<u>Analysis and Discussions (Chapter 4)</u>

In this report, the tremendous amount of information and data of these 24 buildings collected was organized and demonstrated in a comparative way through tables and/or figures, which is easier for readers to compare parameters among these buildings and to identify the differences or similarities.

<u>Suggestions and/or Recommendations (Chapter 4)</u>

Lastly, based on the analysis results, specific suggestions and/or recommendations were given for each individual building. The analysis results as well as these suggestions and/or recommendations will be shared with corresponding building owners in order to help them identify and solve operating difficulties and eventually improve their satisfaction.

Key Takeaways

- ❖ Currently, one of the biggest barriers to the wide application of GHP system in North Dakota is the high capital and/or replacement costs. How to reduce capital costs and improve cost effectiveness of installing and using this type of system are the keys. Financial support from local governments and/or utility companies would give a much needed shot in the arm to the popularity of GHP system in North Dakota.
- ❖ The major reasons for installing geothermal systems include "lower cooling and heating bills", "energy efficiency", and "environmental concerns". Although some of the building owners are expressing more concerns about energy and environment, instead of "Money", these building owners are only limited to non-profit organizations, such as colleges or schools. "Lower cooling and heating bills" is still the top concern for commercial buildings.
- ❖ For these 24 buildings, 75% of the building owners are very satisfied with their GHP systems in terms of noise, cost, and indoor comfort, about 71% of the investigated GHP systems have not had serious operating difficulties, and more than 85% of the respondents would like to suggest this type of system to other people. These survey results indicate the reliability and applicability of GHP systems in North Dakota as well as the potential for a broader statewide application.
- ❖ On average, the energy savings of these 24 buildings is about 23%, compared to conventional HVAC systems, which is a reasonable number for buildings equipped with GHP systems. The corresponding energy cost savings, however, is relatively low (12%), due to the extremely low natural gas price in North Dakota. The low energy cost savings may cause the loss of attraction of building owners/developers to GHP systems, who would rather consider to use conventional air-conditioning systems that usually have low capital costs but consume more energy and fossil fuels, which will be against the original intention of the state or local

governments about energy efficiency and environmental protection, e.g. the purpose of the State Energy Program (SEP) in North Dakota.

- Compared to the national median (energy use and energy cost of similar buildings nationwide), the overall performance of the actual GHP systems used in North Dakota is slightly better, i.e. about 8% energy savings and 5% energy cost savings on average.
- The estimated simple payback period (the use of the current GHP system against conventional air-conditioning system) is long, which is between 9 and 20 years or even goes to infinity (for buildings where there is no energy cost savings identified compared to conventional systems). Additionally, according to the feedback from the building owners/end users, most of the investigated buildings did not receive any incentives for the installation and use of GHP systems. Therefore, the financial support either from governments or utility companies, or both, may improve the cost effectiveness of using GHP systems, and may encourage the installation of GHP systems and contribute to making use of geothermal energy.
- On average, the design water flow rates per ton (3.4 gpm/ton with a range between 2.1 and 5.4) for the ground loops of the investigated GHP systems are slightly more than the upper level of the typical values (2.5~3.0 gpm/ton). This may indicate the oversizing of water flow rate in ground loops, which may result in higher pump power and increased operational costs.
- Several investigated GHP systems have shorter borehole separation distances than the suggested minimum of 15 feet. One of these investigated systems (National Energy Center of Excellence at Bismarck State College) had already encountered a serious operating issue, i.e. high return water temperatures (warm ground) and low cooling capacities. Some of the other buildings, such as NDSU Richard H. Barry Hall-New Addition, have detected warm return water temperatures, which, however, haven't caused any issues yet. However, it is suggested to continuously monitor the GHP systems in these buildings in order to avoid serious problems before they really happen.
- In North Dakota, most of the studied buildings are equipped with vertical closed-loop GHP systems, which indicates the high acceptance of this type of system by building owners, end users, and designers/engineers in North Dakota, compared to other types of GHP systems.
- In North Dakota, on average, the depth of GHP boreholes is typically about 200 feet below the ground surface, due to the local geologic formations and the relatively high water table.
- Test wells before the installation of a GHP system are suggested, which are not only able to test the thermal conductivity of the underground region, but also to ensure how deep the geothermal loops can go and the depth of the water table in that region.
- Supplemental/backup heating for GHP systems is suggested, especially for the initial startup during the first and/or unexpectedly cold winters in North Dakota.

1. Background

As shown in Figure 1.1, the U.S. consumes approximately 19% of the total energy of the world, in which buildings (commercial and residential) account for 41% of the U.S. energy consumption. However, only 9% of the U.S. building energy is renewable.

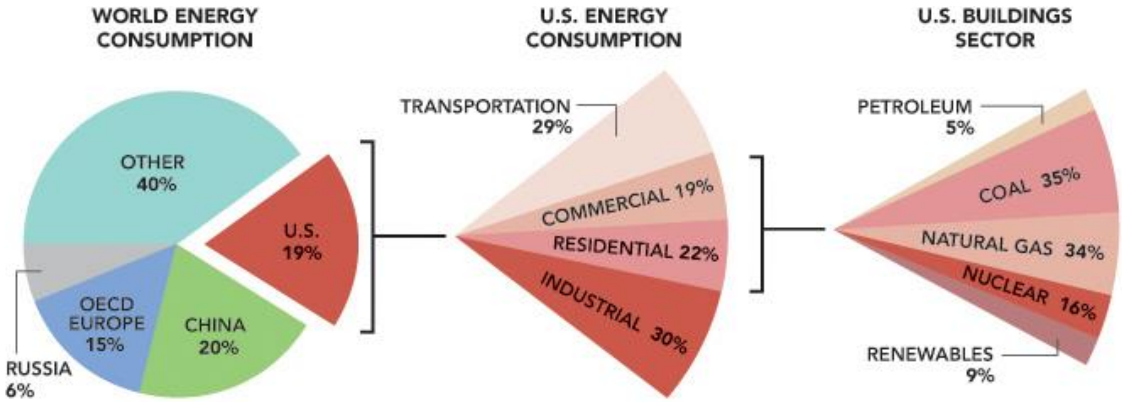

Figure 1.1: World and U.S. Energy Consumption [1]

Within the 41% of the U.S. energy consumption, Heating, Ventilating, and Air Conditioning (HVAC), including water heating as well as space cooling and heating (Figure 1.2), accounts for approximately 60% of U.S building site energy consumption [1]. Additionally, 45% of U.S. carbon dioxide (CO_2) emissions (Figure 1.3) is caused by buildings, compared to 21% for industry and 34% for transportation [1].

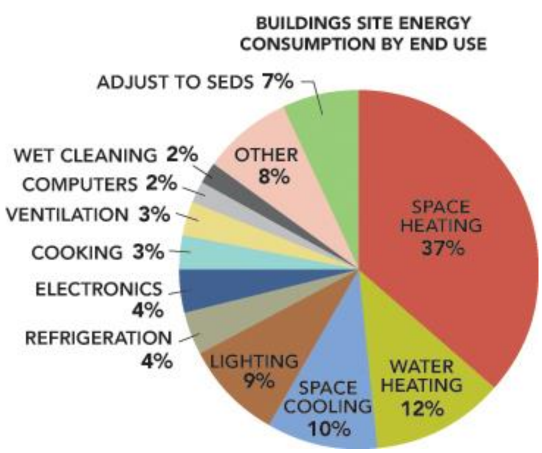

Figure 1.2: Buildings Site Energy Consumption by End Use [1]

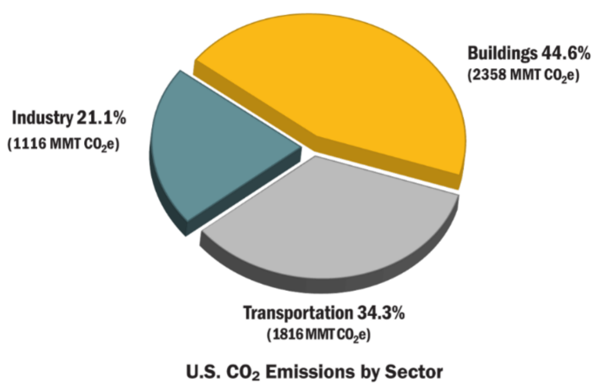

Figure 1.3: U.S. CO2 Emissions by Sector [1]

Although the situation in terms of energy use in the state of North Dakota is a little different from that in the U.S., especially for the usage of renewable energy such as wind energy, due to its special geographical location and industrial structure, the major energy source of North Dakota still comes from nonrenewable energy, such as coal, natural gas, oil, etc., as shown in Figure 1.4. For example, in 2014, 75% of the electricity was generated by using coal in North Dakota [2].

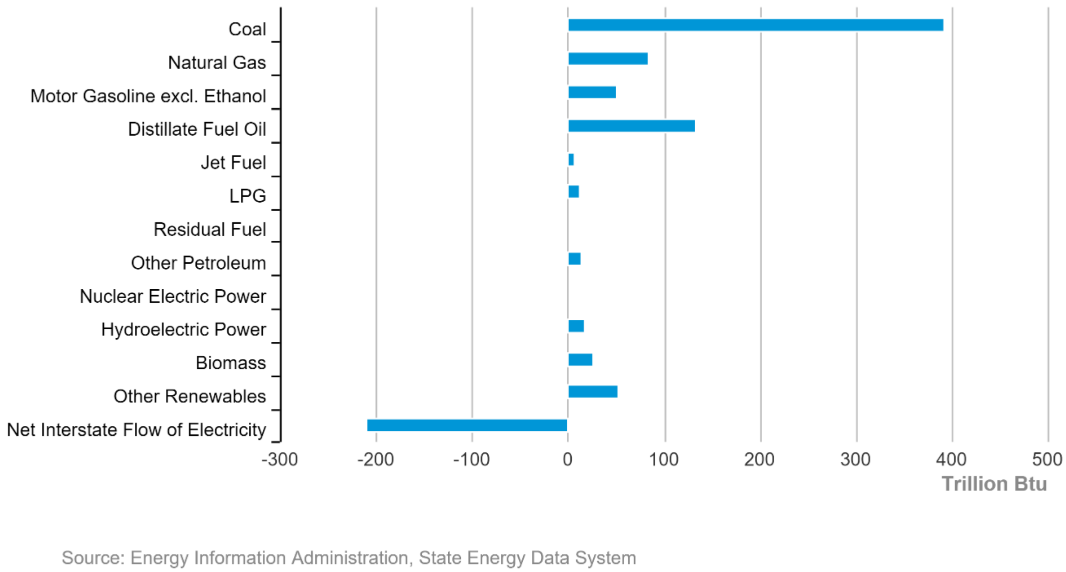

Figure 1.4: North Dakota Energy Consumption Estimates [2]

Renewable energy, also known as clean energy, usually comes from the sources that are able to be naturally replenished on a human timescale basis. The available renewable energy in North Dakota includes wind, biomass, alternative fuels (such as biodiesel), ethanol, geothermal, and solar [4].

Geothermal energy, as one of the major renewable energy resources in North Dakota, has been exploited and harnessed since the 1980s or even before [5]. The definition of the word "geothermal" in the dictionary [6] is "of, relating to, or produced by the internal heat of the earth." According to this definition, geothermal energy should be the energy contained and stored within the Earth, including the Earth's core, mantle, and crust. Most recently, geothermal energy is, however, typically defined as the thermal energy stored in the crust of the Earth, due to its easier access and exploitation by human beings.

The thermal energy contained within the Earth's crust has been utilized in various ways depending on the available power. Three categories have been classified by ASHRAE [7] in terms of the available temperature from the ground (T):

- High Temperature Application: $T > 300^oF$
- Intermediate Temperature Application: $90^oF \leq T \leq 300^oF$
- Low Temperature Application: $T < 90^oF$.

When the ground temperature is high (around 300°F or greater), the available heat is suitable for electric power generation; when the ground temperature is at the intermediate level, the available heat can be used directly, for example, to provide heating effect to systems or buildings without any supplemental input power or energy; and when the ground temperature is low (T < 90°F), it is difficult to be utilized directly, and thus additional energy must be provided in order to efficiently take advantage of this ground thermal energy.

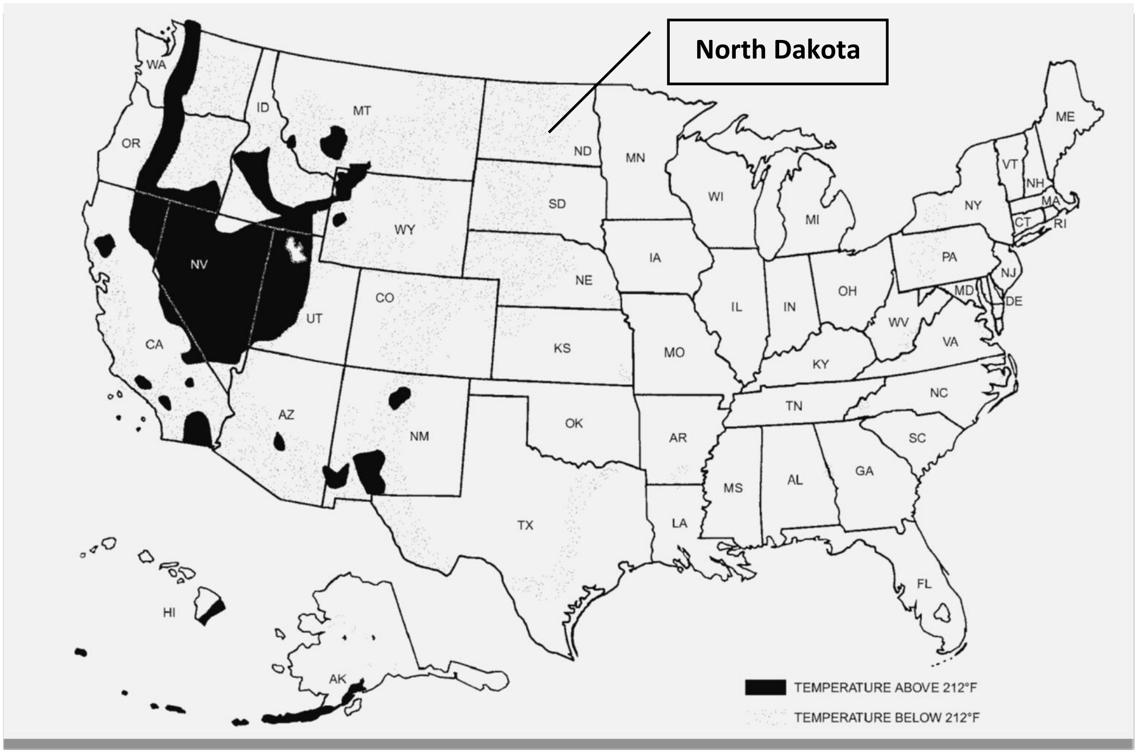

Figure 1.5: U.S. Hydrothermal Resource Areas [7]

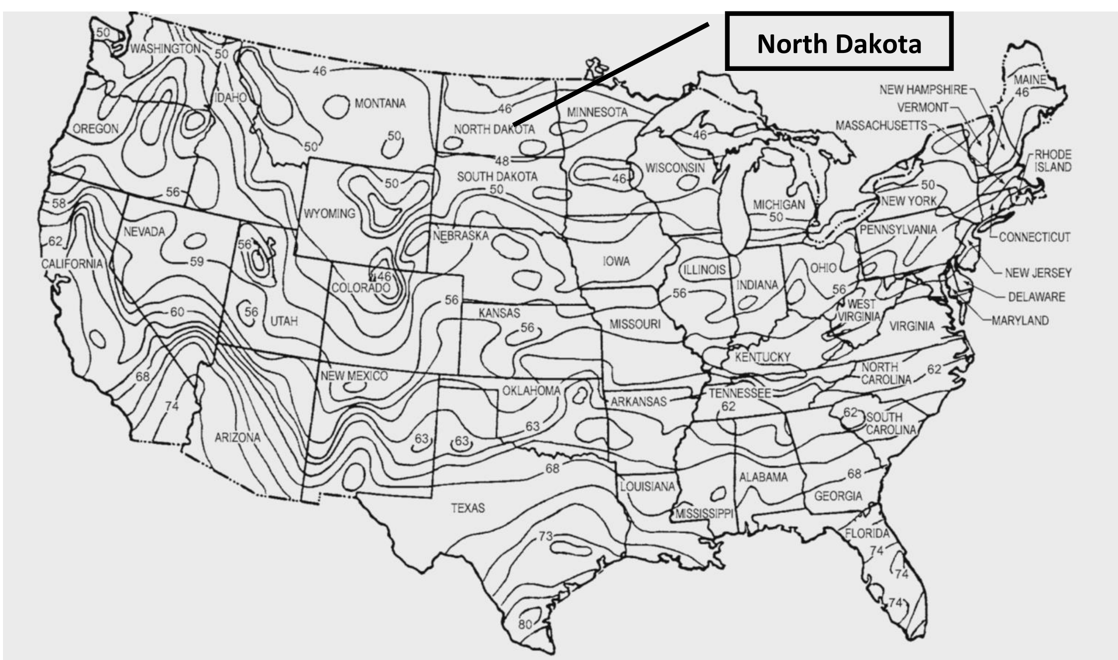

Figure 1.6: Approximate Groundwater Temperatures [°F] in the U.S. [7]

Unfortunately, as shown in Figure 1.5, high or intermediate ground temperatures are typically not widely available in North Dakota. Therefore, the utilization of geothermal energy has been focused on the low temperature applications, in which geothermal heat pump (GHP) systems are typically used to extract the ground thermal energy. North Dakota has already realized the tremendous potential for the development and application of GHP systems. For example, the North Dakota Department of Commerce - Division of Community Services was one of the first states to enter into a partnership with the Geothermal Heat Pump Consortium, Inc. [8], expressing its commitment to promoting the development of this renewable energy source.

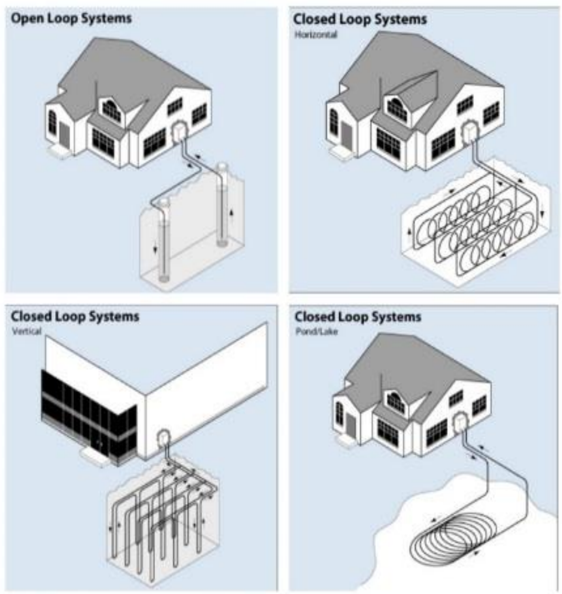

Figure 1.7: Open and Closed Loop Systems [9]

As we know, GHP systems take advantage of the nearly constant ground temperatures (typically in the range of 45 – 50^{o}F in North Dakota, as shown in Figure 1.6), rejecting building heat into the ground during summer and conversely extracting heat from the ground to provide the heating effect to buildings during winter.

According to the different types of ground source heat exchangers, GHP systems can be categorized as direct-exchange systems, closed-loop systems, and open-loop systems. As the oldest type of GHP system, direct-exchange systems are rarely used today, in which the working fluid in the heat exchanger loop, called "refrigerant" (such as R134a), carries heat and transfers it between the terminal heat pump and the ground. Unlike the direct-exchange system, water (or a mixture of water and anti-freeze) is typically used in open- and closed-loop systems, as shown in Figure 1.7. As their names imply, the difference between open- and closed-loop systems depends on whether the working fluid is directly exposed to the ambient medium or not. Closed-loop systems, including horizontal loop, vertical loop, and lake/pond loop (Figure 1.7), are the most popularly used systems in North Dakota, especially the vertical loop GHP systems, in which geothermal loop pipes will be buried vertically in boreholes or wells that are typically 50 to 450 feet in depth with the separation distance of at least 15 feet between each borehole/well.

By using GHP systems, the energy savings and the reduction of the greenhouse emissions are significant compared to the conventional air-conditioning systems that use air-cooled condensing unit/chiller and natural gas furnace/boiler to provide cooling and heating effects to buildings/houses[5][7][10][11]. The possible energy savings and emission reductions of GHP systems can be as high as 72% and 44%, respectively [12]. The major energy savings for GHP systems typically come from the high Coefficient of Performance (COP), especially when the system is in heating mode [5][13]. COP is typically used to measure the effectiveness of a heat pump system. Theoretically, 1.0 COP is equivalent to 100% efficiency. For example, usually a condensing boiler would have an efficiency of 90%-95%, which is equivalent to 0.9-0.95 COP. A GHP system typically has a COP of 3-4, which is 3-4 times than that of a boiler. This is one of the major reasons why GHP systems have superior performance during winter compared to conventional heating devices, such as boilers or furnaces.

However, further on-site investigations are needed in order to evaluate whether the buildings equipped with GHP systems demonstrate superior operational performance and reasonable energy savings compared to conventional HVAC systems. The operation of a GHP system is influenced by many factors, such as

- ❖ if the design and selection of the GHP system are reasonable (no over- or under- sizing) and if the system is able to meet the heating and cooling loads of the entire facility,
- ❖ if the control strategies are appropriate for the building usage without significant energy waste caused by improper control sequence,
- ❖ if there are defective parts in the system that could result in significant unnecessary energy consumption,
- ❖ if the major equipment, such as heat pump units, are too old to maintain their high-efficient operations,
- ❖ if regular maintenance services are missing, which causes additional energy usage.

Any of these factors could have significant impacts on the normal operation of GHP systems as well as the achievement of expected energy savings. For example, William [14] conducted a comparison of carbon emission between residential heating and cooling options and found that for a residential building located in Daytona Beach, Florida, and equipped with a high-efficiency GHP system, no significant energy savings were observed compared to conventional air-conditioning systems, due to the fact that this building is nearly cooling dominated throughout the year, according to the local weather conditions. Therefore, the large potential of GHPs on energy savings in heating mode is not fully apparent. Similar situations could happen to the buildings in North Dakota. Although the state of North Dakota is in the cold region (Climate Zone 6 and 7) of the U.S. and has a relatively long winter, some of the buildings are still requesting cooling instead of heating during this time, especially for commercial buildings, such as offices, schools, colleges, etc., due to the large amount of heat generated by equipment (computers, printers, etc.), people, and lighting systems. In this case, compared to conventional HVAC systems, the energy savings for the buildings equipped with GHP systems in North Dakota would be reduced greatly.

Additionally, to encourage the usage of renewable energy and to increase the percentage of renewable energy in the overall energy consumption of the state, incentives and tax credits (N.D.C.C. § 57-38-01.8 [3]) have been provided from the State of North Dakota. For example, as stated in the North Dakota Income Tax document [3],

"A corporation may claim a tax credit for the cost of acquisition and installation of a geothermal, solar, wind, or biomass energy device installed BEFORE January 1st, 2015." "The credit is equal to 3% of the cost of the device, each year for five years."

According to the above statement, however, it appears that these tax credits for the use and installation of geothermal energy device were only available until January 1st, 2015. After that, this benefit no longer exists. Building owners or developers may hesitate to use renewable energy devices due to the relatively high capital cost. Fortunately, incentives are also provided by some of the North Dakota utility companies to their customers who decide to use and install GHP systems in their buildings. Table 1.1 shows the current incentives provided by some of the local utility companies in North Dakota.

Table 1.1: Incentives for the use and installation of GHPs in North Dakota

Organization	**Program**	**Incentive**	**Other Credit**
Cass County Electric Cooperative[1]	Residential Off-Peak Incentive Program for new installation (residential)	$200/ton	Additional Install Credit $150
Otter Tail Power Company[2]	Heat Pump Rebates for new installation (residential or commercial)	$250/ton	-
Cavalier Municipal Utilities with Bright Energy Solutions[3]	Geothermal heat pump rebates for business and residential customers for new installation	$200/ton	Additional $250 for Desuperheater[9]
Hillsboro Municipal Utilities with Bright Energy Solutions[4]	Geothermal heat pump rebates for residential customers for new installation	$200/ton	Additional $250 for Desuperheater[9]
Lakota Municipal Light Plant with Bright Energy Solutions[5]	Geothermal heat pump rebates for residential customers for new installation	$200/ton	Additional $250 for Desuperheater[9]
Northwood Municipal Utilities with Bright Energy Solutions[6]	Geothermal heat pump rebates for residential customers for new installation	$200/ton	Additional $250 for Desuperheater[9]
Valley City Public Works with Bright Energy Solutions[7]	Geothermal heat pump rebates for residential customers for new installation	$200/ton	Additional $250 for Desuperheater[9]
Minnkota Power Cooperative[8]	Heating Rebates for new geothermal heat pump installation	$200/ton	-

1. https://kwh.com/content/off-peak
2. https://www.otpco.com/ways-to-save/rebates-and-savings/heat-pumps-residential/
3. http://www.brightenergysolutions.com/generatepdf?fid=8275&mid=5305, http://www.brightenergysolutions.com/generatepdf?fid=8278&mid=5305
4. http://www.brightenergysolutions.com/generatepdf?fid=8275&mid=5317, http://www.brightenergysolutions.com/generatepdf?fid=8278&mid=5317
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7. http://www.brightenergysolutions.com/generatepdf?fid=8278&mid=5345, http://www.brightenergysolutions.com/generatepdf?fid=8275&mid=5345
8. http://www.minnkota.com/off-peak-rebate-programs.html
9. A desuperheate is used to heat domestic hot water for the business

2. Research Objectives and Needs

In this project, a study and evaluation was undertaken through on-site surveys and computer simulations for the buildings that are located in North Dakota and equipped with GHP systems, in order to evaluate whether these buildings, as the recipients of the incentives and/or tax credits, are operating as anticipated and designed, and whether the energy savings of these buildings, which were predicted at the building design stage, are over- or under- estimated, compared to the actual data in the survey.

Specifically, this project can:

- be regarded as a reference and used by the state to review its incentive or tax credit program for the geothermal application and then adjust or revise it if necessary;
- help owners to identify and solve operating difficulties, improve their buildings' performance and their satisfaction;
- be used as a reference by building designers/contractors in North Dakota for GHP applications in order to establish the confidence of design teams and the acceptance of potential end users.

3. Project Design and Development

The four steps were followed and implemented in the project, including

- ❖ Preliminary preparation
- ❖ On-site visit and investigation
- ❖ Computer simulation
- ❖ Data analysis and discussion

Preliminary Preparation

The first step of this project involves the preliminary preparations, including selecting the target buildings, obtaining the permissions for on-site investigations, and preparing the survey documents.

<u>Selecting the target buildings</u>

The target buildings in this project are the buildings located in North Dakota and equipped with GHP systems (closed-loop, open-loop, and/or direct-exchange if available). The information regarding which buildings are using GHPs was obtained from the following sources:

- ❖ Website searching, including newspapers, articles, papers, and publications
- ❖ Collaboration with the local government to obtain necessary building information
- ❖ Mechanical designers, architects, and contractors from local companies

In 2011, Lorraine Manz [15] conducted an investigation about the locations of geothermal installations in North Dakota (Figure 3.1). As shown in this figure, the utilization of geothermal systems is focused on these three regions in North Dakota: Minot, Bismarck-Mandan, and Fargo. This figure was regarded as a reference in this project when selecting target buildings.

From the above-mentioned sources, the potential target buildings that the research team found are listed in Appendix A, which includes 14 university/college buildings, 17 school buildings, 14 church buildings, 37 public/commercial buildings, and 2 residential buildings, with the total 84 buildings.

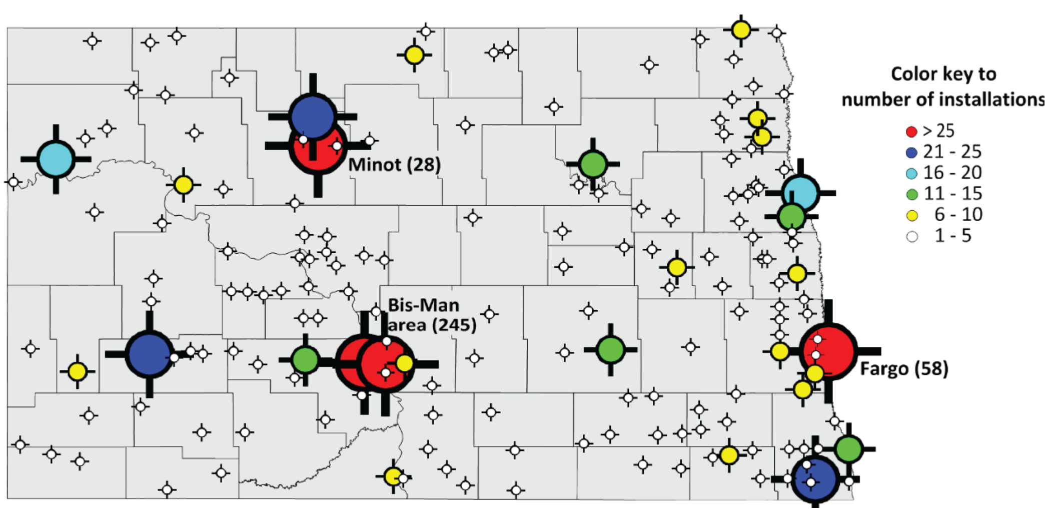

Figure 3.1: Locations of geothermal installations in North Dakota [15]

Obtaining the permissions

Once the initial target buildings were selected, requests were sent to the building owners through email, fax, or phone call, in order to ask whether they are willing to participate in the survey and to obtain permission for on-site investigations. Responses were received from 37 building owners with the total 84 requests that were sent out. These owners showed the willingness to help our research project and provide necessary building information/documents. These 37 buildings are listed in Appendix B.

The final list of the target buildings was generated (with totally 24 buildings), as shown in Table 3.1 below, considering several factors, such as the building locations and types, the ages of GHP systems, and the richness and availability of the received information and documents of each building. As shown in this final list, various building types were considered in this project, including schools, colleges, offices, mix-use buildings, residential buildings, and churches. Figure 3.2 indicates the target buildings by different building types. The location of each target building in the final list was selected carefully in order to cover most of the typical cities in North Dakota, as shown in Figure 3.3.

Table 3.1: Final list of the target buildings

NO.	Building	Location	Building Type
1	NDSU Richard H. Barry Hall-New Addition	Fargo	College
2	National Energy Center of Excellence at Bismarck State College	Bismarck	College
3	United Tribes Technical College - Science & Technology Building	Bismarck	College
4	United Tribes Technical College - Wellness Center	Bismarck	College
5	United Tribes Technical College - Dormitory	Bismarck	College
6	NDSU Dickinson Research Center	Dickinson	College
7	NDSU Langdon Learning Center	Langdon	College
8	University of North Dakota Gorecki Alumni Center	Grand Forks	College
9	Williston State College - Residence Hall	Williston	College
10	Discovery Middle School	Fargo	School
11	Kennedy Elementary School	Fargo	School
12	Judge Ronald N. Davies High School	Fargo	School
13	Bennett Elementary School	Fargo	School
14	Northwood Public School	Northwood	School
15	Rugby High School	Rugby	School
16	Zion Lutheran Church	Minot	Church
17	St Anthony of Padua	Fargo	Church
18	Grand Forks Airport International Terminal	Grand Forks	Commercial
19	Black Gold Corporate Headquarters	Grand Forks	Commercial
20	Cass County Electric Cooperative Building	Fargo	Commercial
21	Osgood Fire Station 7	Fargo	Public
22	Lostwood National Wildlife Refuge - Office	Kenmare	Public
23	Lostwood National Wildlife Refuge - Residence	Kenmare	Residential
24	Coteau Prairie Residence	Stanley	Residential

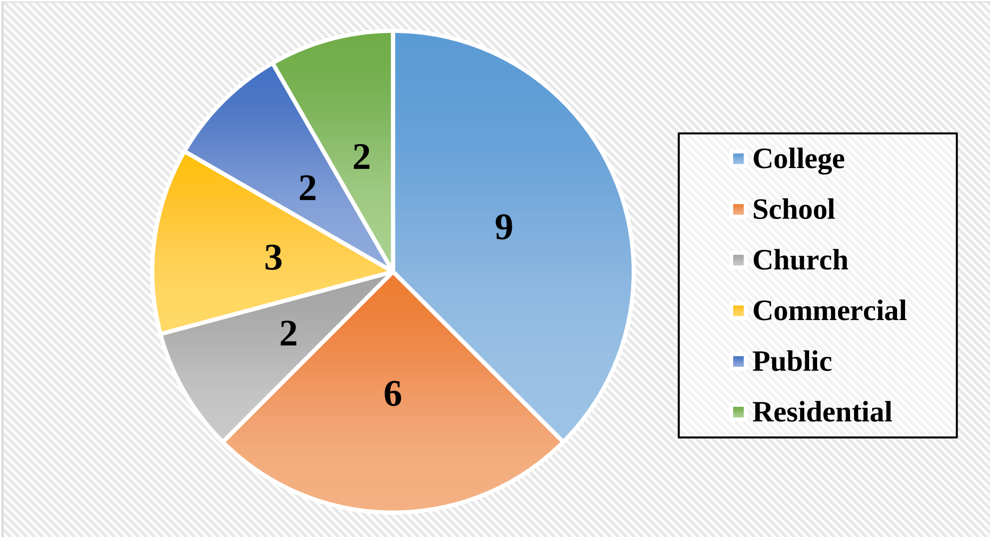

Figure 3.2: Target building allocation by building type

Figure 3.3: Target buildings on a map

Another critical factor that needs to be considered in the project is the year the structures were built. Which year the building was built and the GHP system installed are the typical questions that were considered. After certain years, some of the heat pump units could be too old to be used due to high maintenance cost and low operation efficiency. Table 3.2 shows the building construction and GHP installation years for each target building.

Table 3.2: The age of building and GHP system

NO.	Building	Building Construction Year	GHP Installation Year
1	NDSU Richard H. Barry Hall-New Addition	2009	2009
2	National Energy Center of Excellence at Bismarck State College	2008	2008
3	United Tribes Technical College - Science & Technology Building	2010 – 2012 (Phase 1&2)	2010 – 2012 (Phase 1&2)
4	United Tribes Technical College - Wellness Center	2006	2006
5	United Tribes Technical College - Dormitory	2003	2003
6	NDSU Dickinson Research Center	2006	2006
7	NDSU Langdon Learning Center	2004	2010
8	University of North Dakota Gorecki Alumni Center	2012	2012
9	Williston State College - Residence Hall	2011	2011
10	Discovery Middle School	1994	1994 & 2013 for several replacement HPs
11	Kennedy Elementary School	2007 & 2012 for New Addition	2007 & 2012 for New Addition
12	Judge Ronald N. Davies High School	2011	2011
13	Bennett Elementary School	1999 & 2009 for New Addition	1999 & 2009 for New Addition
14	Northwood Public School	2008	2008
15	Rugby High School	1956	2012
16	Zion Lutheran Church	2006	2006
17	St Anthony of Padua	1917-1932	2005
18	Grand Forks Airport International Terminal	2011	2011
19	Black Gold Corporate Headquarters	2012	2012
20	Cass County Electric Cooperative Building	2008	2008
21	Osgood Fire Station 7	2009	2009
22	Lostwood National Wildlife Refuge - Office	1992	1992
23	Lostwood National Wildlife Refuge - Residence	2002	2002
24	Coteau Prairie Residence	2003	2003

As described in the original proposal, these target buildings were categorized into three groups depending on the years for which their heat pump systems have been used (Table 3.3).

Table 3.3: Three groups for building selection based on the age of heat pump system

	Heat Pump System Age [years]	Number of Buildings
Group One	<10	13
Group Two	≥10 and ≤25	11
Group Three	>25	0

As shown in Table 3.3, no buildings are placed in Group Three considering the fact that the effective life of an indoor heat pump unit is typically 20~25 years, and thus older heat pump units had already been replaced with new ones in buildings.

Preparing the survey documents

Once the agreements and permissions were obtained, the survey documents were prepared for the on-site investigations. These documents include the following:

- ❖ The agreement documents for the building owners including the description of this project, the importance of this survey, the objectives and goals of this project, how the information and results would be eventually published, the protection of privacy, and the details regarding information and document sharing (Appendix C);
- ❖ The on-site survey questionnaires for building owners, end users and/or maintenance staff. Questions in the questionnaires include the reasons for installing a GHP system, the capital costs of the building and HVAC systems, if there are operating difficulties, and the satisfaction of the owners and/or end users, as well as the basic building and system information including building type, building floor area, the ages of building and HVAC system, the numbers of heat pump units and boreholes/wells, and service providers (Appendix D and E).
- ❖ A list indicating the detailed building information that needs to be requested from the owners and/or the design companies, including design plans/drawings (architectural, mechanical, electrical, etc.) and/or specifications, the annual utility bills, the maintenance activity log and cost, and the design documents, such as the Owner's Project Requirements (OPR), the Basis Of Design (BOD), the installation and operations manuals, as shown in the Appendix C - Attachment A.

On-site Visit and Investigation

On-site visits and investigations took place right after the building permissions were obtained. Depending on the location of building, each visit and investigation took about 1~2 days. During the building visit, the survey questionnaire was completed, and the detailed information and documents were requested and collected. Particular interests were given to the buildings equipped with Building Automation System (BAS), which provides controls to the building HVAC system, lighting system, etc. with a real-time monitoring on the different building parameters, such as supply air temperature/volume and indoor environment conditions, and detailed information regarding system performance and energy consumption. Instead of using the energy information obtained from utility bills, this detailed real-time information from BAS may allow a deeper analysis on the operational performance of the building HVAC system, and thus contribute to a more comprehensive analysis.

The result of the on-site visit and investigation of each target building is organized and demonstrated in Appendix F.

Computer Simulation

One of the goals of this project is to identify energy and energy cost savings of the existing GHP systems compared to conventional HVAC systems. The information about the actual energy usage of the existing systems was obtained from BAS and/or utility bills provided by building owners. Nevertheless, in order to simulate and estimate the energy consumption of a conventional HVAC system and to determine the energy and energy cost savings between these two systems, a whole building energy simulation was established for each target building as long as the data and information collected for that building are enough for this type of simulation. In this simulation, two models were set up, in which every building parameter is exactly identical except that regarding HVAC systems. As shown in Figure 3.4, Model One has the same system as the existing design, i.e. the GHP system; and Model Two has the conventional HVAC system, defined in the ASHRAE Standard 90.1 – Appendix G (the publication year of the code/standard depends on where the building is located and which corresponding building code is applied). For example, Figure 3.5 shows the conventional systems per the ASHRAE Standard 90.1 – 2007 [16], which are based on the building type and area. Appendix G in the ASHRAE 90.1 Standard describes the Performance Rating Method that is typically used for rating the energy efficiency of building designs that exceed the requirements of this ASHRAE standard.

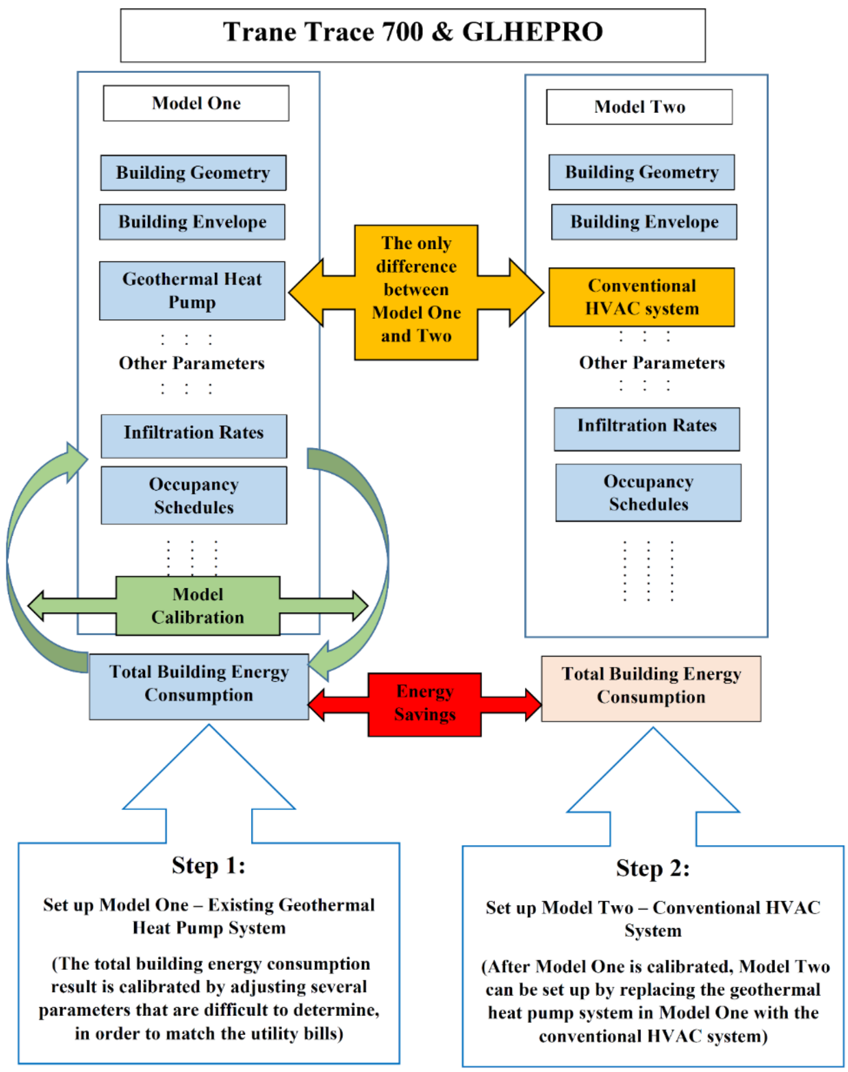

Figure 3.4: Computer simulation procedure

Please note that, this Performance Rating Method was only used to determine the conventional HVAC system based on building type and area. Therefore, in the model with the conventional HVAC system (Model Two), only the mechanical system was changed according to this Performance Rating Method. Other building parameters, such as building wall and roof constructions, lighting power density of each space, etc., were not changed (see Figure 3.4). This is different from using the Performance Rating Method to perform a whole building energy simulation, e.g., for pursuing LEED (Leadership in Energy and Environmental Design) building credits/certification, where the baseline energy simulation model has to be established exactly in compliance with the requirements of this Performance Rating Method, i.e. all building parameters for the baseline model, such as the building construction, interior and exterior light power densities, mechanical systems, etc., should exactly follow this standard, regardless of what the actual design is.

Building Type	**Fossil Fuel, Fossil/Electric Hybrid, and Purchased Heat**	**Electric and Other**
Residential	System 1—PTAC	System 2—PTHP
Nonresidential and 3 Floors or Less and <2300 m^2	System 3—PSZ-AC	System 4—PSZ-HP
Nonresidential and 4 or 5 Floors and <2300 m^2 or 5 Floors or Less and 2300 m^2 to 14,000 m^2	System 5—Packaged VAV with Reheat	System 6—Packaged VAV with PFP Boxes
Nonresidential and More than 5 Floors or >14,000 m^2	System 7—VAV with Reheat	System 8—VAV with PFP Boxes

System No.	**System Type**	**Fan Control**	**Cooling Type**	**Heating Type**
1. PTAC	Packaged terminal air conditioner	Constant volume	Direct expansion	Hot-water fossil fuel boiler
2. PTHP	Packaged terminal heat pump	Constant volume	Direct expansion	Electric heat pump
3. PSZ-AC	Packaged rooftop air conditioner	Constant volume	Direct expansion	Fossil fuel furnace
4. PSZ-HP	Packaged rooftop heat pump	Constant volume	Direct expansion	Electric heat pump
5. Packaged VAV with Reheat	Packaged rooftop VAV with reheat	VAV	Direct expansion	Hot-water fossil fuel boiler
6. Packaged VAV with PFP Boxes	Packaged rooftop VAV with reheat	VAV	Direct expansion	Electric resistance
7. VAV with Reheat	Packaged rooftop VAV with reheat	VAV	Chilled water	Hot-water fossil fuel boiler
8. VAV with PFP Boxes	VAV with reheat	VAV	Chilled water	Electric resistance

Figure 3.5: Conventional HVAC system type and description per ASHRAE Standard 90.1 – 2007 [16]

In order to improve the accuracy and reliability of the simulation, a model calibration was conducted for Model One by adjusting several parameters that are difficult to determine, such as infiltration rates, occupancy schedules, etc., in order to match the simulation results with the actual data obtained from the utility bills and/or BAS, as shown in Figure 3.4. The model calibration result for each target building is shown in Appendix F.

Once these simulation models have been established successfully, the energy and energy cost savings were identified for each target building, and the results are discussed and shown in Chapter 4.

This comparative analysis was accomplished by using the software packages of Trane Trace 700 [17] coupled with GLHEPRO [18]. Trane Trace 700 is a commercial simulation tool for whole building energy analysis and load estimation, in which various HVAC systems can be selected and defined, including heat pump system, chilled beam system, Variable Air Volume (VAV) system, and other typical mechanical systems. GLHEPRO can be used to design and simulate ground loop heat exchangers. The integration of Trane Trace 700 with GLHEPRO allows users to accurately simulate and estimate the energy consumption related to GHP systems.

Data Analysis and Discussion

After the necessary information was collected and the corresponding energy simulation/estimation was done, the results were analyzed in a comparative way between the actual GHP system and a conventional HVAC system in terms of capital and operational costs, as well as annual energy performance. The capital cost information on the existing GHP systems was obtained from the building owners; whereas the capital costs of conventional HVAC systems, if not available, were estimated by using the RS Means Mechanical Cost data [22]. The simple payback period was determined based on the analysis result. Detailed results for each building can be found in Appendix F, which are also discussed in Chapter 4. Additionally, the economical influences of the incentives or tax credits from the government program on the owner's decision of using geothermal systems were included and discussed in the following chapter.

4. Results and Outcomes

Specifically, this final project report includes the case studies of 24 target buildings that are located in North Dakota and equipped with GHP systems. Each case study includes the following aspects:

- Building background including the basic building information;
- System description including a brief description regarding the existing GHP system;
- System performance
- Project cost analysis including the information on system investments and operational expenses, a cost comparative analysis between existing and conventional systems, as well as a simple payback period calculation;
- A basic summary information of each target building, including the parameters of the building and the GHP system, the building cost data, operating difficulties, owner satisfaction, and/or suggestions.

This chapter summarizes the results of these 24 case studies in terms of Building Background, Building Mechanical System Parameters, Building Energy Simulation, Building Cost Analysis, System Trouble Shooting, and Suggestions and/or Recommendations. The detailed description of each case study is demonstrated in the Appendix F.

Building Background

The background information of these 24 target buildings is summarized in Table 4.1, including building area, building construction year, building type, and whether or not the building is LEED certified. As shown in this table, the target buildings have the building areas between 7,500 ft^2 and 279,000 ft^2, with the building construction years with a range from 1917 to 2013. These buildings include 9 college buildings, 6 school buildings, 2 churches, 3 commercial buildings, 2 public buildings, and 2 residential buildings. These target buildings were selected carefully in order to cover most of the typical buildings in North Dakota and to ensure the reliability of the analysis and study as well as its universal applicability. Within these 24 buildings, three of them are LEED certified buildings, including the first LEED Platinum building in North Dakota - University of North Dakota Gorecki Alumni Center. LEED is one of the most popular green building certification programs used worldwide. LEED typically has four levels of certification, i.e. Certified, Silver, Gold, and Platinum. A higher certification level represents a higher achievement in green buildings in terms of sustainability. So far, there are only 18 LEED projects in North Dakota, which are much less than other states, e.g. our neighbor, Minnesota, which has 504 LEED-certified buildings by May, 2017 [23].

Table 4.1 Building Background Summary ("-" means "Not Provided")

NO.	Building	Building Total Area (ft^2)	Building Construction Year	Building Type	LEED Building
1	NDSU Richard H. Barry Hall-New Addition	135,000	2009	College	No
2	National Energy Center of Excellence at Bismarck State College	106,200	2008 2013 for the 4th floor	College	No
3	United Tribes Technical College - Science & Technology Building	32,000	2010-2012	College	No
4	United Tribes Technical College - Wellness Center	19,185	2006	College	No
5	United Tribes Technical College - Dormitory	28,032	2003	College/Dormitory	No
6	NDSU Dickinson Research Center	10,446	2006	College/Office	No
7	NDSU Langdon Learning Center	7,500	2004	College/Office	No
8	University of North Dakota Gorecki Alumni Center	38,000	2012	College	LEED - Platinum
9	Williston State College - Residence Hall	60,841	2011	College/Dormitory	No
10	Discovery Middle School	205,000	1994	School	No
11	Kennedy Elementary School	89,667	2007 2012 for New Addition	School	No
12	Judge Ronald N. Davies High School	279,000	2011	School	No
13	Bennett Elementary School	90,268	1999 2009 for New Addition	School	No
14	Northwood Public School	103,000	2008	School	No
15	Rugby High School	99,000	1956	School	No
16	Zion Lutheran Church	24,000	2006	Church	No
17	St Anthony of Padua	50,000	1917-1932	Church	No
18	Grand Forks Airport International Terminal	53,548	2011	Public/Commercial	LEED - Silver
19	Black Gold Corporate Headquarters	13,445	2012	Office/Commercial	LEED - Gold
20	Cass County Electric Cooperative Building	57,500	2008	Office/Commercial	No
21	Osgood Fire Station 7	12,032	2009	Public/Government	No
22	Lostwood National Wildlife Refuge - Office	-	1992	Public	No
23	Lostwood National Wildlife Refuge - Residence	-	2002	Residential	No
24	Coteau Prairie Residence	-	2003	Residential	No

Table 4.2: Building Mechanical System Summary ("-" means "Not Provided")

NO.	Building	HVAC/GHP Installation Year	Installation Type	GHP system type	Number of Boreholes	Borehole Depth (ft)	Borehole Separation Distance (ft)	Borehole Length (ft)	Underground Pipe Length (ft)	Borehole Length per ton (ft/ton)	Underground Pipe Length per ton (ft/ton)	GHP water flow rate per ton (gpm/ton)	Heat Pump Efficiency Range
1	NDSU Richard H. Barry Hall-New Addition	2009	New for the addition	Vertical closed loop	120	203	15	24,360	48,720	270	540	4.5	Cooling: 16.2 EER Heating: 2.7~3.3 COP
2	National Energy Center of Excellence at Bismarck State College	2008	New	Vertical closed loop	504	200	15 or less	100,800	201,600	-	-	-	-
3	United Tribes Technical College - Science & Technology Building	2010-2012	New	Vertical closed loop	130	300	15	39,000	78,000	361	722	5.4	-
4	United Tribes Technical College - Wellness Center	2006	New	Vertical closed loop	36	200	15	7,200	14,400	154	308	2.8	-
5	United Tribes Technical College - Dormitory	2003	New	Vertical closed loop	70	200	15	14,000	28,000	171	341	3.0	-
6	NDSU Dickinson Research Center	2006	New	Vertical closed loop	30	200	15	6,000	12,000	200	400	3.5	Cooling: 15.7~16.8 EER Heating: 3.2~3.4 COP
7	NDSU Langdon Learning Center	2010 for Upgrade	Retrofit/ Upgrade	Vertical closed loop	26	200	10~15	5,200	10,400	224	449	3.6	Cooling: 16.2 EER Heating: 3.3 COP
8	University of North Dakota Gorecki Alumni Center	2012	New	Vertical closed loop	142	210	15	29,820	59,640	216	433	3.6	Cooling: 15.4~20.1 EER Heating: 3.4~3.5 COP
9	Williston State College - Residence Hall	2011	New	Vertical closed loop	120	300	20	36,000	72,000	235	471	3.1	Cooling: 14~17.7 EER Heating: 3.1~3.9 COP
10	Discovery Middle School	Ground loop and HPs: 1994 73 replacement HPs: 2013	New	Vertical closed loop	688	150	10	103,200	206,400	-	-	-	Old HPs for cooling: 12~15 EER Replacement HPs for cooling: 26~30 EER
11	Kennedy Elementary School	2007 with 50 HPs 2012 for New Addition with 9 new HPs	New	Vertical closed loop	288	150~200	8~12	43,200	86,400	198	395	4.0	Cooling: 13.7~16.4 EER Heating: 3.2~3.9 COP
12	Judge Ronald N. Davies High School	2011	New	Vertical closed loop	928	200	-	185,600	371,200	231	462	2.9	Cooling: 18.5 or less EER Heating: 3.0~6.4 COP
13	Bennett Elementary School	1999 with 54 HPs 2009 for New Addition with 3 new HPs	New	Vertical closed loop	320	150	8~12	48,000	96,000	209	417	3.8	Cooling: 11.6~18.9 EER Heating: 3.3~3.6 COP
14	Northwood Public School	2008	New	Vertical closed loop	384	200	15	76,800	153,600	241	482	3.6	Cooling: 12.7~20.0 EER Heating: 2.7~3.4 COP
15	Rugby High School	2012	Retrofit	Vertical closed loop	72	250	20	18,000	36,000	154	307	2.1	-
16	Zion Lutheran Church	2006	New	Vertical closed loop	48	200	15	9,600	19,200	192	384	3.1	-
17	St Anthony of Padua	2005	Retrofit	Vertical closed loop	100	150	-	15,000	30,000	-	-	-	-
18	Grand Forks Airport International Terminal	2011	New	Horizontally bored closed loop	16	25 and 40	20	500/each Total 8,000	16,000	83	166	2.3	Cooling: 8.9~12.3 EER Heating: 2.6~3.7 COP
19	Black Gold Corporate Headquarters	2012	New	Vertical closed loop	26	200	15	5,200	10,400	141	282	2.4	Cooling: 11.5~15.8 EER Heating: 3.3~4.4 COP
20	Cass County Electric Cooperative Building	2008	New	Vertical closed loop	80	200	15	16,000	32,000	233	466	4.2	Cooling: 8.4~11.8 EER Heating: 2.5~4.2 COP
21	Osgood Fire Station 7	2009	New	Vertical closed loop	18	200	15	3,600	7,200	222	444	3.7	Cooling: 11.5~14 EER Heating: 2.9~3.5 COP
22	Lostwood National Wildlife Refuge - Office	1992	New	-	-	-	-	-	-	-	-	-	-
23	Lostwood National Wildlife Refuge - Residence	2002	New	-	-	-	-	-	-	-	-	-	-
24	Coteau Prairie Residence	2003	New	-	-	-	-	-	-	-	-	-	-

Building Mechanical System Parameters

The mechanical system parameters of these 24 target buildings are summarized in Table 4.2, including HVAC/GHP installation year, installation type (new or retrofit), GHP system type, number of boreholes, borehole depth, borehole separation distance, borehole length, underground pipe length, borehole length per ton, underground pipe length per ton, GHP water flow rate per ton, and heat pump efficiency range.

<u>HVAC/GHP installation year</u>

Most of the investigated GHP systems were installed in the past 20 years. The only systems that were built more than 20 years ago are the ones used in the Discovery Middle School (about 23 years) and the Lostwood National Wildlife Refuge (LNWR) – Office (about 25 years). The Discovery Middle School has started to replace the old heat pump units since 2013, with the replacement heat pump units that have higher cooling efficiencies (26~30 EER) compared to the old ones (12~15 EER). In this system, the original underground loops have been still used for heat rejection and extraction, whose lifespan is usually about 40 ~50 years. The LNWR office building has been using a GHP system to provide heating and cooling for about 25 years, and it is reported by the owner that about 4 years ago (around 2013), the antifreeze solution and pump system went out and needed to be replaced. Other than that, the owner is very satisfied with the current system in terms of noise, cost, and comfort. More details about these two buildings can be found in Appendix F. The average age of these 24 investigated GHP systems is about 11 years old, which is about in the middle of the lifespan of a typical heat pump system. A GHP system with this age is appropriate for this study, since it is not either too old or young and can effectively reflect the operational performance of a typical GHP system.

<u>Installation type</u>

Most of the GHP systems were the original systems for the investigated buildings. The owners of three buildings, i.e. NDSU Langdon Learning Center, Rugby High School, and St. Anthony of Padua, decided to use GHP systems after the failures of their original HVAC systems. The reason for choosing and installing GHP systems in the first place for each target building is summarized in Table 4.3. According to this table, the common reasons are listed below,

- Lower cooling and heating bills;
- Energy efficiency;
- Environmental concerns.

It is not surprising that "lower cooling and heating bills" ranks the first, but the good thing is that some of the building owners are expressing more concerns about energy and environment. These owners, however, are only limited to college or school buildings (non-profit organizations). For commercial buildings, such as the Grand Forks Airport International Terminal, the Black Gold Corporate Headquarters, and the Cass County Electric Cooperative building, reducing the utility bills is still the top concern, which may help them to reduce overhead cost and thus increase profit.

Table 4.3 Reasons for installing GHP systems

NO.	Building	Reason for installing GHP systems
1	NDSU Richard H. Barry Hall-New Addition	I wasn't here at the time, but I believe it was to lower heating/cooling bills and for environmental concerns.
2	National Energy Center of Excellence at Bismarck State College	Not Provided (the building was built about 10 year ago, and the persons involved in this building project were gone.
3	United Tribes Technical College - Science & Technology Building	Energy efficiency
4	United Tribes Technical College - Wellness Center	Energy efficiency
5	United Tribes Technical College - Dormitory	Energy efficiency
6	NDSU Dickinson Research Center	Not Provided
7	NDSU Langdon Learning Center*	• Reduce cooling and heating bills • More environmentally friendly • We were experiencing significant problems with original system
8	University of North Dakota Gorecki Alumni Center	Green product environment concerns
9	Williston State College - Residence Hall	Frontier Hall and its geothermal system were completed prior to my arrival at Williston State College in October of 2014. My first assignment at the college was as the Director for Campus Services/ Facilities, so I am familiar with the building.
10	Discovery Middle School	Green product environment concerns
11	Kennedy Elementary School	Green product environment concerns
12	Judge Ronald N. Davies High School	Green product environment concerns
13	Bennett Elementary School	Green product environment concerns
14	Northwood Public School	Not Provided
15	Rugby High School	Outdated HVAC system. Added cooling to create a better learning environment.
16	Zion Lutheran Church	Design of new building to be more efficient
17	St Anthony of Padua	Lower heating and cooling bills
18	Grand Forks Airport International Terminal	Lower heating and cooling bills (decision and goal from Architect & Airport Authority Board)
19	Black Gold Corporate Headquarters	To aid in obtaining LEED status, and to be seen a good steward of resources in the eyes of our customers, suppliers, and the general public.
20	Cass County Electric Cooperative Building	Efficient heating system with low operating cost
21	Osgood Fire Station 7	Not Provided
22	Lostwood National Wildlife Refuge - Office	Lower heating and cooling bills (long term cost savings)
23	Lostwood National Wildlife Refuge - Residence	Lower heating and cooling bills (long term cost savings)
24	Coteau Prairie Residence	Lower heating and cooling bills (long term cost savings)

GHP system type

Unsurprisingly, most of the investigated GHP systems are vertical closed-loop systems, which are obviously the most common systems used in North Dakota and are the most mature and reliable GHP systems for designers/engineers. A horizontally bored closed-loop system was installed in the Grand Forks Airport International Terminal building. A horizontally bored system is a variant of a conventional horizontal closed-loop system, and can be considered as an intermediate underground heat exchange system between conventional horizontal and vertical closed-loop system. The development of this type of system benefits from a horizontal drilling technique that allows the installation of horizontal heat exchangers in the deeper ground at different layers (usually between 30 and 50 feet), as shown in Figure 4.1. Like a vertical closed-loop system, the horizontal boreholes are typically grouted in order to improve the heat transfer performance. This type of system is less disturbed by outdoor weather compared to conventional horizontal closed-loop systems, and thus may have higher cooling and heating capacities for larger building applications. This airport facility was originally designed to use a vertical closed-loop GHP system (96 boreholes with the depth of about 200 feet) to provide space heating and cooling. This new type of horizontal boreholes, however, was planned for use after realizing the unusual high water table on the field during construction.

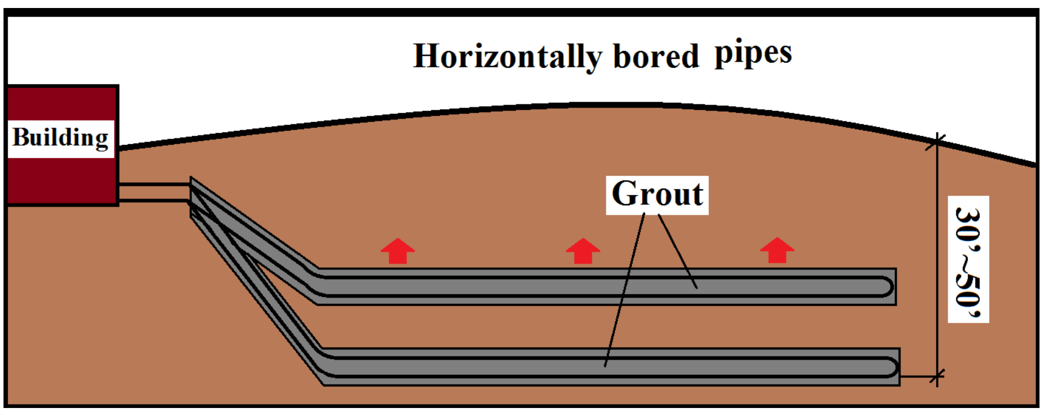

Figure 4.1: Horizontally bored pipes

Number of boreholes

The number of vertical boreholes of these investigated GHP systems varies from 18 to 928. Larger buildings usually require more heating and cooling effects from the ground, and thus need a large number of deeper boreholes. The horizontally bored pipe system has 16 horizontal boreholes that are buried underground with a very long borehole length (500 feet for each) in order to offset the disadvantage of shallower borehole locations underground compared to vertical closed-loop systems.

Borehole depth

Borehole depth is a critical parameter when designing a GHP system. Typically, the thermal behavior of the deeper ground is less disturbed and influenced by outside weather conditions, and therefore the deeper a borehole is, the higher capacity a GHP system can usually reach. The average borehole depth of these 24 investigated GHP systems is about 206 feet, which is common in North Dakota considering the local geologic formation and a relatively high water table. In general, the typical borehole depth for a vertical closed-loop GHP system is between 50 and 450 feet.

<u>Borehole separation distance</u>

The borehole separation distance represents the horizontal distance between two close vertical boreholes. The minimum suggested borehole separation distance is 15 feet. Boreholes that are placed too close to each other may result in the accumulation of building heat in the underground region without effective dissipation. This warm ground issue is known as Ground Temperature Penalty, which is mainly caused by the unbalanced heat extraction and injection from/to the ground, as well as the short distance between boreholes. As shown in Table 4.2, the GHP systems of several investigated buildings have the borehole separation distances less than the minimum requirement, including National Energy Center of Excellence (NECE) at Bismarck State College, NDSU Langdon Learning Center, Kennedy Elementary School, and Bennett Elementary School. Shorter separation distance usually occurred in a building that was designed and built about 20 years ago, when the knowledge and experience regarding GHP system was absent. The underground heat transfer behavior is well-known nowadays, and 15 feet is suggested as the minimum separation distance between boreholes. Among these four buildings above, only the NECE at Bismarck State College was reported by the owner that the ground temperature has been significantly increased by approximately 37^{o}F, since the GHP system was originally installed with the ground temperature of around 50^{o}F. The reason for the increased underground temperature is due to the fact that this facility is south-facing and is covered with a large number of windows, so the cooling degree days are significantly more than the heating degree days (cooling-dominated building). In other words, this building may need cooling instead of heating even during a winter season, due to a large amount of solar gains and/or internal gains because of people, lighting, and equipment. Additionally, the separation distance between boreholes is less than the minimum suggested value for a vertical geothermal system (15 feet). As a result, more heat is conveyed and stored into the wellfield than being removed, which has the effect of increasing the ground temperature over time.

Typically, when building heating and cooling loads are extremely unbalanced, a hybrid system is often used, which may combine the ground loops with a cooling tower/fluid cooler (if for cooling-dominated buildings) or a boiler/solar thermal collectors (if for heating-dominated buildings) in order to offset the impact of excess heat either added or extracted to/from the ground. The main purpose in the use of a hybrid GHP system is to neutralize the underground temperature penalty by using supplemental source(s)/sink(s) in addition to the ground.

A solution to this problem in the NECE building is to use a hybrid GHP system by adding an additional sink element of thermal energy to deal with the unbalanced heat rejection. Therefore, a dry cooler was installed with the GHP system of this NECE building in 2016. This installation allows water being returned to the ground to first be cooled by this dry cooler during the colder months of the year, and thus the cooler water is circulated into the warmer ground to effectively cool it down over time. With this system in place, it is expected by the building owner to take about three years of continual running of the system in the winter months to cool the ground temperature to an appropriate level.

So far, for the other buildings, i.e. NDSU Langdon Learning Center, Kennedy Elementary School, and Bennett Elementary School, there have been no complaints reported by the building owners regarding the operations of their GHP systems, such as warm ground, low heat pump efficiency, or high utility cost. The potential threats of Ground Temperature Penalty, however, still exist, which should get the attention of these building owners/operators.

Borehole length

Borehole length represents the total length of all the boreholes used in a GHP system, which is determined by using the number of boreholes multiplied by the corresponding depth of each borehole. A longer borehole length means a higher capacity of a GHP system for underground heat rejection/extraction. In the meantime, however, it means longer underground pipe length and higher costs for pipe materials and drilling.

Underground pipe length

Each borehole of all the vertical and horizontal GHP systems investigated is configured with a pair of pipes (single U-tube) that are joined by a U-bend at the bottom of the hole. Therefore, the underground pipe length for each system is doubled compared to their borehole lengths.

Borehole length per ton & underground pipe length per ton

The typical borehole length per ton is between 150 and 250 feet/ton, and the corresponding underground pipe length per ton is between 300 and 500 feet/ton, when designing a single U-tube vertical GHP system. The average design values of these two parameters for these investigated GHP systems are 208 and 415 feet/ton respectively, both of which are in the middle range of the suggested values.

GHP water flow rate per ton

The typical design water flow rate in a vertical GHP system is approximately between 2.5 and 3.0 gpm/ton. The average water flow rate per ton of all the investigated systems is 3.4 gpm/ton (a range between 2.1 and 5.4), which is slightly more than the upper level of the typical values. This may indicate the oversizing of the water flow rate in the underground loops in several buildings, e.g. the United Tribes Technical College - Science & Technology building, which has the design gpm/ton of 5.4. The oversizing may result in higher pump energy and unnecessary operational costs.

Heat pump efficiency range

The heat pump efficiency range for each GHP system investigated is shown in Table 4.2. The average cooling efficiency is between 14.2 and 17.3 EER, and the heating efficiency is between 3.0 and 3.9 COP. Considering the average age (11 years) of these 24 investigated GHP systems, these average efficiency values are compared with the minimum efficiencies of the relatively old standard (ANSI/ASHRAE/IES Standard 90.1-2004 [24]), i.e. 13.4 EER for cooling and 3.1 COP for heating. It appears that these average efficiencies of the actual GHP systems all meet the minimum code/standard requirements.

Table 4.4 summarizes the average values of each category mentioned above.

Table 4.4 Average value comparison of mechanical system parameters

	Average	Range	Typical Value
Number of Boreholes for Vertical GHP	197	16~928	Varies
Borehole Depth (ft)	206	25~300	Vertical: 50~450 Horizontally bored: 30~50
Borehole Separation Distance (ft)	16	8~20	15~20
Borehole Length per ton (ft/ton)	208	83~361	150~250
Underground Pipe Length per ton (ft/ton)	415	166~722	300~500
GHP water flow rate per ton (gpm/ton)	3.4	2.1~5.4	2.5~3.0
Heat Pump Efficiency Range	Cooling: 14.2~17.3 EER Heating: 3.0~3.9 COP	Cooling: 8.4~30.0 EER Heating: 2.5~6.4 COP	Mini. Cooling: 13.4 EER* Mini. Heating: 3.1 COP*

* Source: ANSI/ASHRAE/IES Standard 90.1-2004 [24]

Building Energy Simulation

In order to determine the potential energy and energy cost savings between the actual building with a GHP system and a similar building with a conventional HVAC system, an energy simulation model was established for each target building. The principle about how to set up an energy model has already been discussed in Chapter 3. This chapter is only to demonstrate the simulation results of these target buildings.

Please note, the whole building energy simulations were not performed for all the target buildings, since for some of the buildings, the major documents, such as the design plans (architectural, mechanical, electrical, etc.), AutoCAD/Revit drawings, specifications, and/or the actual utility bills, were not available from either the owners or design companies. Without these documents, the detailed knowledge about the buildings would be missing, including building geometry, building envelope information, as well as HVAC system ductwork and design details, which are essential and indispensable to computer energy simulation. In addition, there would be no way to calibrate and validate the simulation model if the actual utility bills or energy usage are not available. Alternatively, the annual building energy consumption can be estimated by using simplified methods, such as degree day method [20], bin method [20], or the online tool of Environmental Protection Agency (EPA)'s Target Finder Calculator [21], in which only basic building information is required, such as building location, total building area, building type, etc. In this project, the online tool of EPA's Target Finder Calculator was used to approximately identify the energy savings between the current GHP system and a conventional air-conditioning system for the buildings without enough documents/information available. Table 4.5 shows which target buildings were simulated following a whole building energy process (indicated as "Detailed") and which were not (indicated as "Simplified"), i.e. using the Target Finder Calculator. This table also shows the energy use and CO_2 gas emissions for each target building, where Site EUI (Energy Use Intensity) represents the amount of heat and electricity consumed by a building as reflected in the utility bills, whereas Source EUI accounts for the total energy use including the Site EUI plus all the delivery and production losses.

Table 4.5: Energy use and CO_2 emissions ("-" means "Not Available")

NO.	Building	Detailed or Simplified Energy Simulation?	Site EUI [kBtu/ft²/yr]			Source EUI [kBtu/ft²/yr]			Greenhouse Gas Emissions (Metric Tons CO2e/yr)		
			Actual GHP System	ASHRAE Conventional System	EPA Similar Building	Actual GHP System	ASHRAE Conventional System	EPA Similar Building	Actual GHP System	ASHRAE Conventional System	EPA Similar Building
1	NDSU Richard H. Barry Hall-New Addition	Detailed	73.9	86.3	117.7	165.0	178.4	262.6	1,305.4	1,397.7	2,077.8
2	National Energy Center of Excellence at Bismarck State College	Simplified	81.0	-	83.6	255.5	-	262.6	1,646.7	-	1,692.1
3	United Tribes Technical College - Science & Technology Building	Detailed	48.3	83.0	85.1	149.0	257.9	262.6	288.9	500.3	509.1
4	United Tribes Technical College - Wellness Center	Simplified	-	-	108.0	-	-	262.6	-	-	298.2
5	United Tribes Technical College - Dormitory	Simplified	-	-	75.9	-	-	235.0	-	-	399.2
6	NDSU Dickinson Research Center	Detailed	49.0	59.4	51.4	153.9	186.4	161.4	97.5	118.1	102.3
7	NDSU Langdon Learning Center	Detailed	78.1	88.7	57.6	245.4	278.6	180.8	111.7	126.8	82.3
8	University of North Dakota Gorecki Alumni Center	Simplified	52.3	-	85.9	159.9	-	262.6	367.9	-	604.1
9	Williston State College - Residence Hall	Simplified	-	-	118.2	-	-	225.2	-	-	786.4
10	Discovery Middle School	Simplified	57.0	-	42.3	167.6	-	125.4	2,073.8	-	1,552.5
11	Kennedy Elementary School	Simplified	41.0	-	45.0	126.3	-	140.1	686.8	-	761.4
12	Judge Ronald N. Davies High School	Simplified	56.0	-	44.0	170.7	-	133.2	2,883.3	-	2,251.0
13	Bennett Elementary School	Simplified	50.0	-	52.0	156.3	-	163.2	855.9	-	894.0
14	Northwood Public School	Simplified	-	-	68.6	-	-	116.7	-	-	677.8
15	Rugby High School	Simplified	43.0	-	46.0	124.8	-	134.1	751.3	-	807.2
16	Zion Lutheran Church	Detailed	30.7	57.4	31.0	84.9	102.5	85.7	122.2	139.8	123.4
17	St Anthony of Padua	Simplified	-	-	51.4	-	-	85.0	-	-	238.4
18	Grand Forks Airport International Terminal	Detailed	87.0	103.3	95.2	255.7	242.6	298.8	825.9	765.9	971.0
19	Black Gold Corporate Headquarters	Detailed	43.4	63.6	63.5	136.3	199.6	199.5	111.2	162.9	162.8
20	Cass County Electric Cooperative Building	Simplified	46.0	-	68.8	143.5	-	216.1	500.5	-	754.0
21	Osgood Fire Station 7	Detailed	69.7	75.6	68.4	168.4	170.7	154.4	119.9	120.5	109.0
22	Lostwood National Wildlife Refuge - Office	-	-	-	-	-	-	-	-	-	-
23	Lostwood National Wildlife Refuge - Residence	-	-	-	-	-	-	-	-	-	-
24	Coteau Prairie Residence	-	-	-	-	-	-	-	-	-	-

The Energy Star Target Finder is EPA's online calculator that helps architects, engineers, and property owners and managers assess the energy performance and track energy costs and carbon emissions of commercial building designs and existing buildings [21]. The Energy Star Target Finder result represents the national median of energy performance of buildings similar to the target ones in the U.S.

The ASHRAE conventional system shown in Table 4.5 for each target building was determined per ASHRAE Standard 90.1 – Appendix G or depending on the actual building situation as shown in Table 4.6. For example, the conventional system for the NDSU Richard H. Barry Hall-New Addition is determined in consideration of using the same system with the existing building (Part One in Figure F.1.2 in Appendix F). For the NDSU Langdon Learning Center, the conventional system is based on the previous air-conditioning system used in that facility before 2010.

Table 4.6: Conventional systems used in whole building energy simulations ("-" means "Not Available")

NO.	Building	Conventional System
1	NDSU Richard H. Barry Hall-New Addition	Four-pipe fan coil system with chilled water chiller cooling and hot water fossil fuel boiler heating
2	National Energy Center of Excellence at Bismarck State College	-
3	United Tribes Technical College - Science & Technology Building	Packaged rooftop VAV with PFP boxes with direct expansion (DX) cooling and electric heating
4	United Tribes Technical College - Wellness Center	-
5	United Tribes Technical College - Dormitory	-
6	NDSU Dickinson Research Center	Packaged rooftop heat pump with constant volume fan control, direct expansion (DX) cooling and electric heat pump heating.
7	NDSU Langdon Learning Center	Air-Cooled Condensing Units with Electric Heat
8	University of North Dakota Gorecki Alumni Center	-
9	Williston State College - Residence Hall	-
10	Discovery Middle School	-
11	Kennedy Elementary School	-
12	Judge Ronald N. Davies High School	-
13	Bennett Elementary School	-
14	Northwood Public School	-
15	Rugby High School	-
16	Zion Lutheran Church	Packaged rooftop air conditioner with constant volume fan control, direct expansion (DX) cooling and fossil fuel furnace heating
17	St Anthony of Padua	-
18	Grand Forks Airport International Terminal	Packaged rooftop air conditioner with constant volume fan control, direct expansion (DX) cooling and fossil fuel furnace heating.
19	Black Gold Corporate Headquarters	Packaged rooftop heat pump with constant volume fan control, direct expansion (DX) cooling and electric heat pump heating
20	Cass County Electric Cooperative Building	-
21	Osgood Fire Station 7	Packaged rooftop air conditioner with constant volume fan control, direct expansion (DX) cooling and fossil fuel furnace heating.
22	Lostwood National Wildlife Refuge - Office	-
23	Lostwood National Wildlife Refuge - Residence	-
24	Coteau Prairie Residence	-

Table 4.7: Energy and energy cost savings ("-" means "Not Available")

NO.	Building	Energy Cost [$/yr]			Energy Cost Density [$/ft^2/yr]			Energy Savings Compared to Conventional System	Energy Savings Compared to Similar Buildings (EPA)	Energy Cost Savings Compared to Conventional System	Energy Cost Savings Compared to Similar Buildings (EPA)
		Actual GHP System	ASHRAE Conventional System	EPA Similar Building	Actual GHP System	ASHRAE Conventional System	EPA Similar Building				
1	NDSU Richard H. Barry Hall-New Addition	$165,977.7	$173,967.0	$264,029.3	$1.23	$1.29	$1.96	14%	37%	5%	37%
2	National Energy Center of Excellence at Bismarck State College	$200,315.7	-	$205,842.4	$1.89	-	$1.94	-	3%	-	3%
3	United Tribes Technical College - Science & Technology Building	$36,166.0	$62,163.0	$63,723.4	$1.13	$1.94	$1.99	42%	43%	42%	43%
4	United Tribes Technical College - Wellness Center	-	-	-	-	-	-	-	-	-	-
5	United Tribes Technical College - Dormitory	-	-	-	-	-	-	-	-	-	-
6	NDSU Dickinson Research Center	$12,539.7	$15,370.0	$13,216.3	$1.20	$1.47	$1.27	17%	5%	18%	5%
7	NDSU Langdon Learning Center	$11,698.9	$12,691.0	$8,693.1	$1.56	$1.69	$1.16	12%	-36%	8%	-35%
8	University of North Dakota Gorecki Alumni Center	-	-	-	-	-	-	-	39%	-	-
9	Williston State College - Residence Hall	-	-	$104,850.0	-	-	$1.72	-	-	-	-
10	Discovery Middle School	$210,700.3	-	$157,737.1	$1.03	-	$0.77	-	-34%	-	-34%
11	Kennedy Elementary School	$78,915.7	-	$88,455.9	$0.88	-	$0.99	-	10%	-	11%
12	Judge Ronald N. Davies High School	$346,731.0	-	$270,626.0	$1.24	-	$0.97	-	-28%	-	-28%
13	Bennett Elementary School	$95,211.0	-	$99,449.7	$1.05	-	$1.10	-	4%	-	4%
14	Northwood Public School	-	-	$91,141.0	-	-	$0.88	-	-	-	-
15	Rugby High School	$80,308.6	-	$86,272.3	$0.81	-	$0.87	-	7%	-	7%
16	Zion Lutheran Church	$18,916.9	$19,335.0	$19,100.3	$0.79	$0.81	$0.80	46%	1%	2%	1%
17	St Anthony of Padua	$32,739.0	-	$32,129.0	$0.65	-	$0.64	-	-	-	-2%
18	Grand Forks Airport International Terminal	$110,331.8	$98,574.0	$129,801.0	$2.06	$1.84	$2.42	16%	-	-12%	-
19	Black Gold Corporate Headquarters	$17,945.6	$26,293.0	$26,269.7	$1.33	$1.96	$1.95	32%	32%	32%	32%
20	Cass County Electric Cooperative Building	$68,983.0	-	$103,917.0	$1.20	-	$1.81	-	34%	-	34%
21	Osgood Fire Station 7	$15,832.1	$15,827.0	$14,315.0	$1.32	$1.32	$1.19	8%	-2%	0%	-11%
22	Lostwood National Wildlife Refuge - Office	-	-	-	-	-	-	-	-	-	-
23	Lostwood National Wildlife Refuge - Residence	-	-	-	-	-	-	-	-	-	-
24	Coteau Prairie Residence	-	-	-	-	-	-	-	-	-	-

The corresponding energy and energy cost savings are summarized in Table 4.7 and 4.8. As shown in these tables, the average energy cost density of these 24 target buildings is about $1.21/ft^2/yr, which is lower than the energy cost densities of the buildings equipped with conventional HVAC systems ($1.51/ft^2/yr) or the EPA similar buildings ($1.36/ft^2/yr). Compared to conventional systems, the average energy savings of 23% is achieved, due to the use of high-performance GHP systems. The energy cost savings (12%), however, is not as high as the identified energy savings. For example, the energy savings for NDSU Richard H. Barry Hall-New Addition is about 14%, but the energy cost savings is only 5%. For the building of Zion Lutheran Church, 46% energy savings is achieved, but it only has the energy cost savings of about 2%. The same conclusion can be drawn for the buildings of the Grand Forks Airport International Terminal and the Osgood Fire Station 7.

The difference between these two savings is mainly caused by the extremely low utility rate for natural gas compared to electricity. The average natural gas price for the year of 2016 in North Dakota is $0.526 per therm, while the average price for electricity is 8.96 cents per kWh [25]. To compare these two utility prices, the $0.526 per therm for natural gas was converted to the same energy unit for electricity, which is equivalent to about 0.18 cents per kWh. This is about 50 times less than the electricity price.

Table 4.8 Average value comparison of energy and energy cost savings

	Average	Range
Energy Cost Density - Actual GHP System [$/ft^2/yr]	1.21	0.65~2.06
Energy Cost Density - ASHRAE Conventional System [$/ft^2/yr]	1.54	0.81~1.96
Energy Cost Density - EPA Similar Building [$/ft^2/yr]	1.36	0.64~2.42
Energy Savings Compared to Conventional System	23%	8%~46%
Energy Savings Compared to Similar Buildings (EPA)	8%	-36%~43%
Energy Cost Savings Compared to Conventional System	12%	-36%~43%
Energy Cost Savings Compared to Similar Buildings (EPA)	5%	-35%~43%

As shown in Table 4.6, many of the conventional air-conditioning systems primarily use natural gas (boilers or furnaces) to provide heating effect, while the actual geothermal systems use electricity (heat pumps). Although the high-efficiency heat pump systems can achieve high energy savings due to the high COPs, the energy cost savings is reduced significantly when taking the actual utility rates into account. According to what we found before from Table 4.3, "lower cooling and heating bills" is typically the main reason for many of the building owners to decide to use GHP systems in the first place. However, the low energy cost savings, due to the extremely low natural gas rate in North Dakota, may cause the loss of attraction of building owners/developers to GHP systems. They would rather consider to use conventional air-conditioning systems that usually have low capital costs but consume more energy and fossil fuels, which will be against the original intention of the state or local governments about energy efficiency and environmental protection, e.g. the purpose of the State Energy Program (SEP) in North Dakota.

Compared to the national median (EPA results), the overall performance of the actual GHP systems used in North Dakota is slightly better, i.e. about 8% energy savings and 5% energy cost savings on average. As shown in Table 4.7, although some of the buildings demonstrate energy and energy cost savings when comparing to conventional systems, reduced savings or even no savings are found when comparing them with EPA similar buildings (the national median). These buildings include NDSU Dickinson Research Center, NDSU Langdon Learning Center, Zion Lutheran Church, and Osgood Fire Station 7. For these buildings, the advantage of using GHP systems is not fully apparent, which could be caused by the inappropriate design or control strategy, defective parts, lack of maintenance, etc. This report will be shared with the owners of these 24 buildings. The potential issues of their GHP systems will be discussed with them, along with solutions or suggestions.

Building Cost Analysis

Table 4.9 indicates building cost information, including capital building cost, total cost of HVAC system, annual repair and maintenance cost, incentives from governments or utility companies, as well as simple payback period. As shown in this table, most of the investigated buildings did not receive any incentives from governments or local utility companies for the installation and use of GHP systems. Additionally, the estimated simple payback period (the use of the current GHP system against conventional air-conditioning system) is long, which is between 9 and 20 years or even goes to infinity (for buildings where there is no energy cost savings identified compared to corresponding conventional systems). Please note, simple payback periods were not estimated for all the target buildings because of the lack of necessary information for some of the buildings, such as the actual HVAC costs, the actual energy use and utility bills, etc. The results of simple payback period are typically affected by many factors, such as system initial cost, operational cost, the type of conventional system and its associated costs for installation and operation. In this study, most of the conventional systems used in the building cost analysis were determined based on ASHRAE Standard 90.1 – Appendix G. The results of simple payback period would be changed if another type of conventional system is applied. All the details regarding the cost analysis for each building can be found in Appendix F.

Through the building cost analysis, it appears that the financial support either from governments or utility companies, or both, may improve the cost effectiveness of using GHP systems, and may encourage the installation of GHP systems and contribute to making use of geothermal energy in North Dakota. Take the building of Black Gold Corporate Headquarters as an example, if tax credits are assumed to be obtained from the state with 3% of the cost of the device, each year for five years, the simple payback period would be approximately reduced from 9.3 to 5.1 years, which may significantly increase the competitiveness of GHP systems and encourage the use of this type system in our state.

System Trouble Shooting

In the survey questionnaires (Appendix D), the respondents were asked to answer these three questions:

1. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?
2. As you know, are there any operating difficulties of the geothermal heat pump system?
3. Would you like to suggest geothermal heat pump systems to others, like your friends?

Table 4.10 shows the result of these survey questions.

Table 4.9: Building cost comparison and analysis ("-" means "Not Available" or "Not Provided" or "Unknown")

NO.	Building	Capital Cost of the Building ($)	Total Cost of the HVAC System ($)	HVAC System Average Annual Repair and Maintenance Cost ($)	Government Incentives for the Use of GHP	Utility Incentives for the Use of GHP	Simple Payback Period Compared to Conventional Systems (Years)
1	NDSU Richard H. Barry Hall-New Addition	$13,000,000	$2,600,000	$20,000	No	No	19.5
2	National Energy Center of Excellence at Bismarck State College	$18,500,000	$3,000,000	-	-	-	Less than 10.0
3	United Tribes Technical College - Science & Technology Building	-	-	-	-	-	-
4	United Tribes Technical College - Wellness Center	-	-	-	-	-	-
5	United Tribes Technical College - Dormitory	-	-	-	-	-	-
6	NDSU Dickinson Research Center	$1,200,000	-	-	-	-	-
7	NDSU Langdon Learning Center	$810,000	$144,000	-	No	No	20.5
8	University of North Dakota Gorecki Alumni Center	$12,000,000	-	-	No	No	-
9	Williston State College - Residence Hall	$8,188,158	-	$46,800 for maintenance person	-	-	-
10	Discovery Middle School	$12,890,949	-	$100,000 for upgrade	-	-	-
11	Kennedy Elementary School	$10,663,790.23 for 2007 $1,540,832.94 for 2012 (additional)	-	$10,000	-	-	-
12	Judge Ronald N. Davies High School	$47,473,177	-	$20,000	No	Yes	-
13	Bennett Elementary School	$7,199,212.45 for 1999 $796,650.79 for 2009 (additional)	-	$10,000	-	-	-
14	Northwood Public School	$14,000,000	$2,140,627	-	Yes - $50,000	-	-
15	Rugby High School	$8,000,000	$1,214,500	$10,000	No	No	-
16	Zion Lutheran Church	-	-	-	-	-	-
17	St Anthony of Padua	-	$546,000	$3,000	-	-	-
18	Grand Forks Airport International Terminal	$25,000,000	$1,200,000	$4,600	No	No	Inf. (no energy cost savings)
19	Black Gold Corporate Headquarters	$2,973,000	$400,000	$700	No	No	9.3
20	Cass County Electric Cooperative Building	-	-	$8,000	No	No	-
21	Osgood Fire Station 7	$2,500,000	$430,000	-	No	-	Inf. (no energy cost savings)
22	Lostwood National Wildlife Refuge - Office	$360,000	-	$150	No	$2000 grant for the system purchase	-
23	Lostwood National Wildlife Refuge - Residence	$400,000	-	$100	No	No	-
24	Coteau Prairie Residence	$400,000	-	$100	No	No	-

Table 4.10: Survey results

NO.	Building	Any Complaints in terms of noise, cost, comfort, etc.	Any Operating Difficulties	Suggest GHP to others
1	NDSU Richard H. Barry Hall-New Addition	No big complaints.	At times, the ground warms up during cooling, but it hasn't caused any issues.	Yes, if they have incentives to help with the install costs.
2	National Energy Center of Excellence at Bismarck State College	Some of heat pumps are fighting each other when they are serving to a large open space. This caused the waste of energy and discomfort, due to the simultaneous heating and cooling. It is also reported that there is one individual office space, where three systems and thermostats are used. This mixed use of system in an individual space caused a large amount of energy waste and discomfort reported by the end users.	A dry cooler was installed in 2016 to back charge the warm ground. In the about 10 years of operation, the ground temperature has been increased by approximately 37F (up to 87 F), due to the unbalanced heating and cooling loads.	Not Provided
3	United Tribes Technical College - Science & Technology Building	Not Provided	Not Provided	Yes
4	United Tribes Technical College - Wellness Center	Not Provided	Not Provided	Yes
5	United Tribes Technical College - Dormitory	Had some room temperature issues (one room is about 65F and another nearby room is about 85F) due to the fact that one heat pump unit is typically tie to two thermostats for two or three individual rooms, while an average feedback temperature between these two thermostats is used to control the operation of the heat pump	Several fan motors and compressors went out after operating for 12 years	Yes
6	NDSU Dickinson Research Center	Not Provided	Not Provided	Not Provided
7	NDSU Langdon Learning Center	No	No	Yes
8	University of North Dakota Gorecki Alumni Center	No complaints.	No	Yes, if they can afford it.
9	Williston State College - Residence Hall	Not Provided	We have not had issue with the geothermal system, although the air handlers have been problematic. Frontier Hall's HVAC system is controlled by Johnson Control's Metasys System which Aaron Shapiro, our Assistant Director of Campus Services has been trained to utilize.	Not Provided
10	Discovery Middle School	Heat pump replacement costs are expensive	1. When heat pumps are out, there is no heating in rooms. So we must supplement electric units. 2. Heat pump sized for heating, but typically it is too big for cooling (overcooling).	Yes
11	Kennedy Elementary School	Not Provided	Not Provided	Yes
12	Judge Ronald N. Davies High School	Not Provided	Not Provided	Yes

13	Bennett Elementary School	Not Provided	Not Provided	Yes
14	Northwood Public School	We are very satisfied with the comfort and noise levels.	Yes, we experienced a lightning strike that grounded throughout geothermal equipment in 2010. The problems caused by the lightning strike: > Several heat pump units were broken > Pump seals were broken and caused leaking > Failure of pumps (we believe the system was over designed and built with more than enough circulating water flow rate)	Maybe.
15	Rugby High School	No complaints.	It is working well.	Yes
16	Zion Lutheran Church	We are satisfied. Slow to respond due to nature of the system.	Costly to repair when a pump goes out.	Yes
17	St Anthony of Padua	Satisfied No complaints	No	Yes
18	Grand Forks Airport International Terminal	Satisfied except electrical costs. No complaints from users.	No	Possibly
19	Black Gold Corporate Headquarters	There are some comfort issues that can be discussed.	Aside from the start-up season and learning curve issues, there have been no difficulties other than nuisance items. The caveat to be made is the system has been in operation only five years, and we have not experienced a colder than average winter.	Yes, with reservations.
20	Cass County Electric Cooperative Building	No complaints.	No difficulties that I am aware of.	Depending on the application and scale of the project and what other heating systems are available. Geothermal can be a great choice in the right scenario.
21	Osgood Fire Station 7	Not Provided	Not Provided	Not Provided
22	Lostwood National Wildlife Refuge - Office	Very satisfied.	About 4 years ago, the antifreeze solution and pump system needed to be replaced. It was an old type of fluid that was very corrosive. Old fluid was pumped out of the system and disposed of by Safety Kleen. A new pump system was installed and filled with new, non-corrosive antifreeze. Been working like a charm ever since. Total cost of repair was about $2,600.	Yes, if they can afford the initial cost of installation and will be using the system for the long term.
23	Lostwood National Wildlife Refuge - Residence	Very satisfied.	About 3 years ago, the antifreeze solution and pump system needed to be replaced. It was an old type of fluid that was very corrosive. Old fluid was pumped out of the system and disposed of by Safety Kleen. A new pump system was installed and filled with new, non-corrosive antifreeze. Total cost of repair was about $2,900.	Yes, if they can afford the initial cost of installation and will be using the system for the long term.
24	Coteau Prairie Residence	Very satisfied.	No	Yes, if they can afford the initial cost of installation and will be using the system for the long term.

As shown in Table 4.10, 75% of the respondents who answered the first question (Figure 4.2) are very satisfied with their GHP systems in terms of noise, cost, and indoor comfort. About 71% of the investigated GHP systems (according to the total respondents who answered the second question) have not had serious operating difficulties (Figure 4.3), and 85% of the respondents who answered the third question would like to suggest this type of system to other people (Figure 4.4).

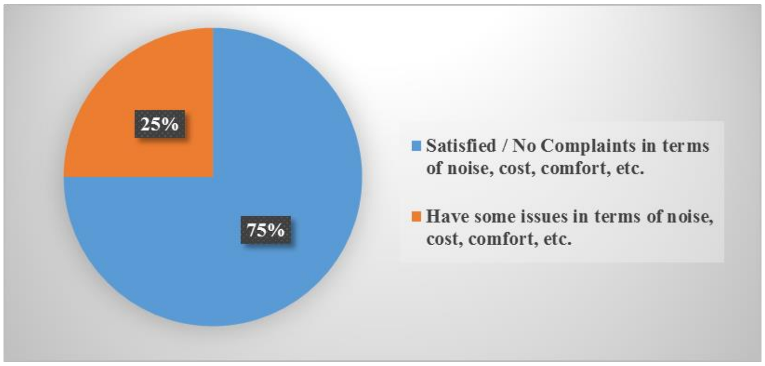

Figure 4.2: Survey result for noise, cost and comfort

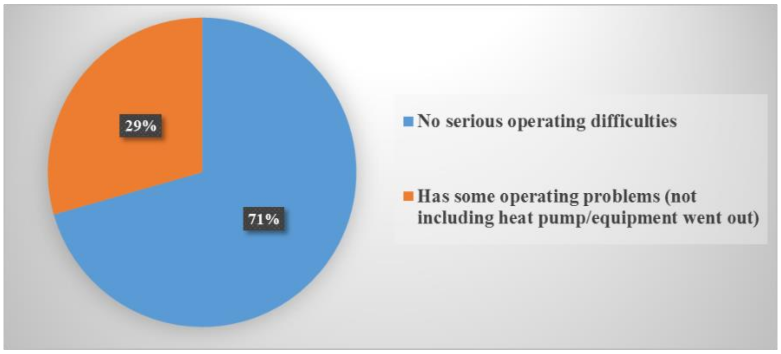

Figure 4.3: Survey result for operating difficulties

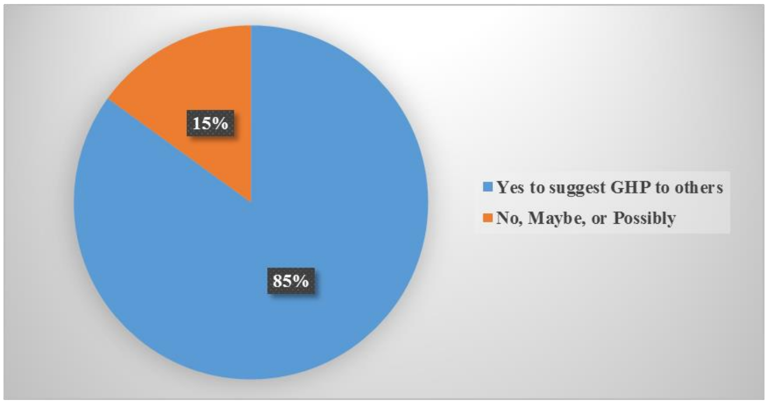

Figure 4.4: Survey result for suggesting GHP to others

Issues were also pointed out by the building owners regarding their systems. For example, for the National Energy Center of Excellence (NECE) at Bismarck State College, the simultaneous heating and cooling exists in a large open space that is usually conditioned by multiple heat pump units, each of which typically has its own thermostat. Due to the inappropriate design, control, and thermostat locations, some of the heat pumps are fighting each other by providing warm and cold air to a space at the same time, which definitely causes the waste of energy and discomfort. It is also reported that in the NECE building there is one individual office space (Figure F.2.5), where three systems with three thermostats are used. This mixed use of systems in an individual space caused a large amount of energy waste and discomfort reported by the end users. Additionally, at the beginning of 2016, a proposal was prepared by a staff of NECE to request about $225,000 to install an auxiliary dry cooler in order to solve the problem regarding the warm underground and low cooling capacity and performance of the geothermal system. At the time the wellfield was drilled, the ground temperature was about 50 F. In the about 10 years of operation, the ground temperature has been increased by approximately 37 F (up to 87 F). This puts extreme stress on the heat pumps and results in inefficient operation, or even may cause the failures or complete shut-down of the GHP system.

For the Dormitory of the United Tribes Technical College, according to the original design (Figure F.5.2), two or more rooms are served by one heat pump unit that is typically connected to two thermostats located in two different rooms. An average temperature (guessed by the owner) between these two thermostats is regarded as the feedback temperature for the heat pump unit, which could cause comfort issues. For example, one room has the temperature of 60F and the other has 85F, which give a desirable feedback temperature (around 72F), so the heat pump would be turned off automatically, but the indoor temperatures for these two rooms are not at a comfort level.

For the Northwood Public School, this building experienced a lightning strike in 2010, which nearly destroyed the entire electrical system. According to the building owner, the problems for the mechanical system after the lightning strike may include

- pump seals were broken which caused leaking issues;
- the failure of water pumps;
- several heat pump units were damaged and had to be replaced.

Additionally, the owner believes that the building water circulation system in the heat pump loop was oversized with more-than-enough water flow rates, which could be the reason that caused the failure of water pumps. Other problems and impacts of the lightning strike on the GHP system are unknown, and a further in-depth investigation is needed in the future.

For the Black Gold Corporate Headquarters, the issues reported by the operation specialist of this building are shown below.

- It was difficult for the geothermal system to initially start up during the first winter in 2012, due to the absence of a backup heating system and that the underground region had not absorbed enough building heat during the summer period, which thus is too cold and not ready to provide enough heat. So it is reported that temporary auxiliary heating devices were used to heat up the entire building during that winter.
- The location of one return grill of a heat pump unit is not appropriately designed, which results in the ice formation on the cooling coil of that heat pump unit due to the much less return air flow going through that coil.

For the Lostwood National Wildlife Refuge office and residence buildings, the old type of antifreeze was corrosive, which was replaced with a type of non-corrosive antifreeze several years ago.

Several key points from Table 4.10 are listed below.

- High initial costs of GHP system and whether it is affordable for building owners.
- Warm ground issues for GHP systems due to the unbalanced heating and cooling loads and inappropriate underground loop design.
- Inappropriate thermostat control strategies may cause discomfort.
- Simultaneous heating and cooling may exist in a large open space that is served by two or more heat pump units with more than one thermostat.
- In North Dakota, heat pump units are sized based on heating load due to a cold winter, which may cause the oversizing for cooling coil and overcooling.
- Heat pump replacement costs are expensive.
- Slow response of the GHP to the change of building cooling/heating loads.
- The difficulties for the geothermal system to initially start up during the first winter, due to the absence of a backup heating system and that the underground region had not absorbed enough building heat during the summer period.
- Antifreeze used in old heat pump systems might be corrosive, which may cause environmental issues.
- GHP systems are not appropriate for all the buildings in North Dakota. It depends on the application and scale of the project and what other heating systems are available. Geothermal energy can be a great choice in the right scenario.
- Incentives can help to reduce the high installation costs of GHP systems.
- Supplemental/backup heating for GHP systems seems necessary in North Dakota.

Suggestions and/or Recommendations

As one of the goals of this project, suggestions and/or recommendations for each target building will be given to the corresponding building owners in order to help them to identify and solve operating difficulties and eventually improve their satisfaction. These suggestions and/or recommendations are summarized in Table 4.11 below.

Table 4.11: Suggestions and/or recommendations for each target building

NO.	Building	Suggestions and/or Recommendations
1	NDSU Richard H. Barry Hall-New Addition	• An unusual natural gas usage for heating during summer was noticed through the whole building energy simulation, which will be reported to the building owner and help them to identify the problem. • Energy and energy cost savings are relatively low for this building with a GHP system. • Several heat pump units may need to be replaced, which are more than 10 years ago.
2	National Energy Center of Excellence at Bismarck State College	• No significant issues were identified. Energy use and energy cost are good considering the use of a dry cooler, even though only 3% of energy and energy cost savings are achieved, compared to a similar building based on the EPA's Energy Star Target Finder result for a national median property. • Borehole separation distance is shorter than the minimum requirement of 15 feet. • Several heat pump units may need to be replaced, which are more than 10 years ago.
3	United Tribes Technical College - Science & Technology Building	• Relatively new building, and no significant issues. • The design gpm/ton of 5.4 is high, which may result in higher pump energy and unnecessary operational costs.
4	United Tribes Technical College - Wellness Center	• No significant issues. • Suggest to install a sub-meter for this facility. • Several heat pump units may need to be replaced, which are more than 10 years ago. • Information provided is limited (more building information is needed to identify other problems if any)

5	United Tribes Technical College - Dormitory	• No significant issues. • Suggest to install a sub-meter for this building. • Several heat pump units may need to be replaced, which are more than 10 years ago. • Information provided is limited (more building information is needed to identify other problems if any)
6	NDSU Dickinson Research Center	• No significant issues. • Several heat pump units may need to be replaced, which are more than 10 years ago.
7	NDSU Langdon Learning Center*	• Borehole separation distance is shorter than the minimum requirement of 15 feet. • Energy and energy cost savings are relatively low for the building with a GHP system. • The control of the electric floor radiation panel needs to be optimized. • Further in-depth investigation is needed.
8	University of North Dakota Gorecki Alumni Center	Relatively new building, and no significant issues.
9	Williston State College - Residence Hall	• No significant issues. • Information provided is limited (more building information is needed to identify other problems if any)
10	Discovery Middle School	• Old heat pump units have been used for more than 20 years. It is suggested to replace all the old heat pump units with new ones that have higher efficiencies. • Borehole separation distance is shorter than the minimum requirement of 15 feet, which might cause the warm ground issue in the future. • No energy and energy cost savings were identified compared to the EPA's Energy Star Target Finder result for a national median property. • Further in-depth investigation is needed.
11	Kennedy Elementary School	• Several heat pump units may need to be replaced, which are more than 10 years ago. • Borehole separation distance is shorter than the minimum requirement of 15 feet, which might cause the warm ground issue in the future.
12	Judge Ronald N. Davies High School	• No energy and energy cost savings were identified compared to the EPA's Energy Star Target Finder result for a national median property. • Further in-depth investigation is needed.
13	Bennett Elementary School	• Energy and energy cost savings were low for the building with a GHP system, compared to the EPA's Energy Star Target Finder result for a national median property. • Further in-depth investigation is needed.
14	Northwood Public School	The building was hit by a lightning strike. The GHP system needs to be monitored continuously in order to avoid the potential threats to the system, caused by the lightning strike.
15	Rugby High School	Relatively new system, and no significant issues.
16	Zion Lutheran Church	• High energy savings but low energy cost savings compared to a conventional system, due to the extremely low natural gas price. • Several heat pump units may need to be replaced, which are more than 10 years ago.
17	St Anthony of Padua	• No significant issues. • Information provided is limited (more building information is needed to identify other problems if any)
18	Grand Forks Airport International Terminal	• The efficiency of the heat pumps used for space cooling is low (up to 12.3 EER), compared to the minimum EER of 13.4 per the corresponding code/standard. • No potential energy cost savings identified, compared to a conventional system, due to the extremely low natural gas price.
19	Black Gold Corporate Headquarters	• No significant issues. • High identified energy and energy cost savings.
20	Cass County Electric Cooperative Building	The efficiency of the heat pumps used for space cooling is low (up to 11.8 EER), compared to the minimum EER of 13.4 per the corresponding code/standard.
21	Osgood Fire Station 7	• Energy and energy cost savings are relatively low for the building with a GHP system. • Further investigation is needed in order to achieve more energy and energy cost savings.
22	Lostwood National Wildlife Refuge - Office	• Old heat pump units have been used for more than 20 years. It is suggested to replace all the old heat pump units with new ones that have higher efficiencies. • Information provided is limited (more building information is needed to identify other problems if any)
23	Lostwood National Wildlife Refuge - Residence	• Several heat pump units may need to be replaced, which are more than 10 years ago. • Information provided is limited (more building information is needed to identify other problems if any)
24	Coteau Prairie Residence	• Several heat pump units may need to be replaced, which are more than 10 years ago. • Information provided is limited (more building information is needed to identify other problems if any)

5. Conclusions

By using geothermal energy, GHP systems have a large potential for building energy savings and CO_2 emissions reduction. Therefore, incentives or tax credits have been provided by governments or local utility companies to support the usage of geothermal energy. However, many factors determine the performance of GHP systems, such as control strategy, part/full-load efficiency, the age of system, and whether or not regular maintenance services are provided. Any of these factors could have significant impacts on the normal operation of GHP systems and the achievement of expected energy and energy cost savings. The objectives of this project are to study and evaluate the operational performance of the existing GHP systems currently used in buildings located in North Dakota. Major emphasis is given to the reasons for installing geothermal systems, the data on capital costs and annual energy performance, the discussions of operating difficulties with the systems, as well as owner satisfaction to date. The results of this project can 1) be regarded as a reference and used by the state to review its incentive or tax credit program for the geothermal application and then adjust or revise it if necessary; 2) help owners to identify and solve operating difficulties, improve their buildings' performance and their satisfaction; and 3) be used as a reference by building designers/contractors in North Dakota for GHP applications in order to establish the confidence of design teams and the acceptance of potential end users.

In this study, onsite surveys and investigations, as well as computer simulations of 24 target buildings were carried out. These investigated buildings located in North Dakota include 9 college buildings, 6 school buildings, 2 churches, 3 commercial buildings, 2 public buildings, and 2 residential buildings. Within these 24 buildings, three of them are LEED certified buildings, including the first LEED Platinum building in North Dakota - University of North Dakota Gorecki Alumni Center, the Grand Forks Airport International Terminal, and the Black Gold Corporate Headquarters.

The conclusions of this study are listed below.

- Currently, one of the biggest barriers to the wide application of GHP system in North Dakota is the high capital and/or replacement costs. How to reduce capital costs and improve cost effectiveness of installing and using this type of system are the keys. Financial support from local governments and/or utility companies would give a much needed shot in the arm to the popularity of GHP system in North Dakota.
- The major reasons for installing geothermal systems include "lower cooling and heating bills", "energy efficiency", and "environmental concerns". Although some of the building owners are expressing more concerns about energy and environment, instead of "Money", these building owners are only limited to non-profit organizations, such as colleges or schools. "Lower cooling and heating bills" is still the top concern for commercial buildings.
- For these 24 buildings, 75% of the building owners are very satisfied with their GHP systems in terms of noise, cost, and indoor comfort; about 71% of the investigated GHP systems have not had serious operating difficulties; and more than 85% of the respondents would like to suggest this type of system to other people. These survey results indicate the reliability and applicability of GHP systems in North Dakota as well as the potential for a broader statewide application.

- On average, the energy savings of these 24 buildings is about 23%, compared to conventional HVAC systems, which is a reasonable number for buildings equipped with GHP systems. The corresponding energy cost savings, however, is relatively low (12%), due to the extremely low natural gas price in North Dakota. The low energy cost savings may cause the loss of attraction of building owners/developers to GHP systems, who would rather consider to use conventional air-conditioning systems that usually have low capital costs but consume more energy and fossil fuels, which will be against the original intention of the state or local governments about energy efficiency and environmental protection, e.g. the purpose of the State Energy Program (SEP) in North Dakota.
- Compared to the national median (energy use and energy cost of similar buildings nationwide), the overall performance of the actual GHP systems used in North Dakota is slightly better, i.e. about 8% energy savings and 5% energy cost savings on average.
- The estimated simple payback period (the use of the current GHP system against conventional air-conditioning system) is long, which is between 9 and 20 years or even goes to infinity (for buildings where there is no energy cost savings identified compared to conventional systems). Additionally, according to the feedback from the building owners/end users, most of the investigated buildings did not receive any incentives for the installation and use of GHP systems. Therefore, the financial support either from governments or utility companies, or both, may improve the cost effectiveness of using GHP systems, and may encourage the installation of GHP systems and contribute to making use of geothermal energy.
- On average, the design water flow rates per ton (3.4 gpm/ton with a range between 2.1 and 5.4) for the ground loops of the investigated GHP systems are slightly more than the upper level of the typical values (2.5~3.0 gpm/ton). This may indicate the oversizing of water flow rate in ground loops, which may result in higher pump power and increased operational costs.
- Several investigated GHP systems have shorter borehole separation distances than the suggested minimum of 15 feet. One of these investigated systems (National Energy Center of Excellence at Bismarck State College) had already encountered a serious operating issue, i.e. high return water temperatures (warm ground) and low cooling capacities. Some of the other buildings, such as NDSU Richard H. Barry Hall-New Addition, have detected warm return water temperatures, which, however, haven't caused any issues yet. However, it is suggested to continuously monitor the GHP systems in these buildings in order to avoid serious problems before they really happen.
- In North Dakota, most of the studied buildings are equipped with vertical closed-loop GHP systems, which indicates the high acceptance of this type of system by building owners, end users, and designers/engineers in North Dakota, compared to other types of GHP systems.
- In North Dakota, on average, the depth of GHP boreholes is typically about 200 feet below the ground surface, due to the local geologic formations and the relatively high water table.
- Test wells before the installation of a GHP system are suggested, which are not only able to test the thermal conductivity of the underground region, but also to ensure how deep the geothermal loops can go and the depth of the water table in that region.
- Supplemental/backup heating for GHP systems is suggested, especially for the initial startup during the first and/or unexpectedly cold winters in North Dakota.

6. Future Study

Although, as the project goal, a large advancement for the knowledge of the current application of GHP systems in North Dakota has been successfully achieved through this study, there remain some unanswered questions and additional research opportunities.

In this study, 24 buildings have been investigated through onsite surveys and questionnaires, but not all the necessary information was collected or provided by building owners, which limited the number of buildings for in-depth analysis, such as the establishment of a whole building energy simulation to identify potential energy and energy cost savings, the determination of simple payback period, etc. Additionally, more buildings, especially residential buildings or single houses, could be studied to enhance the statewide influence and engagement of this project in North Dakota, which would require more time and budget to allow additional surveys and analysis.

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Appendix A - Potential Target Buildings

NO.	Building	Location in ND	Building Type
1	NDSU Richard H. Barry Hall-New Addition	Fargo	College
2	NDSU New Vet Diagnostic Lab Building	Fargo	College
3	NDSU AES Greenhouse Building	Fargo	College
4	National Energy Center of Excellence at Bismarck State College	Bismarck	College
5	United Tribes Technical College - Science & Technology Building	Bismarck	College
6	United Tribes Technical College - Wellness Center	Bismarck	College
7	United Tribes Technical College - Dormitory	Bismarck	College
8	University of North Dakota Gorecki Alumni Center	Grand Forks	College
9	Energy & Environmental Research Center	Grand Forks	College
10	Turtle Mountain Community College Student Union Addition	St. John	College
11	Turtle Mountain Community Vo-Tech College	St. John	College
12	Williston State College - Residence Hall	Williston	College
13	NDSU Langdon Research Extension Center	Langdon	College
14	NDSU Dickinson Research Extension Center	Dickinson	College
15	Discovery Middle School	Fargo	School
16	Kennedy Elementary School	Fargo	School
17	Judge Ronald N. Davies High School	Fargo	School
18	Bennett Elementary School	Fargo	School
19	Ninth Grade Center	West Fargo	School
20	The Circle of Nations School	Wahpeton	School
21	Wahpeton Middle School	Wahpeton	School
22	Jamestown High School	Jamestown	School
23	Central Valley Public School	Buxton	School
24	Northwood Public School	Northwood	School
25	Rugby High School	Rugby	School
26	New Town Elementary School	New Town	School
27	Sweetwater Elementary School	Devils Lake	School
28	Will-Moore Elementary School	Bismarck	School
29	Parshall High School	Parshall	School
30	Ojibwa Millennium Indian School	Belcourt	School
31	Fort Yates Middle School	Fort Yates	School
32	St Anthony of Padua	Fargo	Church
33	St. Mary's Church	Fargo	Church
34	St Andrew Lutheran Church	West Fargo	Church
35	Church of Corpus Christi	Bismarck	Church
36	McCabe Methodist Church	Bismarck	Church
37	Century Baptist Church	Bismarck	Church
38	Good Shepherd Lutheran Church Family Activity/Gym Center	Bismarck	Church
39	St. James Basilica Church	Jamestown	Church
40	St. Michael's Church	Grand Forks	Church
41	St John's Catholic Church	Wahpeton	Church
42	St. Philip's Catholic Church	Hankinson	Church

43	Zion Lutheran Church	Minot	Church
44	Horace Lutheran Church	Horace	Church
45	Sacred Heart Monastery	Richardton	Church
46	Cass County Electric Cooperative Building	Fargo	Public/Commercial
47	Woodhaven Plaza	Fargo	Public/Commercial
48	Family and Cosmetic Dentistry	Fargo	Public/Commercial
49	Microsoft Commons Building	Fargo	Public/Commercial
50	Osgood Fire Station 7	Fargo	Public/Commercial
51	Smiles Solutions	Fargo	Public/Commercial
52	Century Center	Bismarck	Public/Commercial
53	Bis-Man Transit	Bismarck	Public/Commercial
54	Bank of North Dakota	Bismarck	Public/Commercial
55	Bismarck Public Schools Career & Technical Center	Bismarck	Public/Commercial
56	St. Alexius Medical Center	Bismarck	Public/Commercial
57	Choice Wellness Center	Grand Forks	Public/Commercial
58	Grand Forks Airport International Terminal	Grand Forks	Public/Commercial
59	Black Gold Corporate Headquarters	Grand Forks	Public/Commercial
60	Dickinson Public Library	Dickinson	Public/Commercial
61	Dickinson Airport Terminal	Dickinson	Public/Commercial
62	Martin Building	Dickinson	Public/Commercial
63	Confluence Area Interpretive Center	Williston	Public/Commercial
64	Bethel Lutheran Home Assisted Living Apartments	Williston	Public/Commercial
65	IRET Properties	Minot	Public/Commercial
66	International Hotel	Minot	Public/Commercial
67	Audubon National Wildlife Refuge - Shop	Coleharbor	Public/Commercial
68	Audubon National Wildlife Refuge - Office and Visitors Center	Coleharbor	Public/Commercial
69	Lostwood National Wildlife Refuge - Office	Kenmare	Public/Commercial
70	Veteran's Home of Lisbon	Lisbon	Public/Commercial
71	Minto Community Center	Minto	Public/Commercial
72	Open Road Honda Powerhouse Dealership	Mandan	Public/Commercial
73	Pioneer Heritage Center	Cavalier	Public/Commercial
74	Three Affiliated Tribes Cultural Interpretive Center	New Town	Public/Commercial
75	Mor-Gran Electric Cooperative	Flasher	Public/Commercial
76	Agizzi Drain tile Facility	Wahpeton	Public/Commercial
77	Farm Credit Services Office Building	Bottineau	Public/Commercial
78	Sully’s Hill National Game Preserve - Shop	St Michael	Public/Commercial
79	Sully’s Hill National Game Preserve - Bunkhouse	St Michael	Public/Commercial
80	Sully’s Hill National Game Preserve - Visitor Center	Fort Totten	Public/Commercial
81	Oakes Community Hospital	Oakes	Public/Commercial
82	Arrowwood National Wildlife Refuge	Kensal	Public/Commercial
83	Coteau Prairie Residence	Stanley	Residential
84	Lostwood National Wildlife Refuge Residence	Kenmare	Residential

Appendix B – First Round Screening for the Target Buildings

NO.	Building	Location	Building Type
1	NDSU Richard H. Barry Hall-New Addition	Fargo	College
2	NDSU New Vet Diagnostic Lab Building	Fargo	College
3	NDSU AES Greenhouse	Fargo	College
4	National Energy Center of Excellence at Bismarck State College	Bismarck	College
5	United Tribes Technical College - Science & Technology Building	Bismarck	College
6	United Tribes Technical College - Wellness Center	Bismarck	College
7	United Tribes Technical College - Dormitory	Bismarck	College
8	NDSU Dickinson Research Center	Dickinson	College
9	NDSU Langdon Learning Center	Langdon	College
10	University of North Dakota Gorecki Alumni Center	Grand Forks	College
11	Williston State College - Residence Hall	Williston	College
12	Discovery Middle School	Fargo	School
13	Kennedy Elementary School	Fargo	School
14	Judge Ronald N. Davies High School	Fargo	School
15	Bennett Elementary School	Fargo	School
16	St Anthony of Padua	Fargo	Church
17	St. Mary's Church	Fargo	Church
18	St Andrew Lutheran Church	Fargo	Church
19	Northwood Public School	Northwood	School
20	Rugby High School	Rugby	School
21	Wahpeton Middle School	Wahpeton	School
22	Zion Lutheran Church	Minot	Church
23	Grand Forks Airport International Terminal	Grand Forks	Commercial
24	Black Gold Corporate Headquarters	Grand Forks	Commercial
25	Cass County Electric Cooperative Building	Fargo	Commercial
26	Agizzi Drain tile Facility	Wahpeton	Commercial
27	Farm Credit Services Office Building	Bottineau	Commercial
28	Osgood Fire Station 7	Fargo	Public
29	Lostwood National Wildlife Refuge Office	Kenmare	Public
30	Lostwood National Wildlife Refuge Residence	Kenmare	Residential
31	Audubon National Wildlife Refuge - Shop	Coleharbor	Public
32	Audubon National Wildlife Refuge - Office and Visitors Center	Coleharbor	Public
33	Coteau Prairie Residence	Stanley	Residential
34	Sully’s Hill National Game Preserve - Shop	St Michael	Public
35	Sully’s Hill National Game Preserve - Bunkhouse	St Michael	Public
36	Sully’s Hill National Game Preserve - Visitor Center	Fort Totten	Public
37	Arrowwood National Wildlife Refuge	Kensal	Public

Appendix C

DATA USE AGREEMENT FOR RESEARCH

This Data Use Agreement (the "Agreement") is effective as of the date of the last signature below, by and between North Dakota State University, having an office at 1715 NDSU Research Park Dr., Dept. 4000, PO Box 6050, Fargo, ND 58108-6050 (hereinafter the "Recipient") and the undersigned (hereinafter "Provider").

Provider maintains and/or has access to certain data as identified herein and is willing and able provide such data to Recipient for the purposes of carrying out a research project entitled "Geothermal Heat Pump Study" (hereinafter the "Project") to assess the operational performance of existing geothermal heat pump systems currently used in buildings across North Dakota.

This Project is funded in part by the North Dakota Department of Commerce (NDDOC) through its State Energy Program; and

Provider agrees to provide the data as described below for use in the Project on the following terms and conditions:

A . DATA REQUESTED. The data provided pursuant to this Agreement will include information regarding the building and its geothermal heat pump system, including, but not necessarily limited to the data listed in Attachment A (hereinafter “Data”).

B. PERMITTED USES AND DISCLOSURES. Recipient shall use the Data only for the Project. The Recipient will limit access to the Data to Project investigators. Recipient shall be permitted to disclose Data to the NDDOC upon its request or audit. Recipient shall be permitted to publish its analysis of the Data and other results of the Project.

C. RESEARCH RESULTS. Upon request, Recipient agrees to provide the results of the Project, including copies of any publications produced to Provider. All requests should be directed to the Principal Investigator, Dr. Yao Yu, NDSU, PO Box 6050, Department 2475, Fargo, ND 58108-6050, Yao.Yu@ndsu.edu , 701-231-8822.

D. TERMINATION. The Recipient agrees to destroy all data provided pursuant to this Agreement upon the conclusion of the Project.

E. PERMISSIONS. Provider agrees to allow this Agreement to serve as authorization for any third party to disclose to Recipient any information to which it has access that is relative to the building(s) designated below and this Project.

North Dakota State University:

Signature:____

Yao Yu (Principal Investigator) Date
Assistant Professor, Construction Management and Engineering

Provider:

Signature:____

Date

Name: ________________________________

Title: ________________________________

Email: ________________________________

Building(s): _____________________________

Building Address: ______________________________

Attachment A

Data needed for the Project funded by the State Energy Program of NDDOC

- Cost and investment documents for the building and HVAC system
- Utility bills for last year
- Architectural plan (pdf, AutoCAD, or Revit)
- Mechanical plan (pdf, AutoCAD, or Revit)
- Energy modeling results from design or utility companies, especially if it is a LEED building (EAp2/EAc1)
- Electrical plan (pdf, AutoCAD, or Revit)
- Plumbing plan (pdf, AutoCAD, or Revit)
- Owners' Project Requirements (OPR)
- Basis of Design (BOD)
- Specifications
- Installation and operations manuals
- Equipment/system catalogs
- Drilling report for the borehole thermal response test
- Sequence of operation for controls

The items above are listed in order of importance for this study.

Appendix D Questionnaire for Building Owner

For the research study supported by the State Energy Program of North Dakota Department of Commerce

- **Contact Information**

Name	
Telephone/Mobile	
Fax	
Email	
Address	

- **Building Information**

Building Name	
Building Address	
Building Type (please circle one)	College / School / Church / Public / Commercial / Residential / Hospital / Other (please specify):
Building Construction Date (year)	
Building Total Area (ft^2)	
Total Number of Floor	Above ground: Below ground:
Full Occupancy (No. of People)	
Total Number of Rooms (if known)	
Utility/Service Providers	Electricity: Natural gas: Other:
LEED Building	YES / NO Other certification (please specify if applicable):
Building Design Company (architect)	

- **HVAC/Geothermal Heat Pump (GHP) Information**

HVAC/GHP Installation Year	
Installation Type	Retrofit / New
Number of Boreholes for Vertical GHP (if known)	
Borehole Depth (ft) (if known)	
Mechanical Design Company (mechanical engineer)	

➢ Cost Information

Capital Cost of the Buildings ($)	$
Total Cost of the HVAC/GHP System ($)	Total Cost: $
	Cost Breakdown (if known) • Exterior Ground-loop installation and component cost (including borehole drilling, headers, piping, etc.): $ • Interior HVAC/GHP System installation and component cost (including heat pump units, ducting, controls, etc.): $
HVAC System Average Annual Repair and Maintenance Cost ($)	$
Government Incentives for the Use of GHP	YES / NO Incentives (if known): $
Utility Incentives for the Use of GHP	YES / NO Incentives (if known): $

➢ Data Sharing*

Would you please share more detailed cost breakdown information regarding the building and HVAC/GHP system (if available) with us?	YES / NO / N.A
Shall we obtain your permission to access the Building Automation System (if available) to collect data for this study?	YES / NO / N.A
Would you please share the utility bills for last year with us?	YES / NO
Would you please share the building plans/drawings (pdf, AutoCAD and/or Revit) with us (including architectural, mechanical plans, specifications, owner's project requirement, basis of design, etc.)?	YES / NO
Shall we obtain your permission (if necessary) to request and access more detailed data/documents from building design companies (architects, mechanical engineers, etc.) for this study?	YES / NO
Shall we obtain your permission to visit your building and meet with maintenance staffs to obtain more information regarding the GHP system for this study?	YES / NO

*All the data provided are protected as described in the Data Sharing Agreement.

1. Why did you decide to install the geothermal heat pump system in your building?
(the possible reasons include lower heating and cooling bills, reduced size of equipment room, government incentives/tax credits/grants, utility company's incentives, green product environment concerns, more comfortable indoor environment)

2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?

3. As you know, are there any operating difficulties of the geothermal heat pump system?

4. Would you like to suggest geothermal heat pump systems to others, like your friends?

5. Do you know other buildings in the region using geothermal heat pump system?

For research team use only		
Today's Date:	Signature:	Notes/Comments:

Appendix E Questionnaire for Maintenance Staff

For the research study supported by the State Energy Program of North Dakota Department of Commerce

➢ Contact Information

Name	
Telephone/Mobile	
Fax	
Email	
Address	

➢ Building Information

Building Name	
Building Address	
Building Type (please circle one)	College / School / Church / Public / Commercial / Residential / Hospital / Other (please specify):
Building Construction Date (year)	
Building Total Area (ft^2)	
Total Number of Floor	Above ground: Below ground:
Full Occupancy (No. of People)	
Total Number of Rooms (if known)	
Utility/Service Providers	Electricity: Natural gas: Other:
LEED Building	YES / NO Other certification (please specify if applicable):

➢ HVAC/Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	
Installation Type	Retrofit / New
Number of Boreholes for Vertical GHP (if known)	
Borehole Depth (ft) (if known)	
Type of GHP System (choose one)	• Direct-exchange system • Closed-loop system (vertical loop, horizontal loop, lake or pond loop) • Open-loop system (pump and reinjection system, standing column well system

	• Hybrid system, please specify:
Type of Refrigerant	
Antifreeze percentage	
Suitable/design supply and return water temperature for EXTERIOR ground loop	Supply: F Return: F
Suitable/design supply and return water temperature for INTERIOR building loop	Supply: F Return: F
Is there a backup heating or cooling system?	YES / NO If Yes, please specify:
How many Heat Pump units?	
Type of Heat Pump	Water-to-air Heat Pump / Water-to-water Heat Pump

- **Cost Information**

HVAC System Average Annual Repair and Maintenance Cost ($)	$

- **Data Sharing***

Would you please share maintenance logs with us?	YES / NO
Shall we obtain your permission to access the Building Automation System (if available) to collect data for this study?	YES / NO / N.A
Would you please share the utility bills for last year with us?	YES / NO

*All the data provided are protected as described in the Data Sharing Agreement.

1. **Are you satisfied with the current HVAC system in terms of noise, indoor and comfort, operation, maintenance, and repair? Any complaints from building users?**

2. **Are there any operating difficulties of the geothermal heat pump system?**

3. **Do you have any suggestions for the geothermal heat pump system designer? (Design Flaw)**

4. **Do you know other buildings in the region using geothermal heat pump system?**

For research team use only		
Today's Date:	Signature:	Notes/Comments:

Appendix F – Building Details

#1. North Dakota State University (NDSU) Richard H. Barry Hall - New Addition

❖ Background

The Richard H. Barry Hall (Figure F.1.1) was named after Richard H. Barry (1909-1988) who was a renowned financial consultant and economic catalyst. This building is located in the downtown of the city of Fargo. It was built and opened in 2009. This building has an area of about 135,000 ft^2 with 12 conference rooms, a two-story atrium, 12 classrooms, a 250-seat auditorium, a six-story faculty office tower including 131 offices, student study areas, a behavioral lab, the investment management center, the Bison Connection student service center, the branch of the NDSU bookstore, the branch of the NDSU library, and a coffee bar. The building of the Richard H. Barry Hall consists of the former Pioneer Mutual Life building (about 60,000 ft^2) that was built in 1925 and a 75,000 ft^2 addition. In the existing building, a traditional four-pipe fan coil unit system is used, whereas a vertical closed-loop GHP system has been installed and applied in the addition to provide space cooling and heating. The total number of vertical boreholes is 120 with the depth of about 203 feet underground. Other features include Variable Speed Drive (VSD) fans and water pumps, Makeup Air Units (MAUs) with energy recovery, Demand Control Ventilation (DCV) with CO_2 sensors, etc.

Figure F.1.1: NDSU Richard H. Barry Hall

❖ System Description

In the Richard H. Barry Hall building, the space cooling and heating are provided by two types of air-conditioning systems. As shown in Figure F.1.2, Part One is the former Pioneer Mutual Life building that is served by a system with 201 fan coil units (four pipes) and a make-up air rooftop unit as the source of ventilation with the total design airflow rate of 5,600 cfm. These fan coil units are fed by hot and cold water supplied from two boilers with the efficiency of 86% and one air-cooled chiller that rejects heat through a dry cooler with the cooling capacity of about 75 tons, respectively. A vertical closed-loop GHP system is applied in this building to condition the addition areas, marked as Part Two in Figure F.1.2. 53 water-to-air heat pumps are included in this system, which are located at room levels and directly tied to the geothermal loop (120 boreholes with the depth of 203 feet and a minimum separation distance of 15 feet, as shown in Figure F.1.2), i.e. there is no heat exchanger between the indoor and outdoor loops, as shown in Figure F.1.3). Water in this system is circulated between the heat pumps and the ground loops through two VSD pumps (one is for backup). Ventilation requirement for the areas of Part Two is met by an Energy Recovery Unit (ERU) with the total design air flow rate of 18,035 cfm. Ducts from this unit are tied to each heat pump to supply fresh air to each occupied space. Two energy recovery wheels are equipped in both of the MAU (for Part One) and the ERU (for Part Two), respectively, to exchange the heat between exhaust and intake air. In addition to the 53 water-to-air heat pumps, there exist 3 water-to-water heat pumps that are connected to both of the hot water boiler and the chilled water loops and are controlled to continuously transfer heat between these two loops, in order to provide cold and hot water to the MAU and ERU.

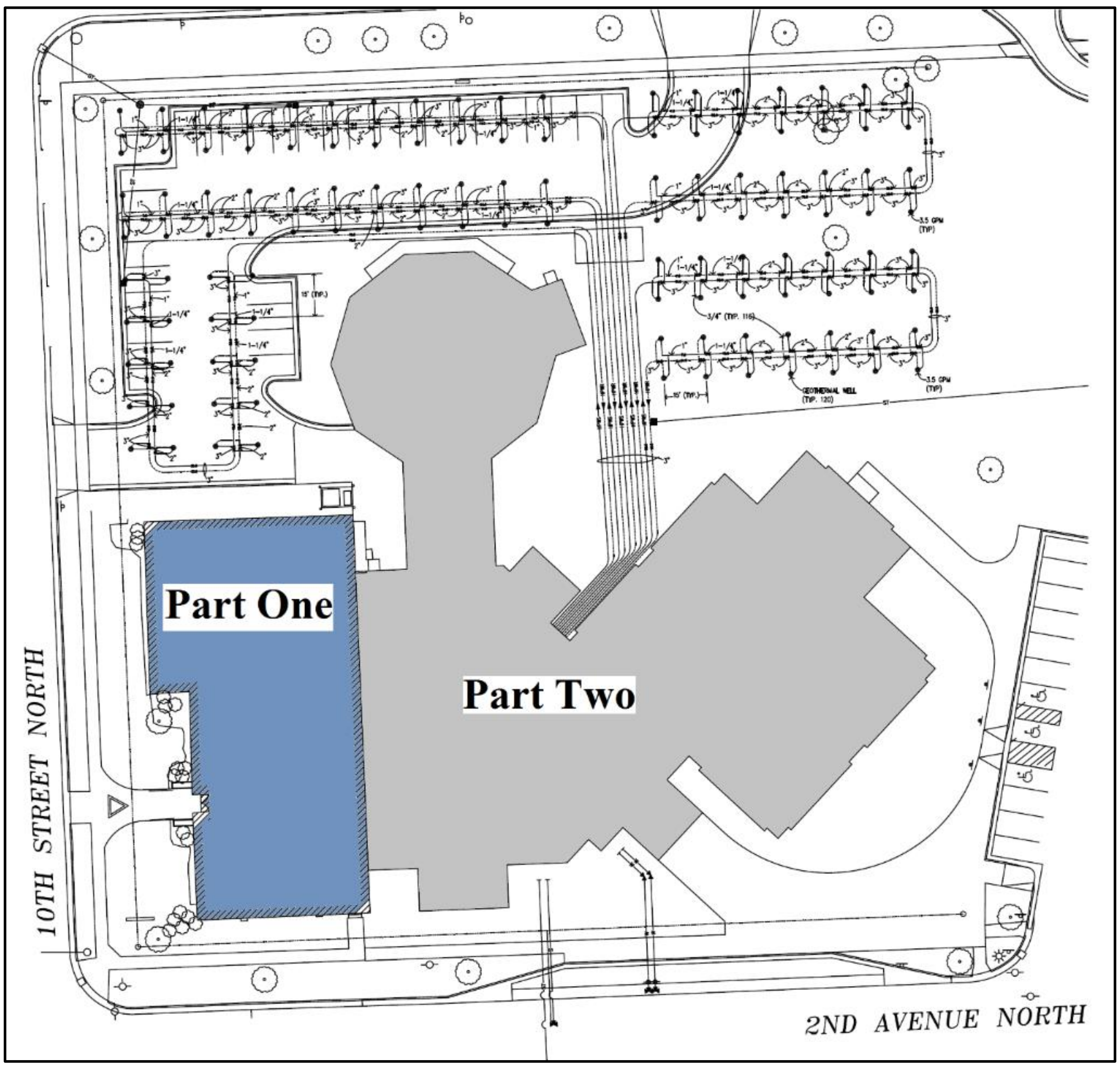


Figure F.1.2: NDSU Richard H. Barry Hall building – Underground loops

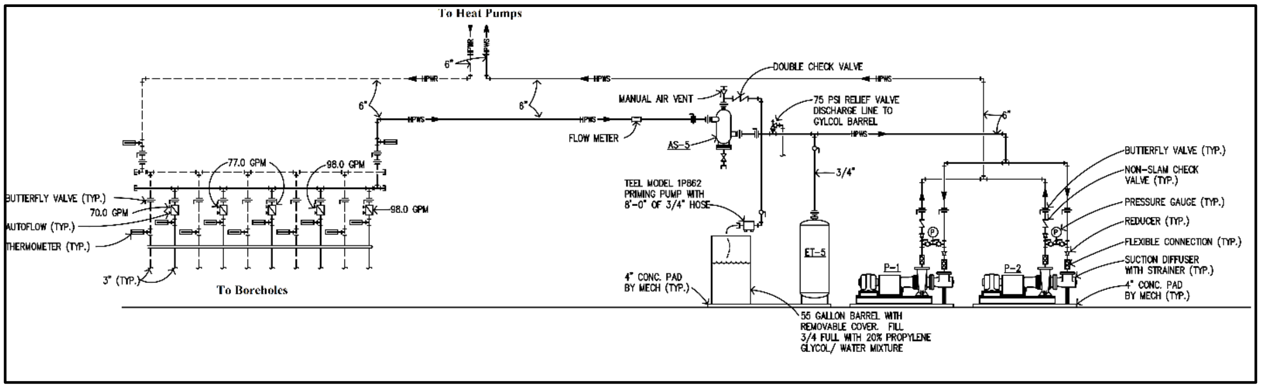


Figure F.1.3: Piping schematic of the geothermal loop

❖ System Performance

The monthly energy use of the Richard H. Barry Hall building between July, 2015 and June, 2016 was given and is displayed in Figure F.1.4, with the total energy use of 1,654,800 kWh and 43,390 therm per year. The corresponding site Energy Use Intensity (EUI) is equal to 74 kBtu/ft^2/yr. The corresponding energy cost is shown in Figure F.1.5 with the total cost of $165,977.65 per year, i.e. $1.23/ft^2/yr. In order to determine the potential energy and energy cost savings between the actual building with a geothermal heat pump system and a similar building with a conventional air-conditioning system, an energy simulation model was established as shown in Figure 3.4, where these two buildings were simulated simultaneously. To enhance the reliability of the simulation results, the model with the actual building design was calibrated by using the actual energy usage and utility cost. Figure F.1.6 and F.1.7 show the calibration results, i.e. the comparisons of the results between the simulation model and the actual building data in terms of energy usage between July, 2015 and June, 2016. The utility rates for electricity and natural gas used in the simulation models were determined based on the actual utility bills and are represented in a form of yearly average, i.e. 8.85 cents per kwh for electricity and $0.45 per therm for natural gas.

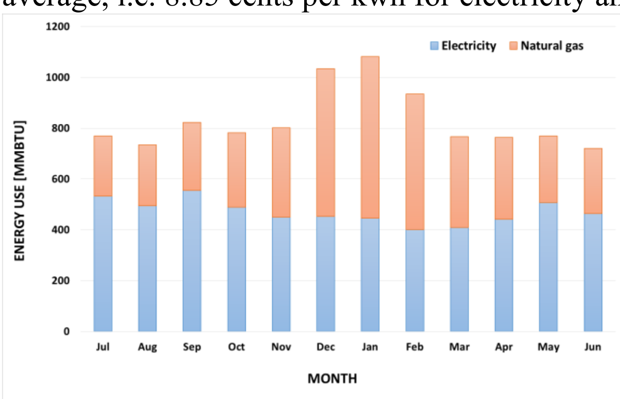


Figure F.1.4 Monthly energy use between 2015 and 2016

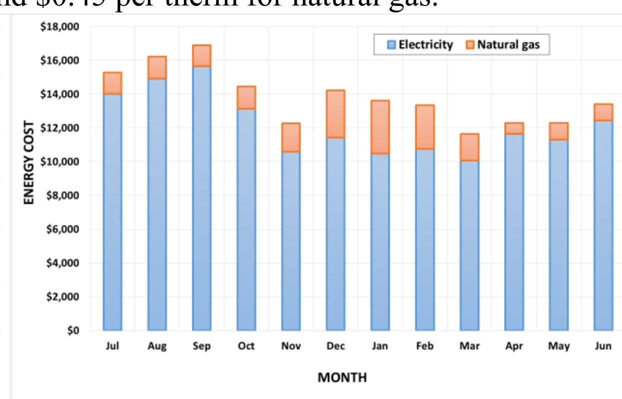
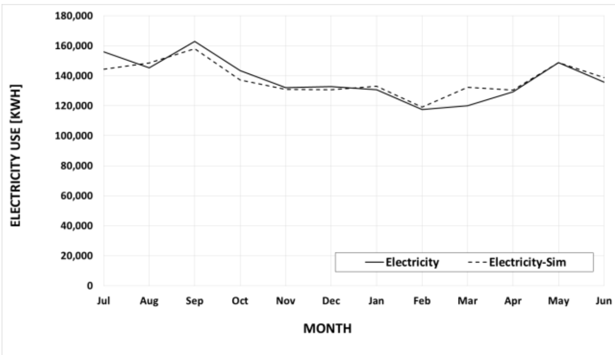


Figure F.1.5 Monthly energy cost between 2015 and 2016



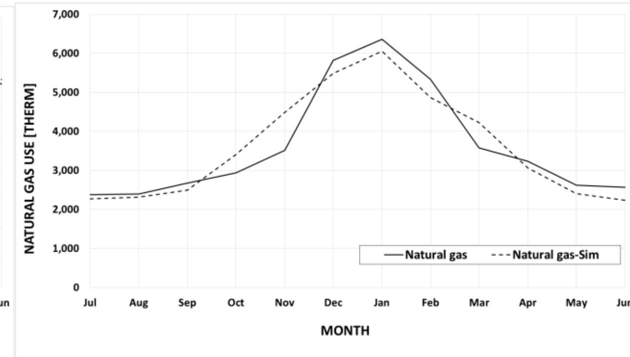


Figure F.1.6 Electricity use comparison

Figure F.1.7 Natural gas use comparison

A baseline model for a similar building with a conventional air-conditioning system design was established based on the calibrated model. The difference between these two models is shown in Table F.1.1 below.

Table F.1.1: Model Difference

Model with the actual GHP system	Model with a conventional air-conditioning system
GHP systems as designed	Four-pipe fan coil system with chilled water chiller cooling and hot water fossil fuel boiler heating (others are the same as the actual system)

As shown in Table F.1.1, the conventional air-conditioning system was determined in consideration of using the same system with the existing building, i.e. the former Pioneer Mutual Life building (Part One in Figure F.1.2). Once these simulation models have been established successfully, the energy and energy cost savings can be identified, which are shown below and also in Table F.1.2.

- 14% of energy savings is achieved between the actual building and a similar building equipped with the conventional air-conditioning system (a four-pipe fan coil system).
- Energy cost savings between the actual building and a similar building with a conventional air-conditioning system is shown as 5%.
- 37% of energy and energy cost savings are achieved between the actual building and a similar building based on the EPA's Energy Star Target Finder result for a national median property.

Such low energy cost savings (5%) (compared to the 14% energy savings) is caused by the extremely low utility rate for natural gas compared to electricity. The conventional air-conditioning system primarily uses natural gas (boilers) to provide heating effect, while the actual geothermal system uses electricity (heat pumps).

Table F.1.2: Energy Performance Comparison

	Actual GHP System		ASHRAE Conventional System	Similar Building*
	Actual Utilities	Simulated	Simulated	Estimated (the national median)*
Electricity Usage (kwh/yr)	1,654,800	1,652,261	1,661,794	-
Electricity Cost ($/yr)	146,442.40	146,218.00	147,062.00	-
Natural Gas Usage (therm/yr)	43,390	43,293	59,760	-
Natural Gas Cost ($/yr)	19,535.25	19,491.00	26,905.00	-
Actual Site Energy Usage (MMBTU/yr)	9,981	9,967	11,646	15,886.6
Estimated Source Energy Usage (MMBTU/yr)*	22,271.8	22,247.6	24,078.7	35,449.6
Total Actual Energy Cost ($/yr)	165,977.65	165,710.00**	173,967.00**	264,029**
Actual Site EUI (kBtu/ft^2/yr)	73.9	73.8	86.3	117.7
Estimated Source EUI (kBtu/ft^2/yr)*	165.0	164.8	178.4	262.6
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	1,305.4	1,304.1	1,397.7	2,077.8
Energy Savings Compared to Conventional System	14%			
Energy Cost Savings Compared to Conventional System	5%			
Energy Savings Compared to Similar EPA Buildings	37%			
Energy Cost Savings Compared to Similar EPA Buildings	37%			

* Based on Energy Star Target Finder results
** Determined by using the actual average annual utility rates, i.e. 8.85 cents per kwh and $0.45 per therm

❖ Project Costs

The total capital cost of the building is approximately $13,000,000 with the total HVAC system cost of about $2,600,000, i.e. $19.3/ft^2. Table F.1.3 indicates the system cost comparison and analysis between the actual design and the virtual conventional system (Table F.1.1). As shown in this table, the simple payback period because of the use of GHP system against the conventional air-conditioning system for this building is 19.5 years.

Table F.1.3: Cost Comparison Analysis

Actual GHP System		Conventional System	
GHP system:	$2,600,000.00	Four-pipe Fan Coil System with Chilled Water Chiller Cooling and Hot Water Fossil Fuel Boiler Heating (others are the same as the actual system**):	$2,146,500.00*
Yearly energy cost:	$165,977.65	Yearly energy cost:	$173,967.00
HVAC System Average Annual Repair and Maintenance Cost ($/yr)	$20,000	HVAC System Average Annual Repair and Maintenance Cost ($)	$35,250*
Simple payback period (Years):		19.5	

* Estimated by using [1], [2], [3], and/or [4]
** Others may include sump pumps, energy recovery units, exhaust fans, roof hoods, water heaters, etc.

[1] RS Means data. https://www.rsmeans.com/
[2] Climatemaster System Selling Binder. climatemaster.com/downloads/06RepMtg-selling%20wshp-LM.ppt
[3] Steve Kavanaugh and Kevin Rafferty. 2014. Geothermal Heating and Cooling Design of Ground-source Heat Pump Systems. ASHRAE. ISBN 978-1-936504855. 1791 Tullie Circle, NE, Atlanta, GA 30329.
[4] Bloomquist, R.G., 2001. The economics of geothermal heat pump systems for commercial and institutional buildings. Proceedings of the International Course on Geothermal Heat Pumps, Bad Urach, Germany.

Table F.1.4 provides the summary information of this building.

Table F.1.4: Building Summary

Building Information

Building Name	NDSU Richard H. Barry Hall
Building Address	Fargo
Building Type	College Building
Building Construction Year	2009
Building Total Area (ft^2)	135,000 (Existing: 60,000; Addition: 75,000)
Total Number of Floor	Above ground: 6 Below ground: 1
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2009
Installation Type	New for the addition
GHP system type	Vertical closed loop
Number of Boreholes for Vertical GHP	120
Borehole Depth (ft)	203
Borehole Separation Distance (ft)	15
Borehole Length (ft)	24,360
Underground Pipe Length (ft)	48,720
Borehole Length per ton (ft/ton)	270
Underground Pipe Length per ton (ft/ton)	540
GHP water flow rate per ton (gpm/ton)	4.5
Number of Heat Pump Units	Water-to-Air Heat Pump: 53 Water-to-Water Heat Pump: 3
Total Capacity of Heat Pump Units (tons)	90
Total Capacity of the entire HVAC System (tons)	273
Heat Pump Efficiency Range	Cooling: 16.2 EER Heating: 2.7~3.3 COP

Cost Information

Capital Cost of the Building ($)	13,000,000
Total Cost of the HVAC System ($)	2,600,000
HVAC System Average Annual Repair and Maintenance Cost ($)	20,000
Government Incentives for the Use of GHP	No
Utility Incentives for the Use of GHP	No

Question & Answer

Questions answered by	Brent DeKrey Associate Director (Maintenance and Repair) of NDSU Facilities Management Department Tel: 701-231-7322 Fax: 701-231-8008 brent.dekrey@ndsu.edu
1. Why did you decide to install the geothermal heat pump system in your building?	I wasn't here at the time, but I believe it was to lower heating/cooling bills and for environmental concerns.
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Yes, no big complaints.
3. As you know, are there any operating difficulties of the geothermal heat pump system?	At times, the ground warms up during cooling, but it hasn't caused any issues.
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes, if they have incentives to help with the install costs.

#2. National Energy Center of Excellence (NECE)

❖ Background

The National Energy Center of Excellence (NECE) (Figure F.2.1) at Bismarck State College (BSC) is located in Bismarck, North Dakota, and was built in 2008. As shown in Figure F.2.2, this building has an area of about 106,200 ft^2 with offices, a media studio, classrooms, computer labs, break rooms, a lounge, laboratories, an auditorium with 164 seats, conference rooms, and one state room on the 4th floor with 512 seats. This facility houses BSC's energy programs, continuing education division and administration. This facility is using a vertical closed-loop GHP system to provide space heating and cooling. The total number of vertical boreholes is 504 with the depth of about 200 feet underground. Other features include[1],

- Heat recovery system extracts unusable heat from the building and transfers this heat to the outside air.
- Temperature of underground loop ranges from 40^{o}F to 70^{o}F.
- Payback period for loop system is less than 10 years.
- Energy efficient lighting system meets requirements of LEED without the certification.
- Interior lighting with high-efficiency T8 fluorescent lamps, multi-level switching, and occupancy sensors.
- Exterior lighting with high-efficiency pulse start metal halide lamps that provide good uniform lighting in parking lots and sidewalks without light spilling onto adjacent properties. Controlled via building automation system for efficient control of illumination.
- Flexcrete, a construction material manufactured from fly ash, was donated by Great River Energy as a demonstration of the use of North Dakota fly ash as a building material. The Flexcrete material is recycled from coal combustion byproducts (which require disposal) and has been used throughout the interior of the building.

Figure F.2.1: National Energy Center of Excellence building
(Source: http://ndstudies.gov/energy/level2/module-3-coal/electricity-generation-and-products)

[1] https://bismarckstate.edu/energy/nece/buildinghighlights/

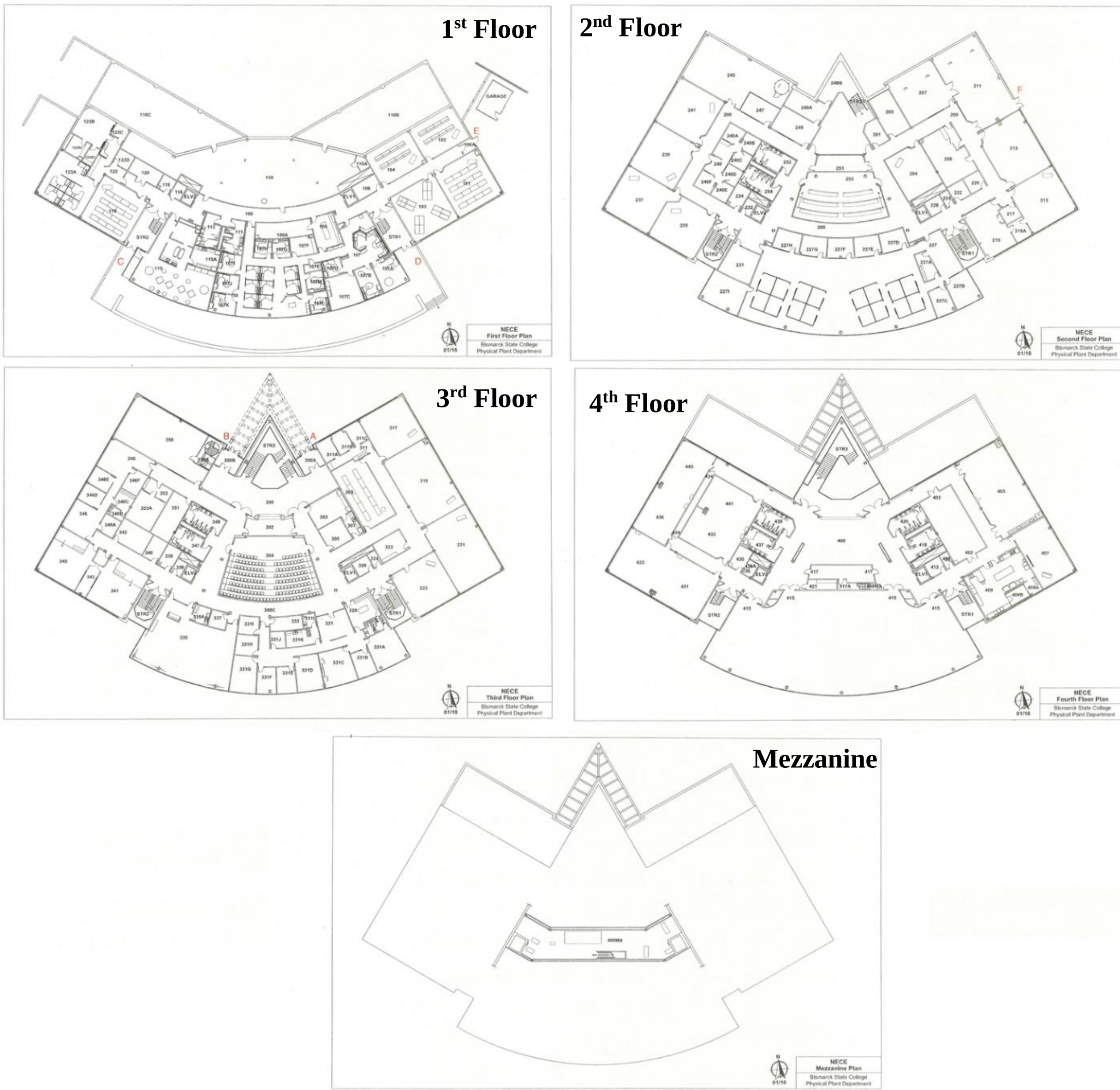


Figure F.2.2: NECE floor plan

❖ System Description

In the NECE building, water-to-air heat pump units are used to condition the indoor occupied spaces. As designed, heat rejection and extraction were carried out through 504 vertical boreholes with the depth of about 200 feet below the ground surface. Two VSD pumps (one is for backup) are used to convey water to the ground loops, shown as P-1A and P-1B in Figure F.2.3. Ventilation requirement for this building is met by an ERU to pre-condition the outdoor air. Ducts from this unit are tied to each water-to-air heat pump to mix with room return air before supplying it to each individual occupied space.

At the beginning of 2016, a proposal was prepared by a staff of NECE to request about $225,000 to install an auxiliary dry cooler in order to solve the problems regarding the warm underground and low cooling capacity and performance of the geothermal system. The majority of the NECE building was completed in 2008 and the 4th floor was completed in 2013. The building is heated and cooled with a geothermal wellfield that was sized at the time of the original construction of the anticipated needs of the facility, anticipating the facility would need about equal cooling and heating degree days. However, because the facility is south-facing and is covered with a large number of windows, the cooling degree days are significantly more than the heating degree days. In other words, this building may need cooling instead of heating even during a winter season, due to a large amount of solar gains and/or internal gains because of people, lighting, and equipment. Additionally, the separation distance between boreholes is less than the minimum suggested value for a vertical geothermal system (15 feet). As a result, more heat is conveyed and stored into the wellfield than being removed, which has the effect of increasing the ground temperature over time (about 10 years). This is known as Ground Temperature Penalty, which is mainly caused by the unbalanced heat extraction and injection from/to the ground by a GHP system. At the time the wellfield was drilled, the ground temperature was about 50^{o}F. In the about 10 years of operation, however, the ground temperature has been increased by approximately 37^{o}F (up to 87^{o}F). This puts extreme stress on the heat pumps and results in inefficient operation, or even may cause the failures or complete shut-down of the GHP system. Figure F.2.4 shows the supply and return water temperatures of the ground loop against the outdoor dry-bulb air temperatures during the summer of 2016 (6/7~7/17).

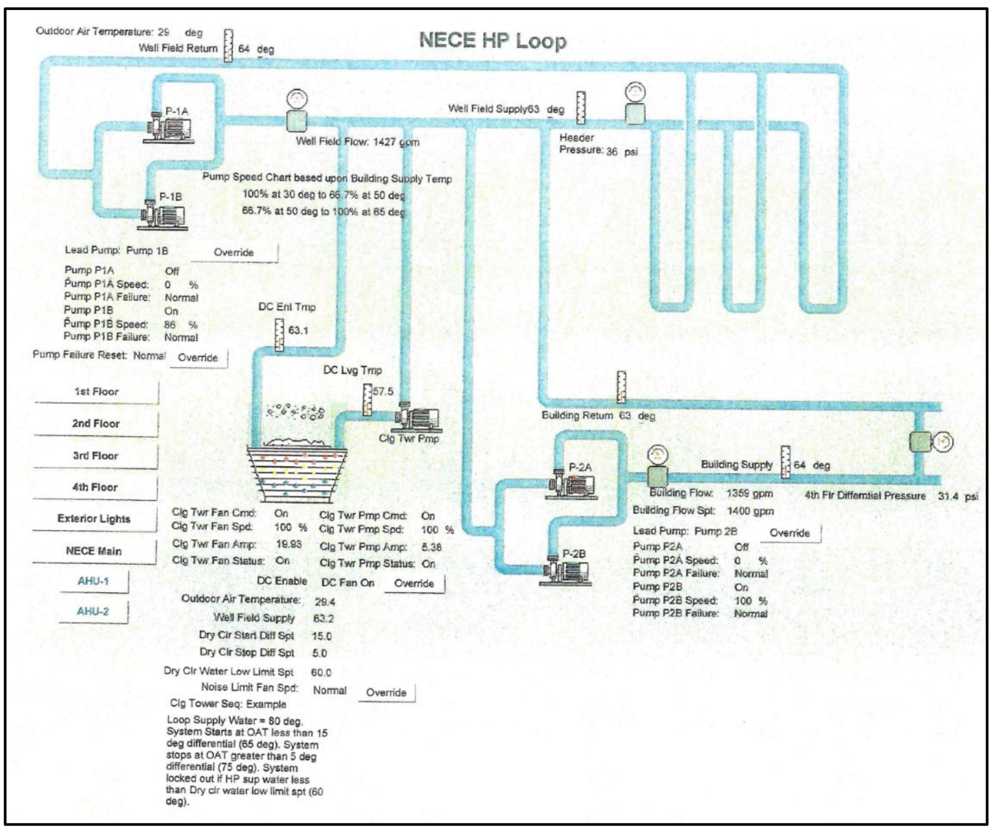


Figure F.2.3: NECE heat pump loop

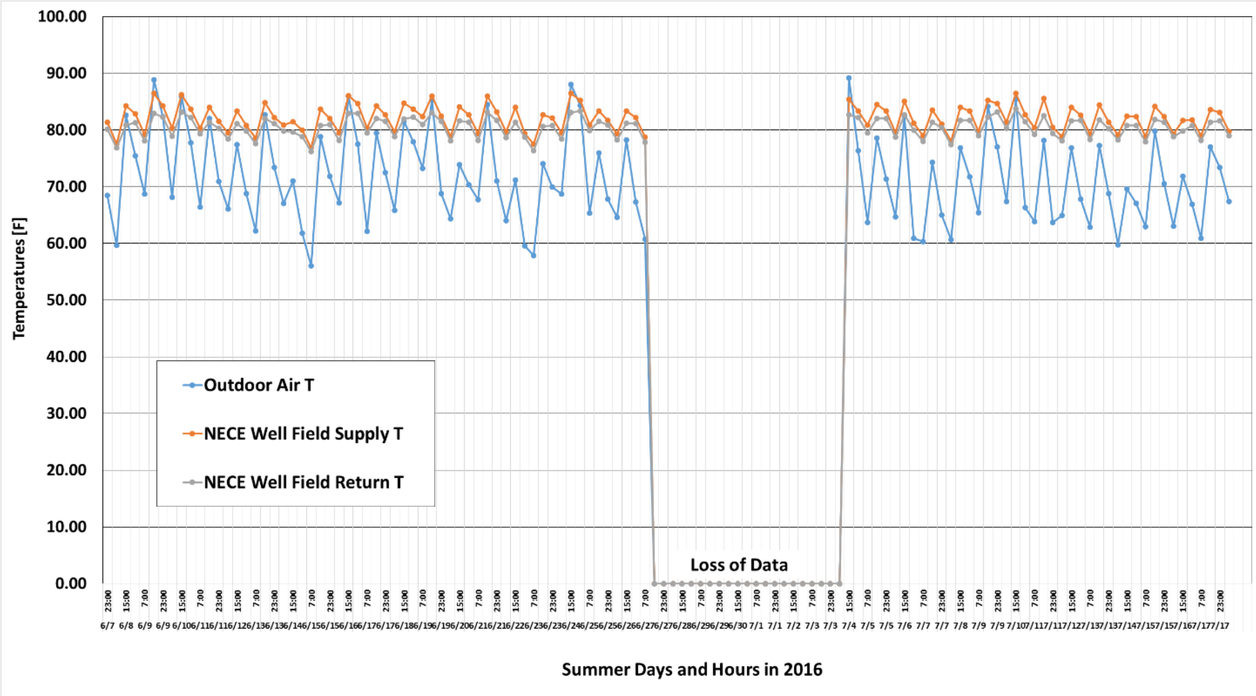


Figure F.2.4: Ground water temperature profiles during the summer of 2016

A solution to this problem is to use a hybrid GHP system by adding an additional sink element of thermal energy. Therefore, a dry cooler was installed with the GHP system for the NECE building, as shown in Figure F.2.3. This installation allows water being returned to the ground to first be cooled by this dry cooler during the colder months of the year, and thus the cooler water is circulated into the warmer ground to effectively cool it down over time. With this system in place, it is expected to take about three years of continual running of the system in the winter months to cool the ground temperature to an appropriate level.

Other issues reported by the NECE staffs are the simultaneous heating and cooling in a large open space which is conditioned by multiple heat pump units in this building. Each of these heat pump units typically has its own thermostat. Due to the inappropriate design, control, and thermostat locations, some of the heat pumps are fighting each other by providing warm and cold air to a space at the same time, which definitely causes the waste of energy and discomfort. It is also reported that there is one individual office space (Figure F.2.5), where three systems with three thermostats are used. This mixed use of system in an individual space caused a large amount of energy waste and discomfort reported by the end users. In fact, these issues are mainly caused by an inappropriate design of the GHP system and the absence of enough knowledge and experience regarding this type of system at that time when the building was built. Fortunately, these problems can be effectively avoided nowadays, thanks to the rich and tremendous studies, research, experience, and resources about GHP systems, in terms of design, operation, maintenance, commissioning, etc.

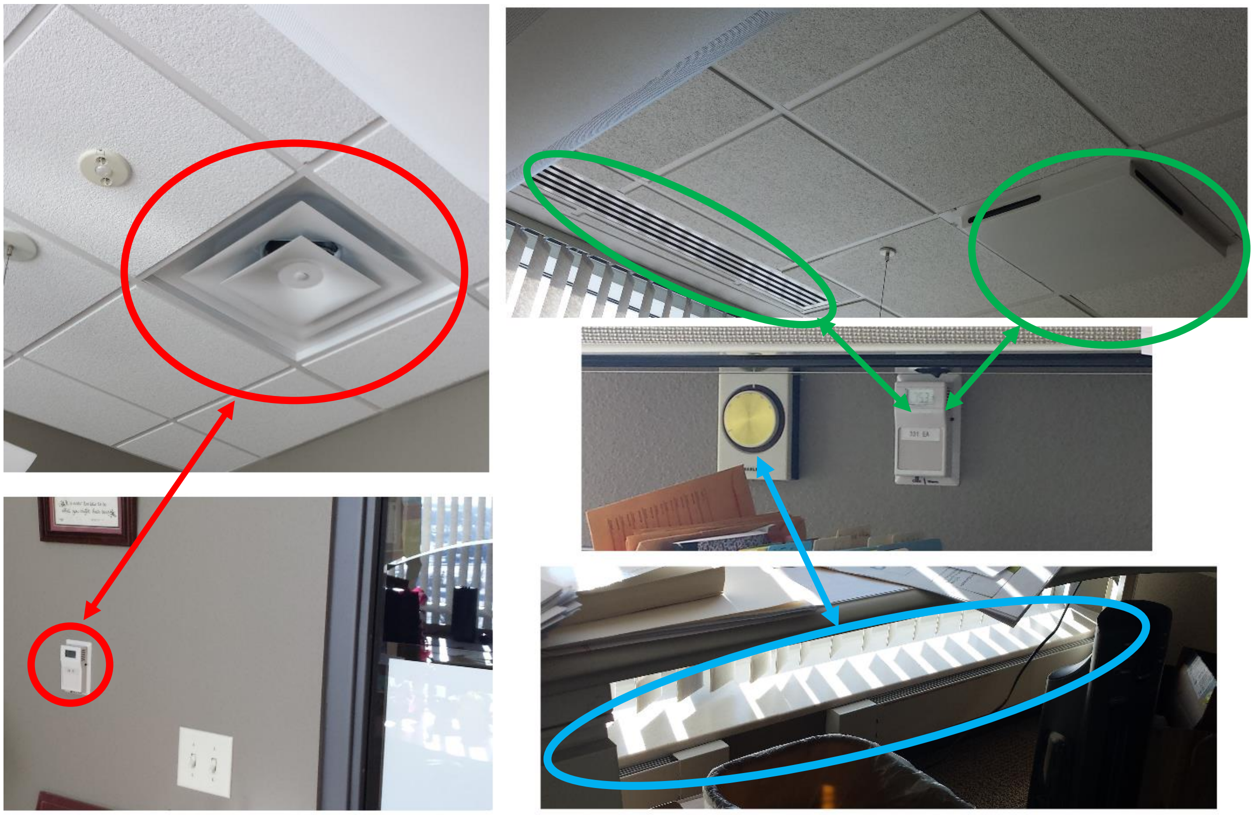


Figure F.2.5: An office with three different systems and thermostats

❖ System Performance

The monthly energy use of the NECE building between July, 2015 and December, 2016 is shown in Figure F.2.6 below, and the corresponding actual site EUI of the building is 81 kBtu/ft^2/yr. Figure F.2.7 and F.2.8 show the corresponding electricity and natural gas usages, respectively, between July, 2015 and December, 2016. As shown in these figures, electricity is the major energy consumption, due to the heavy use of the GHPs for both space cooling and heating.

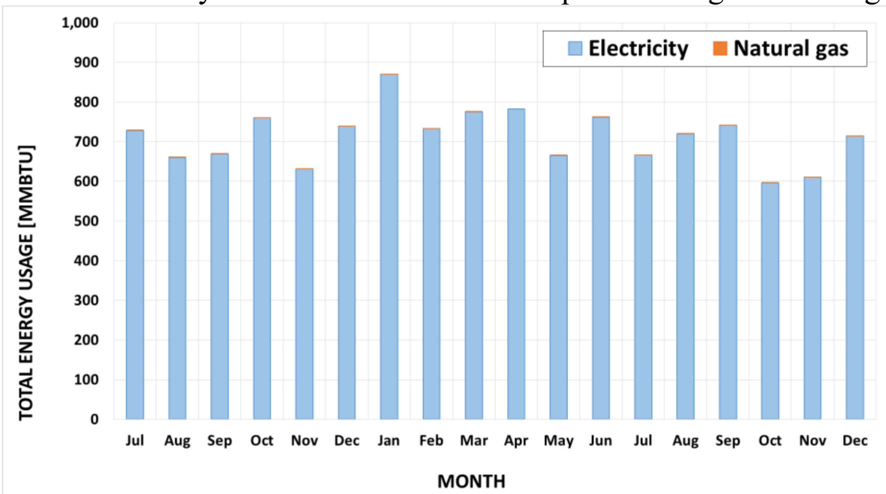


Figure F.2.6: Monthly energy use between 2015 and 2016

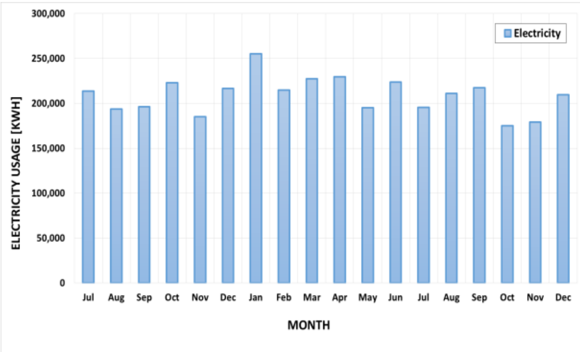


Figure F.2.7: Monthly electricity use between 2015 and 2016

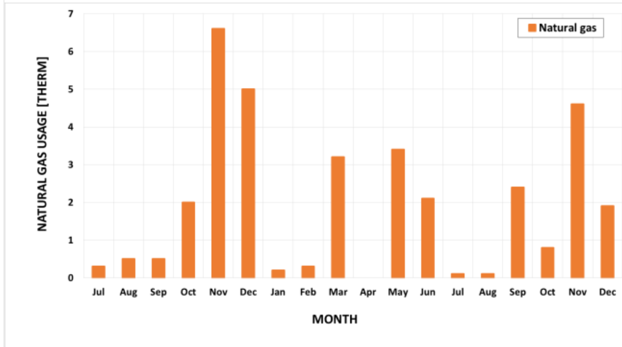


Figure F.2.8: Monthly natural gas use between 2015 and 2016

The corresponding annual energy cost is $200,315.70 ($1.89/ft^2/yr) for the year of 2016 with $199,539.13 for electricity and $776.57 for natural gas.

In order to identify the potential energy and energy cost savings of the building, the actual energy consumption result of this building was eventually compared with the EPA's Energy Star Target Finder result which represents the national median of the energy performance of similar buildings in the U.S. These results are shown in Table F.2.1, which indicates a 3% of energy and energy cost savings between the actual building and a similar building based on the Energy Star Target Finder result for a national median property.

Table F.2.1: Energy Performance Comparison

	Actual GHP System	Similar Building*
	Actual Utilities	Estimated (the national median)*
Electricity Usage (kwh/yr)	2,532,850	-
Electricity Cost ($/yr)	199,539.13	-
Natural Gas Usage (therm/yr)	19	-
Natural Gas Cost ($/yr)	776.57	-
Actual Site Energy Usage (MMBTU/yr)	8,644	8,882.5
Estimated Source Energy Usage (MMBTU/yr)*	27,138.1	27,887.1
Total Actual Energy Cost ($/yr)	200,315.70	205,842.42**
Actual Site EUI (kBtu/ft^2/yr)	81	83.6
Estimated Source EUI (kBtu/ft^2/yr)*	255.5	262.6
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	1,646.7	1,692.1
Energy Savings Compared to Similar EPA Buildings	3%	
Energy Cost Savings Compared to Similar EPA Buildings	3%	

* Based on Energy Star Target Finder results
** Determined by using the actual average annual utility rates, i.e. 7.878 cents per kwh and $40.66 per therm (mainly due to the basic service charge for natural gas)

❖ Project Costs

The total capital cost of the building is known as $18,500,000 with the total cost of the mechanical system of $3,000,000 ($28.25/ft^2). Since the actual design documents, such as architectural and MEP drawings, were not provided, it was difficult to determine the size and capacity of a conventional system appropriate for this building. Therefore, the cost comparative analysis and the simple payback period calculation for this building were not able to be conducted due to the lack of such information about this building. As reported, however, the simple payback period for the GHP system is less than 10 years.

The basic summary information of this building is shown in Table F.2.2 below.

Table F.2.2: Building Summary

Building Information

Building Name	National Energy Center of Excellence
Building Address	Bismarck
Building Type	College
Building Construction Year	2008 2013 for the 4th floor
Building Total Area (ft^2)	106,200
Total Number of Floor	Above ground: 4 + Mezzanine
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2008
Installation Type	New
GHP system type	Vertical closed loop
Number of Boreholes for Vertical GHP	504
Borehole Depth (ft)	200
Borehole Separation Distance (ft)	15 or less
Borehole Length (ft)	100,800
Underground Pipe Length (ft)	201,600

Cost Information

Capital Cost of the Building ($)	18,500,000
Total Cost of the HVAC System ($)	3,000,000
HVAC System Average Annual Repair and Maintenance Cost ($)	Not Provided
Government Incentives for the Use of GHP	Unknown
Utility Incentives for the Use of GHP	Unknown

Question & Answer

Questions answered by	Don Roethler Chief Buildings and Grounds Officer Tel: 701-224-5485 donald.roethler@bismarckstate.edu
1. Why did you decide to install the geothermal heat pump system in your building?	Not Provided (the building was built about 10 year ago, and the persons involved in this building project were gone.
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Some of heat pumps are fighting each other when they are serving to a large open space. This caused the waste of energy and discomfort, due to the simultaneous heating and cooling. It is also reported that there is one individual office space, where three systems with three thermostats are used. This mixed use of system in an individual space caused a large amount of energy waste and discomfort reported by the end users.
3. As you know, are there any operating difficulties of the geothermal heat pump system?	A dry cooler was installed in 2016 to charge back to the warm ground. In the about 10 years of operation, the ground temperature has been increased by approximately 37°F (up to 87°F), due to the unbalanced heating and cooling loads.
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Not Provided

#3. United Tribes Technical College (UTTC) – Science & Technology Building

❖ Background

The UTTC Science & Technology building (Figure F.3.1) is located in Bismarck, North Dakota, and was built between 2010 and 2012 with two phases. This building has an area of about 32,000 ft^2, mainly including offices, classrooms, conference rooms, and laboratories. This facility is using a vertical closed-loop GHP system to provide heating and cooling. The total number of vertical boreholes is 130 with the depth of about 300 feet underground. Other features include four ERUs, VSD water pumps, etc.

Figure F.3.1: UTTC Science & Technology building (Source: http://thefirstscout.blogspot.com/2011/12/)

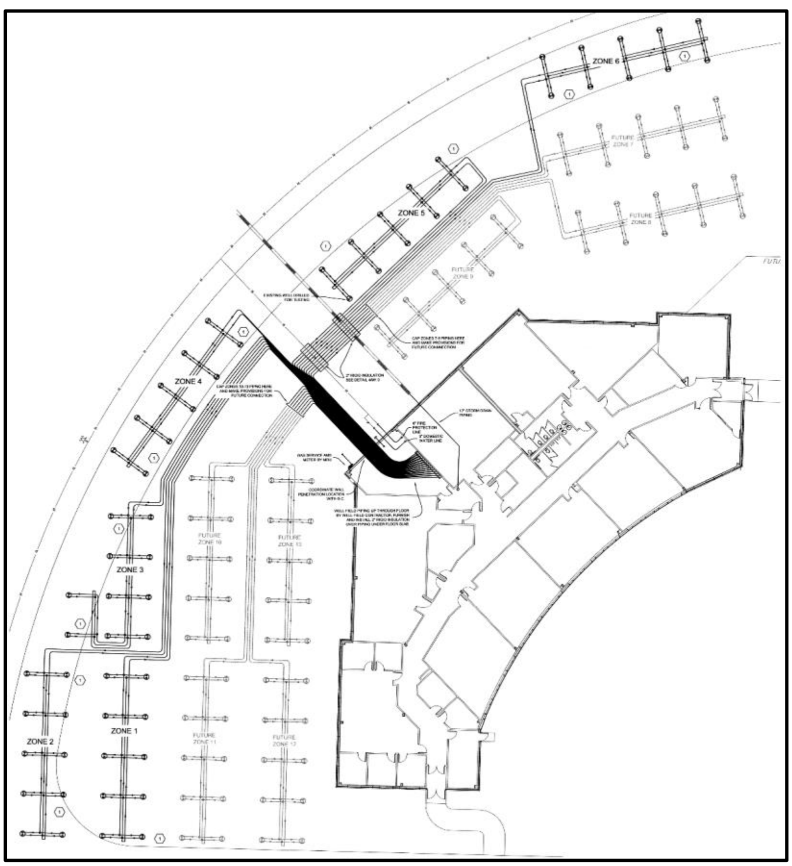


Figure F.3.2: UTTC Science & Technology underground boreholes

❖ System Description

In the UTTC Science & Technology building, 41 water-to-air heat pump units are used to condition the indoor occupied spaces. Heat rejection and extraction take place through 130 vertical boreholes with the depth of about 300 feet below the ground surface and a minimum separation distance of 15 feet, as shown in Figure F.3.2. Water in this system is conveyed to the ground loops through two VSD pumps (one is for backup), as shown in Figure F.3.3. The other two pumps (P-3 and P-4 shown in Figure F.3.3) are the VSD pumps used to circulate the water to each heat pump unit inside the building. Ventilation requirement for this building is met by four ERUs with the total design air flow rate of about 10,000 cfm. Ducts from this unit are tied to each heat pump to supply fresh air to each occupied space.

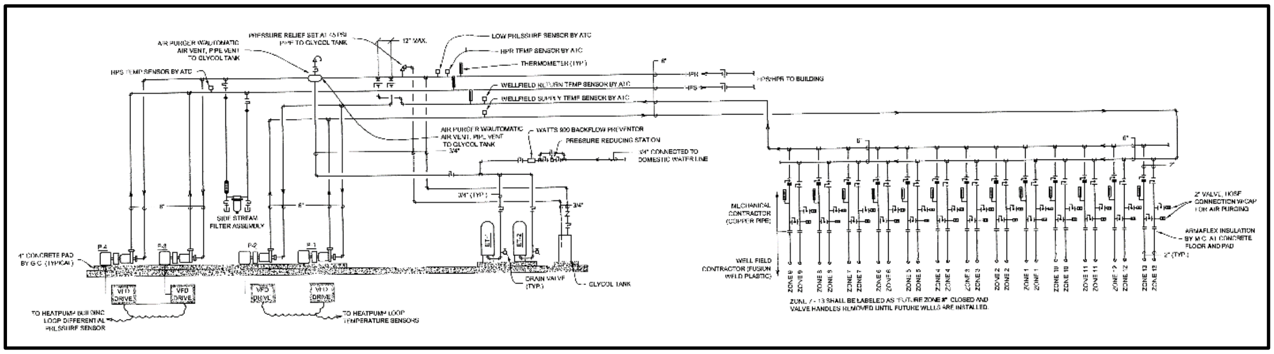


Figure F.3.3: UTTC Science & Technology heat pump piping detail

❖ System Performance

The monthly energy use of the UTTC Science & Technology building between March, 2016 and February, 2017 is shown in Figure F.3.4 below, and the corresponding actual site EUI of the building is 48.3 kBtu/ft^2/yr, which is about 41.8% lower compared to the baseline building (with the conventional system defined in the ASHRAE 90.1 - Appendix G) that has a site EUI of 83 kBtu/ft^2/yr. The simulation model was established and calibrated against the actual electricity and natural gas consumption (Figure F.3.5 and F.3.6).

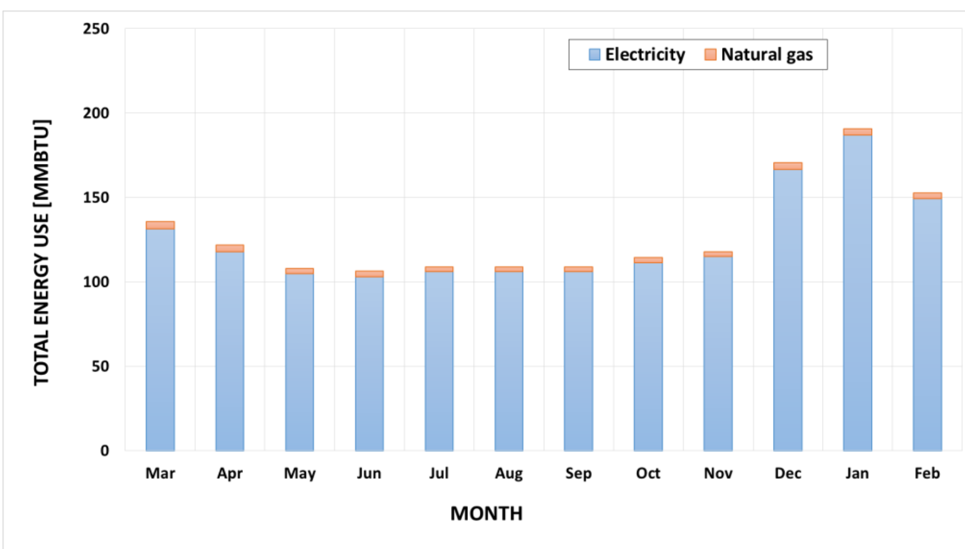


Figure F.3.4: Monthly energy use between 2016 and 2017

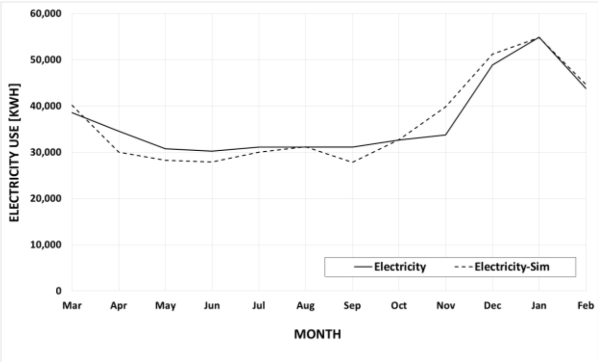


Figure F.3.5: Electricity use comparison

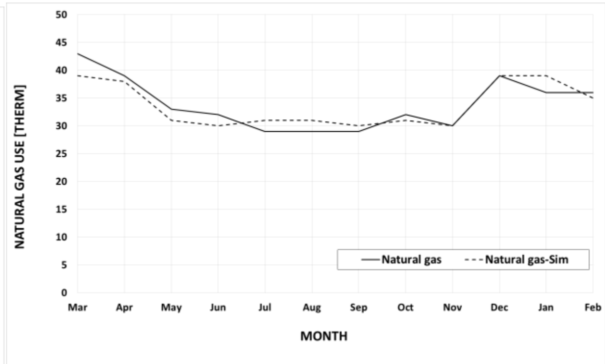


Figure F.3.6 Natural gas use comparison

The baseline model for the similar building with a conventional air-conditioning system design was established based on the calibrated model. The difference between these two models is shown in Table F.3.1 below.

Table F.3.1: Model difference

Model with the actual GHP system	Model with a conventional air-conditioning system
Geothermal heat pump systems as designed	Packaged rooftop VAV with PFP Boxes with direct expansion (DX) cooling and electric heating (others are the same as the actual system).

The corresponding actual energy cost is displayed in Figure F.3.7 with the total cost of $36,166 per year, i.e. $1.13/ft^2/yr.

The energy and energy cost savings for this building are summarized below:

- 41.8% of energy savings is achieved between the actual building and a similar building with a conventional air-conditioning system;
- 43.3% of energy saving is achieved between the actual building and a similar building based on the EPA's Energy Star Target Finder result for a national median property;
- Energy cost savings between the actual building and a similar building with a conventional air-conditioning system or based on the EPA's Energy Star Target Finder are shown as 41.8% and 43.2% respectively, due to the use of high-efficiency GHP system.

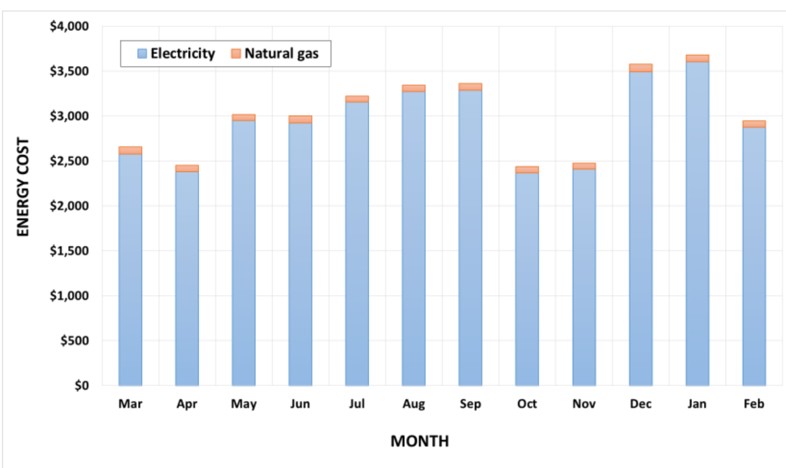


Figure F.3.7: Monthly energy cost between 2016 and 2017

Table F.3.2 shows the performance result of this building in terms of energy and energy cost.

Table F.3.2: Energy Performance Comparison

	Actual GHP System		ASHRAE Conventional System	Similar Building*
	Actual Utilities	Simulated	Simulated	Estimated (the national median)*
Electricity Usage (kwh/yr)	441,143	438,332	766,258	-
Electricity Cost ($/yr)	35,304.90	34,778.00	35,067.00	-
Natural Gas Usage (therm/yr)	407	408	408	-
Natural Gas Cost ($/yr)	861.12	862.00	862.00	-
Actual Site Energy Usage (MMBTU/yr)	1,545	1,536.8	2,656.0	2,723.8
Estimated Source Energy Usage (MMBTU/yr)*	4,769.0	4,739.0	8,252.3	8,402.9
Total Actual Energy Cost ($/yr)	36,166.0	35,929.0**	62,163.0**	63,723.40**
Actual Site EUI (kBtu/ft^2/yr)	48.3	48.0	83.0	85.1
Estimated Source EUI (kBtu/ft^2/yr)*	149.0	148.1	257.9	262.6
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	288.9	287.1	500.3	509.1
Energy Savings Compared to Conventional System	41.8%			
Energy Savings Compared to Similar EPA Buildings	43.3%			
Energy Cost Savings Compared to Conventional System	41.8%			
Energy Cost Savings Compared to Similar EPA Buildings	43.2%			

* Based on Energy Star Target Finder results

** Determined by using the actual average annual utility rates, i.e. 8.003 cents per kwh and $2.116 per therm (mainly due to the basic service charge for natural gas)

❖ Project Costs

The total capital cost of the building as well as the information regarding the total HVAC cost were not given. Therefore, the cost comparative analysis and the simple payback period calculation for this building were not conducted, due to the lack of such cost information about this building.

The basic building information is summarized in Table F.3.3 below.

Table F.3.3: Building Summary

Building Information

Building Name	United Tribes Technical College - Science & Technology Building
Building Address	Bismarck
Building Type	College
Building Construction Year	2010 – 2012 (Phase 1&2)
Building Total Area (ft^2)	32,000
Total Number of Floor	Above ground: 2
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2010 – 2012 (Phase 1&2)
Installation Type	New
GHP system type	Vertical closed loop
Number of Boreholes for Horizontal GHP	130
Borehole Depth (ft)	300
Borehole Separation Distance (ft)	15
Borehole Length (ft)	39,000
Underground Pipe Length (ft)	78,000
Borehole Length per ton (ft/ton)	361
Underground Pipe Length per ton (ft/ton)	722
GHP water flow rate per ton (gpm/ton)	5.4
Number of Heat Pump Units	Water-to-Air Heat Pump: 41
Total Capacity of Heat Pump Units (tons)	108
Total Capacity of the entire HVAC System (tons)	108
Heat Pump Efficiency Range	Unknown

Cost Information

Capital Cost of the Building ($)	Unknown
Total Cost of the HVAC System ($)	Unknown
HVAC System Average Annual Repair and Maintenance Cost ($)	Unknown
Government Incentives for the Use of GHP	Unknown
Utility Incentives for the Use of GHP	Unknown

Question & Answer

Questions answered by	Greg Pollert gpollert@uttc.edu
1. Why did you decide to install the geothermal heat pump system in your building?	Energy efficiency
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Unknown
3. As you know, are there any operating difficulties of the geothermal heat pump system?	Unknown
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes

#4. United Tribes Technical College (UTTC) – Wellness Center

❖ Background

The UTTC Wellness Center (Figure F.4.1) is located in Bismarck, North Dakota, and this building was built in 2006 and as a new addition, it was built to connect to the existing James Henry Gymnasium, as shown in Figure F.4.2. This Wellness Center has an area of about 19,185 ft^2 and mainly consists of offices, health rooms, exam rooms, locker rooms, classrooms, etc. This facility is using a vertical closed-loop GHP system to provide heating and cooling. The total number of vertical boreholes is 36 with the depth of about 200 feet underground. Other features include one ERU, VSD water pumps, and one rooftop unit with DX cooling and gas-fired heating to condition a large fitness open space.

Figure F.4.1: UTTC Wellness Center

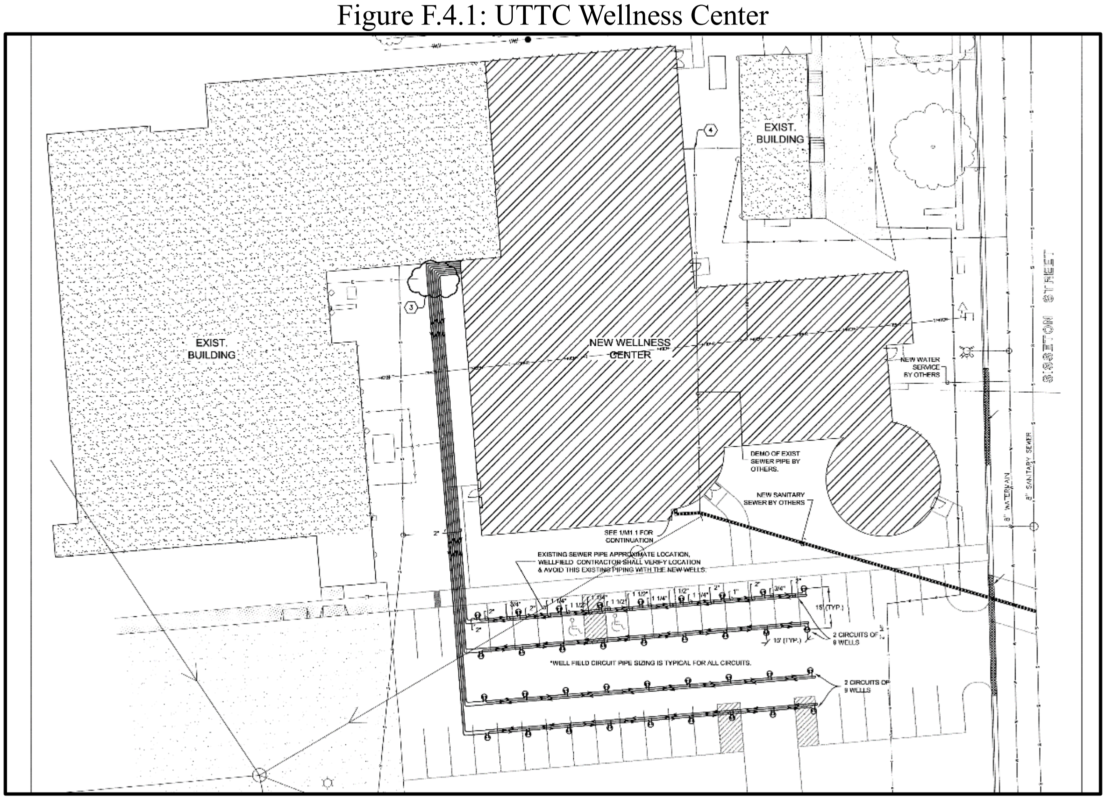


Figure F.4.2: UTTC Wellness Center underground boreholes

❖ System Description

In the UTTC Wellness Center building, 22 water-to-air heat pump units are used to condition the indoor occupied spaces. Heat rejection and extraction take place through 36 vertical boreholes with the depth of about 200 feet below the ground surface and a minimum separation distance of 15 feet, as shown in Figure F.4.2. Water in this system is circulated between heat pumps and ground loops through two VSD pumps (one for backup), as shown in Figure F.4.3. Ventilation requirement for this building is met by one ERU with the total design air flow rate of 2,800 cfm. Ducts from this unit are tied to each heat pump to supply fresh air to each occupied space.

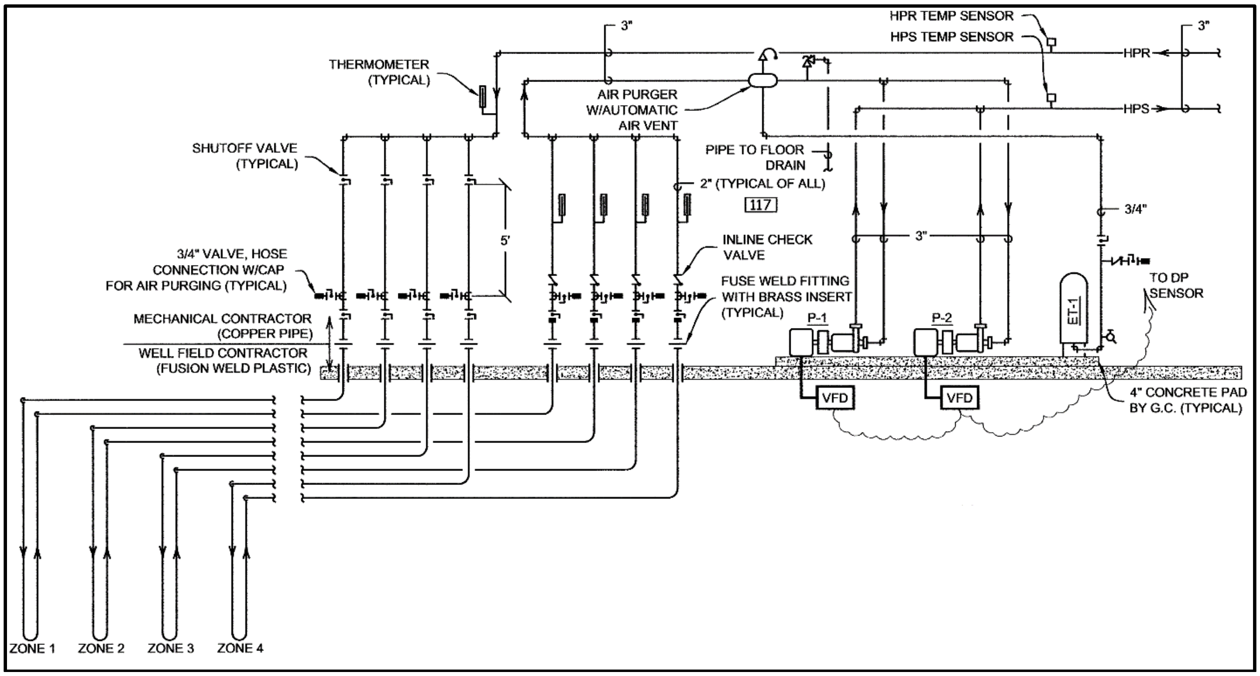


Figure F.4.3: UTTC Wellness Center heat pump piping detail

❖ System Performance

The monthly utility bills of the UTTC Wellness Center for the year of 2016 are given, which, however, show incredibly high energy use with the site EUI of 141.2 kBtu/ft^2/yr (compared to the Energy Star Target Finder result – 108 kBtu/ft^2/yr for a national median property) and the total annual utility cost of $56,078.30, i.e. $2.92/ft^2/yr. These numbers are too high to be true for a wellness center with the total building areas of 19,185 ft^2. After contacting the UTTC staff, it is believed that there are two or more building(s) that share the same meter with the Wellness Center, and unfortunately it is impossible to get a true reading for the target building without the installation of a new sub-meter. Therefore, the energy performance analysis of this wellness center was not conducted due to the lack of such necessary information. The performance of a similar building, however, is given in Table F.4.1, which is based on the EPA's Energy Star Target Finder result for a national median property.

Table F.4.1: Energy Performance Comparison

	Similar Building*
	Estimated (the national median)*
Electricity Usage (kwh/yr)	-
Electricity Cost ($/yr)	-
Natural Gas Usage (therm/yr)	-
Natural Gas Cost ($/yr)	-
Actual Site Energy Usage (MMBTU/yr)	2,071.5
Estimated Source Energy Usage (MMBTU/yr)*	5,037.8
Total Actual Energy Cost ($/yr)	42,880.27**
Actual Site EUI (kBtu/ft^2/yr)	108.0
Estimated Source EUI (kBtu/ft^2/yr)*	262.6
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	298.2

* Based on Energy Star Target Finder results
** Determined by using the actual average annual utility rates, i.e. 9.773 cents per kwh and $0.52 per therm

❖ Project Costs

The total capital cost of the building as well as the information regarding the total HVAC cost was not given. Therefore, the cost comparative analysis and the simple payback period calculation for this building were not conducted due to the lack of such cost information about this building.

The basic building information is summarized in Table F.4.2 below.

Table F.4.2: Building Summary

Building Information

Building Name	United Tribes Technical College - Wellness Center
Building Address	Bismarck
Building Type	College
Building Construction Year	2006
Building Total Area (ft^2)	19,185
Total Number of Floor	Above ground: 1
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2006
Installation Type	New
GHP system type	Vertical closed loop
Number of Boreholes for Horizontal GHP	36
Borehole Depth (ft)	200
Borehole Separation Distance (ft)	15
Borehole Length (ft)	7,200
Underground Pipe Length (ft)	14,400
Borehole Length per ton (ft/ton)	154
Underground Pipe Length per ton (ft/ton)	308
GHP water flow rate per ton (gpm/ton)	2.8
Number of Heat Pump Units	Water-to-Air Heat Pump: 22
Total Capacity of Heat Pump Units (tons)	47
Total Capacity of the entire HVAC System (tons)	63
Heat Pump Efficiency Range	Unknown

Cost Information

Capital Cost of the Building ($)	Unknown
Total Cost of the HVAC System ($)	Unknown
HVAC System Average Annual Repair and Maintenance Cost ($)	Unknown
Government Incentives for the Use of GHP	Unknown

Utility Incentives for the Use of GHP	Unknown

Question & Answer

Questions answered by	Greg Pollert gpollert@uttc.edu
1. Why did you decide to install the geothermal heat pump system in your building?	Energy efficiency
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Unknown
3. As you know, are there any operating difficulties of the geothermal heat pump system?	Unknown
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes

#5. United Tribes Technical College (UTTC) - Dormitory

❖ Background

The UTTC Dormitory building (Figure F.5.1) is located in Bismarck, North Dakota, and was built in 2003. This building has an area of about 28,032 ft^2 and mainly consists of 48 dormitory rooms for students. This facility is using a vertical closed-loop GHP system to provide heating and cooling. The total number of vertical boreholes is 70 with the depth of about 200 feet underground. Up to now, this building has been operating for about 14 years. Several fan motors and compressors went out and were replaced. One concern the owner has is the issue related to thermostats and the associated control strategies. According to the original design (Figure F.5.2), two or more rooms are served by one heat pump unit that is typically connected to two thermostats located in two different rooms. An average temperature (guessed by the owner) between these two thermostats is regarded as the feedback temperature to control the heat pump unit, which could cause comfort issues. For example, one room has the temperature of 60°F and the other has 85°F, which give a desirable feedback temperature (around 72°F), so the heat pump could be turned off automatically, but the indoor temperatures for these two rooms are not at a comfort level.

Figure F.5.1: UTTC Dormitory (Source: http://test.uttc.edu/about/site_ft_lincoln/site.asp)

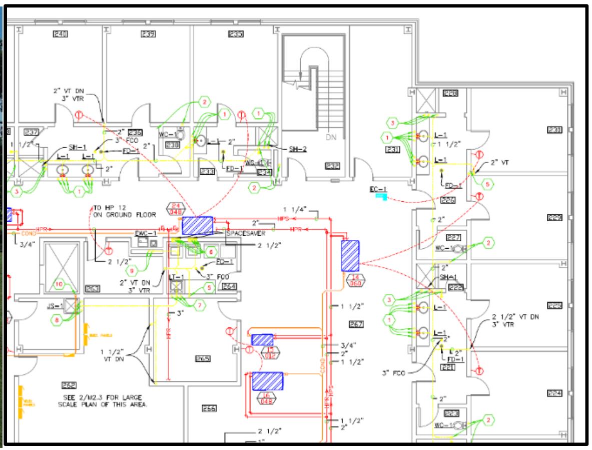


Figure F.5.2: Thermostats connected to heat pump

❖ System Description

In the UTTC Dormitory building, 24 water-to-air heat pump units are used to condition the indoor occupied spaces. Heat rejection and extraction take place through 70 vertical boreholes with the depth of about 200 feet below the ground and a minimum separation distance of 15 feet, as shown in Figure F.5.3. Water in this system is circulated between the heat pumps and the ground loops through 9 pumps, as shown in Figure F.5.4. Seven of them are small constant speed on-off pumps that would be started and operated one after another, if necessary, to provide a staged control depending on the building loads. All of these seven pumps would be on when the building reaches a peak load, while only several of them would operate under part-load conditions. The other two pumps (P-8 and P-9 shown in Figure F.5.4) are VSD pumps that are used to convey the water to each heat pump unit inside the building. Ventilation requirement for this building is met by one

ERU with the total design air flow rate of 2,800 cfm. Ducts from this unit are tied to each heat pump to supply fresh air to each occupied space.

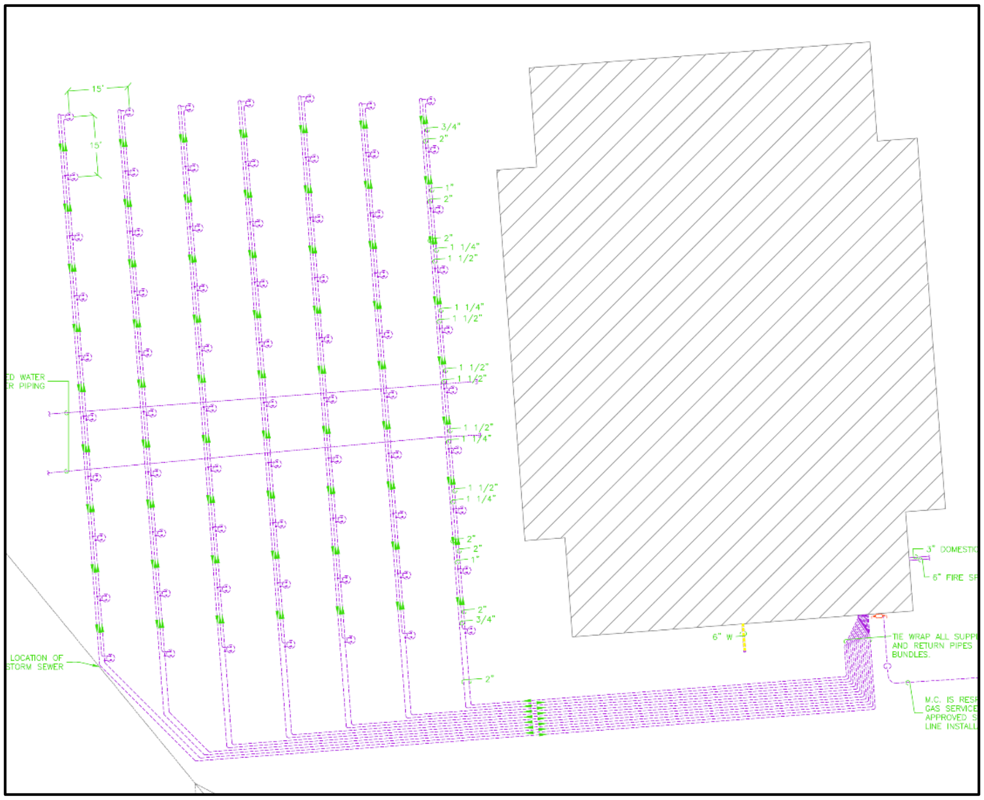


Figure F.5.3: UTTC Dormitory underground boreholes

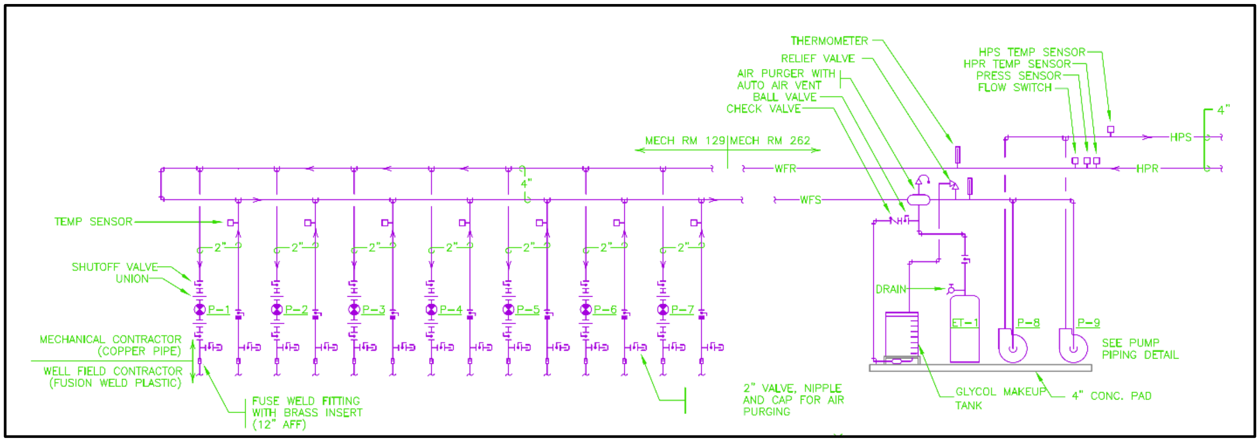


Figure F.5.4: UTTC Dormitory heat pump piping detail

❖ System Performance

The monthly utility bills of the UTTC Dormitory building for the year of 2016 are given, which, however, show incredibly high energy use with the site EUI of 413.5 kBtu/ft^2/yr (compared to the EPA's Energy Star Target Finder result – 75.9 kBtu/ft^2/yr for a national median property) and the total annual utility cost of $295,116, i.e. $10.53/ft^2/yr. These numbers are too high to be true for a dormitory building with the total building areas of 28,032 ft^2. After contacting the UTTC staff, it appears that there are other building(s) that share the same meter with this dormitory, and unfortunately it is impossible to get a true reading for the target dormitory building without the installation of a new sub-meter. Therefore, the energy performance analysis of this building was not conducted, due to the lack of such necessary information. The performance of a similar building, however, is given in Table F.5.1, which is based on the EPA's Energy Star Target Finder result for a national median property.

Table F.5.1: Energy Performance Comparison

	Similar Building*
	Estimated (the national median)*
Electricity Usage (kwh/yr)	-
Electricity Cost ($/yr)	-
Natural Gas Usage (therm/yr)	-
Natural Gas Cost ($/yr)	-
Actual Site Energy Usage (MMBTU/yr)	2,128.1
Estimated Source Energy Usage (MMBTU/yr)*	6,586.7
Total Actual Energy Cost ($/yr)	54,184.75**
Actual Site EUI (kBtu/ft^2/yr)	75.9
Estimated Source EUI (kBtu/ft^2/yr)*	235.0
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	399.2

* Based on Energy Star Target Finder results
** Determined by using the actual average annual utility rates, i.e. 8.838 cents per kwh and $0.5361 per therm

❖ Project Costs

The total capital cost of the building as well as the information regarding the total HVAC cost was not given. Therefore, the cost comparative analysis and the simple payback period calculation for this building were not conducted, due to the lack of such cost information about this building.

The basic building information is summarized in Table F.5.2 below.

Table F.5.2: Building Summary

Building Information

Building Name	United Tribes Technical College - Dormitory
Building Address	Bismarck
Building Type	College/Dormitory
Building Construction Year	2003
Building Total Area (ft^2)	28,032
Total Number of Floor	Above ground: 2
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2003
Installation Type	New
GHP system type	Vertical closed loop
Number of Boreholes for Horizontal GHP	70
Borehole Depth (ft)	200
Borehole Separation Distance (ft)	15
Borehole Length (ft)	14,000
Underground Pipe Length (ft)	28,000
Borehole Length per ton (ft/ton)	171
Underground Pipe Length per ton (ft/ton)	341
GHP water flow rate per ton (gpm/ton)	3.0
Number of Heat Pump Units	Water-to-Air Heat Pump: 24

Total Capacity of Heat Pump Units (tons)	82
Total Capacity of the entire HVAC System (tons)	82
Heat Pump Efficiency Range	Unknown

Cost Information

Capital Cost of the Building ($)	Unknown
Total Cost of the HVAC System ($)	Unknown
HVAC System Average Annual Repair and Maintenance Cost ($)	Unknown
Government Incentives for the Use of GHP	Unknown
Utility Incentives for the Use of GHP	Unknown

Question & Answer

Questions answered by	Greg Pollert gpollert@uttc.edu
1. Why did you decide to install the geothermal heat pump system in your building?	Energy efficiency
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Had some room temperature issues (one room is about 65F and another nearby room is about 85F) due to the fact that one heat pump unit is typically tie to two thermostats for two or three individual rooms, while an average feedback temperature between these two thermostats is used to control the operation of the heat pump
3. As you know, are there any operating difficulties of the geothermal heat pump system?	Several fan motors and compressors went out after operating for 12 years
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes

#6. NDSU Dickinson Research Extension Center (DREC)

❖ Background

The Dickinson Research Extension Center (DREC) (Figure F.6.1) is located in Dickinson, North Dakota, and was built in 2006. This building has an area of about 10,446 ft^2 with 25 offices, 2 conference rooms, 1 library, 1 classroom, and 2 workrooms. This facility is to develop research on crop production for farmers of the region and to improve native and introduced forage crop production for cattle ranchers[1]. This facility is using a vertical closed-loop GHP system to provide space heating and cooling. The total number of vertical boreholes is 30 with the depth of about 200 feet underground. Other features include two Heat Recovery Units (HRUs), VSD water pumps, etc.

Figure F.6.1: Dickinson Research Extension Center (Source: https://www.ag.ndsu.edu/DickinsonREC)

❖ System Description

In the DREC building, 12 water-to-air heat pump units are used to condition the indoor occupied spaces. These heat pump units have the efficiencies between 15.7 ~ 16.8 EER for cooling and 3.2 ~ 3.4 COP for heating. Heat rejection and extraction take place through 30 vertical boreholes with the depth of about 200 feet below the ground and a minimum separation distance of 15 feet, as shown in Figure F.6.2. Two VSD pumps (one is for backup) are used for water circulation within the heat pump building loop, and three constant-speed pumps are used to convey water to the ground loops, as shown in Figure F.6.3. Ventilation requirement for this building is met by two HRUs with the total design air flow rate of 1,430 cfm. Ducts from these units are tied to each heat pump to supply fresh air to each occupied space.

[1] https://www.ag.ndsu.edu/DickinsonREC

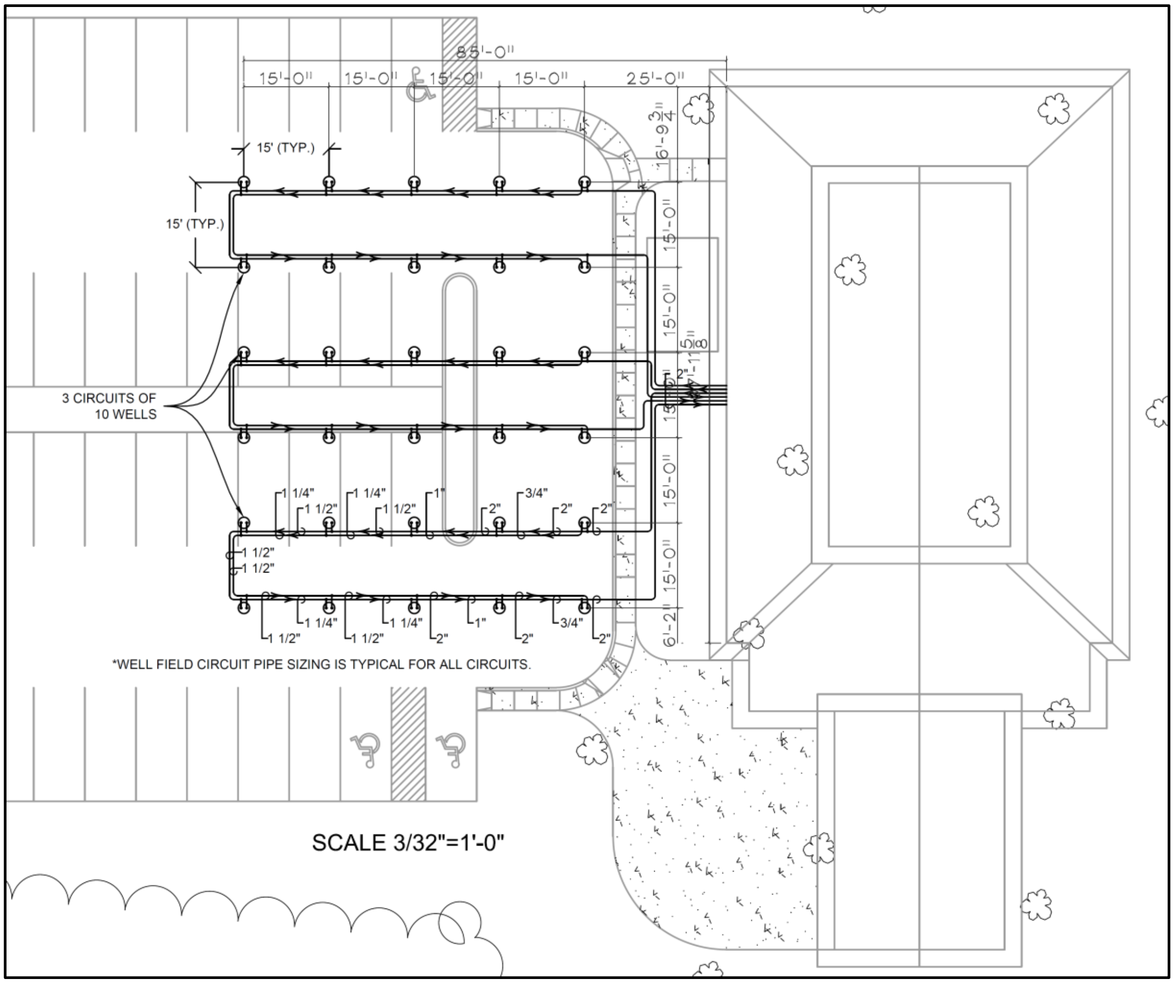


Figure F.6.2: Dickinson Research Extension Center underground boreholes

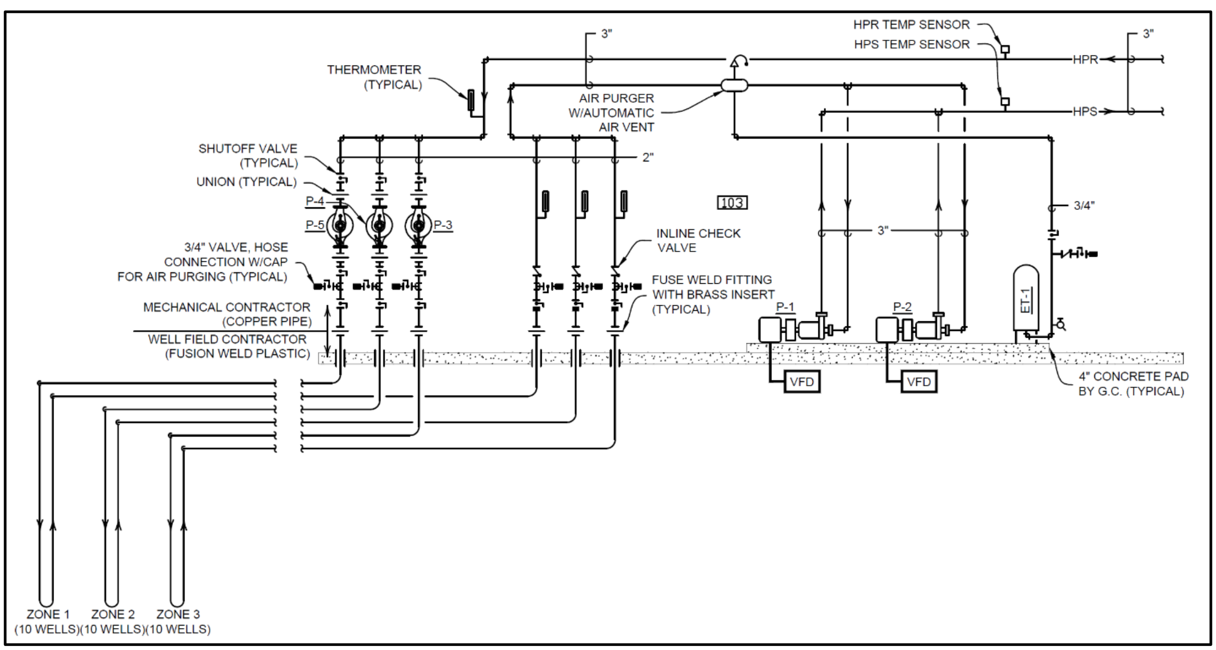


Figure F.6.3: Geothermal system piping schematic

❖ System Performance

The monthly energy use of the DREC building between August, 2015 and July, 2016 is shown in Figure F.6.4, and the corresponding actual site EUI of the building is 49 kBtu/ft^2/yr, which is about 17% lower than the baseline building (with the conventional system defined in the ASHRAE 90.1 – Appendix G) that has a site EUI of 59.4 kBtu/ft^2/yr. The simulation model was established and calibrated against the actual electricity use (Figure F.6.5). As shown in this figure, electricity is the only energy source for this building.

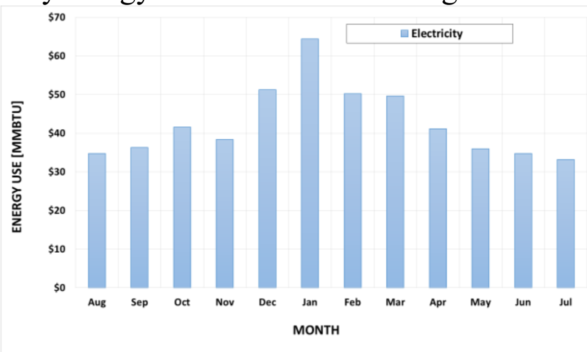


Figure F.6.4: Monthly energy use between 2015 and 2016

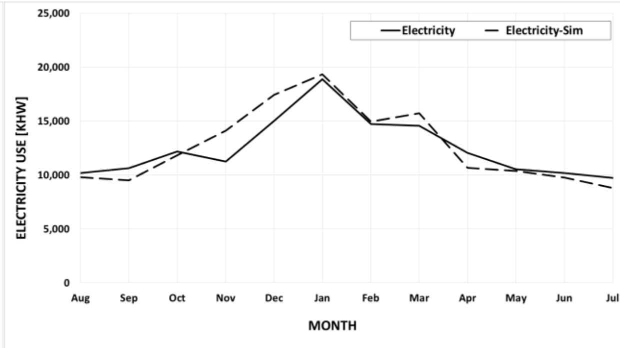


Figure F.6.5: Electricity use comparison

The baseline model for a similar building with a conventional air-conditioning system design was established based on the calibrated model. The difference between these two models is shown in Table F.6.1 below.

Table F.6.1: Model difference

Model with the actual GHP system	Model with a conventional air-conditioning system
Geothermal heat pump systems as designed	Packaged rooftop heat pump with constant volume fan control, direct expansion (DX) cooling and electric heat pump heating (others are the same as the actual system)

The corresponding actual energy cost is displayed in Figure F.6.6 with the total cost of $12,539.7 per year, i.e. $1.2/ft^2/yr.

The energy and energy cost savings for this building are summarized below:

- 17% of energy savings is achieved between the actual building and a similar building with a conventional air-conditioning system;
- 5% of energy and energy cost saving are achieved between the actual building and a similar building based on the EPA's Energy Star Target Finder result for a national median property;
- Energy cost savings between the actual building and a similar building with a conventional air-conditioning system are found (18%), due to the use of the GHP system.

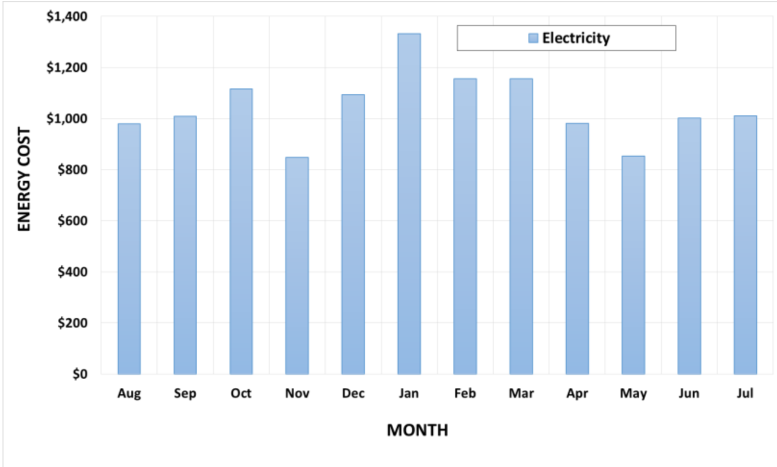


Figure F.6.6: Monthly energy cost between 2015 and 2016

Table F.6.2 shows the performance result of this building in terms of energy and energy cost, where the performance of the existing design is compared to the simulated result of the building that is assumed to use a conventional HVAC and the estimated result of a similar building based on the Energy Star Target Finder result for a national median property.

Table F.6.2: Energy Performance Comparison

	Actual GHP System		ASHRAE Conventional System	Similar Building*
	Actual Utilities	Simulated	Simulated	Estimated as an office building (the national median)*
Electricity Usage (kwh/yr)	150,020	152,364	181,728	157,321
Electricity Cost ($/yr)	12539.7	12916.0	15370.0	13216.3
Natural Gas Usage (therm/yr)	0	0	0	0
Natural Gas Cost ($/yr)	0	0	0	0
Actual Site Energy Usage (MMBTU/yr)	512	520	620	536.8
Estimated Source Energy Usage (MMBTU/yr)*	1,607.3	1,632.4	1,947.0	1,685.7
Total Actual Energy Cost ($/yr)	12,539.7	12,916.0**	15,370.0**	13,216.3**
Actual Site EUI (kBtu/ft²/yr)	49.0	49.8	59.4	51.4
Estimated Source EUI (kBtu/ft²/yr)*	153.9	156.3	186.4	161.4
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	97.5	99.0	118.1	102.3
Energy Savings Compared to Conventional System	17%			
Energy Cost Savings Compared to Conventional System	18%			
Energy Savings Compared to Similar EPA Buildings	5%			
Energy Cost Savings Compared to Similar EPA Buildings	5%			

* Based on Energy Star Target Finder results
** Determined by using the actual average annual utility rates, i.e. 8.36 cents per kwh

The basic building information is summarized in Table F.6.3 below. The cost comparative analysis and the simple payback period calculation for this building were not conducted, due to the limited cost information received from the building owner.

Table F.6.3: Building Summary

Building Information

Building Name	NDSU Dickinson Research Extension Center (DREC)
Building Address	Dickinson
Building Type	College Building/Office
Building Construction Year	2006
Building Total Area (ft^2)	10,446
Total Number of Floor	Above ground: 2
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2006
Installation Type	New
GHP system type	Vertical closed loop
Number of Boreholes for Vertical GHP	30
Borehole Depth (ft)	200
Borehole Separation Distance (ft)	15
Borehole Length (ft)	6,000
Underground Pipe Length (ft)	12,000
Borehole Length per ton (ft/ton)	200
Underground Pipe Length per ton (ft/ton)	400
GHP water flow rate per ton (gpm/ton)	3.5
Number of Heat Pump Units	Water-to-Air Heat Pump: 12
Total Capacity of Heat Pump Units (tons)	30
Total Capacity of the entire HVAC System (tons)	30
Heat Pump Efficiency Range	Cooling: 15.7~16.8 EER Heating: 3.2~3.4 COP

Cost Information

Capital Cost of the Building ($)	1,200,000
Total Cost of the HVAC System ($)	Not Provided
HVAC System Average Annual Repair and Maintenance Cost ($)	Not Provided
Government Incentives for the Use of GHP	Unknown
Utility Incentives for the Use of GHP	Unknown

Question & Answer

Questions answered by	Dr. Kris Ringwall Director Tel: 701-456-1103 kris.ringwall@ndsu.edu
1. Why did you decide to install the geothermal heat pump system in your building?	Not Provided
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Not Provided
3. As you know, are there any operating difficulties of the geothermal heat pump system?	Not Provided
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Not Provided

#7. NDSU Langdon Research Extension Center (LREC)

❖ Background

The Langdon Research Extension Center (LREC) (Figure F.7.1) is located in Langdon, North Dakota, and was built in 2004. This building has an area of about 7,500 ft^2 and mainly consists of offices and conference rooms. This facility is to enhance the quality of life for all North Dakota citizens with a responsive, flexible and accessible agricultural based research program that combines the concepts of agricultural research, university extension, information technology and economic and community development [1]. Previously, this facility used air-cooled condensing units with electric heat to provide space cooling and heating. In 2010, a vertical closed-loop GHP system was installed to replace the existing air-conditioning system, after experiencing significant problems with the original system and due to the motivation of reducing cooling and heating bills. The owner is very happy with the current system, and would like to suggest GHP systems to other building owners or end users. The total number of vertical boreholes is 26 with the depth of about 200 feet underground.

Figure F.7.1: Langdon Research Extension Center (Source: https://www.ag.ndsu.edu/langdonrec/)

❖ System Description

In 2004, a traditional system (air-cooled condensing units with electric heat) was designed and used in the LREC building. After experiencing significant problems with the original system and with a consideration of reducing cooling and heating bills and/or going green, the system was upgraded in 2010 with a GHP system, consisting of 7 water-to-air heat pump units and 26 vertical boreholes with the depth of about 200 feet below the ground surface and a minimum separation distance of 10 feet, as shown in Figure F.7.2. These heat pump units have the efficiencies of 16.2 EER for cooling and 3.3 COP for heating. Two pumps (one is for backup) are used for water circulation between the heat pump building loop and the wellfields (Figure F.7.3). Ventilation requirement for this building is met by one thermal recovery unit with the total design air flow rate of 1,250 cfm. Ducts from these units are tied to each heat pump to supply fresh air to each occupied space.

[1] https://www.ag.ndsu.edu/langdonrec/

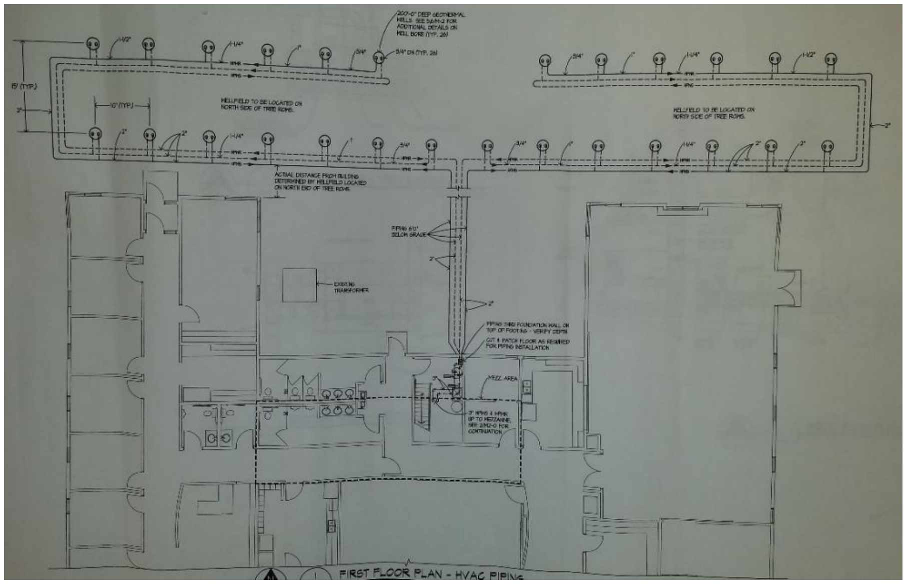


Figure F.7.2: Langdon Research Extension Center underground boreholes

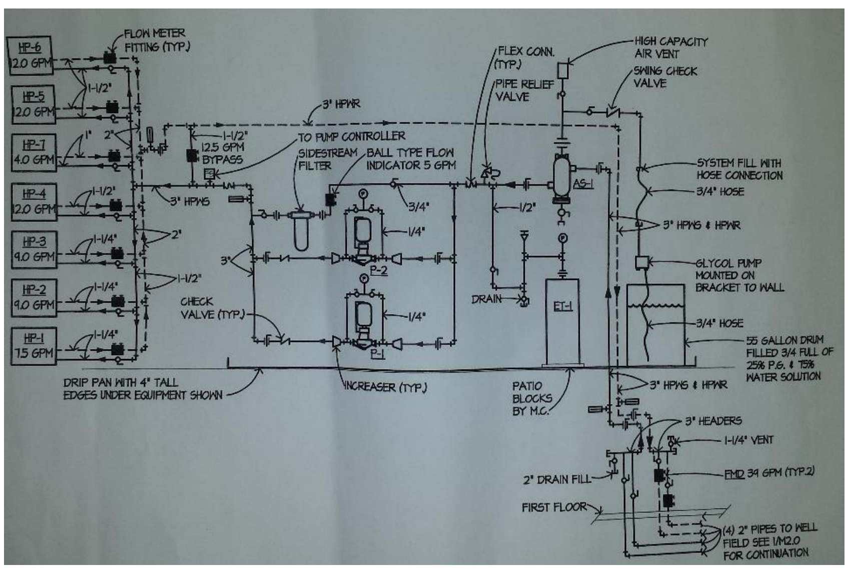


Figure F.7.3: Geothermal system piping schematic

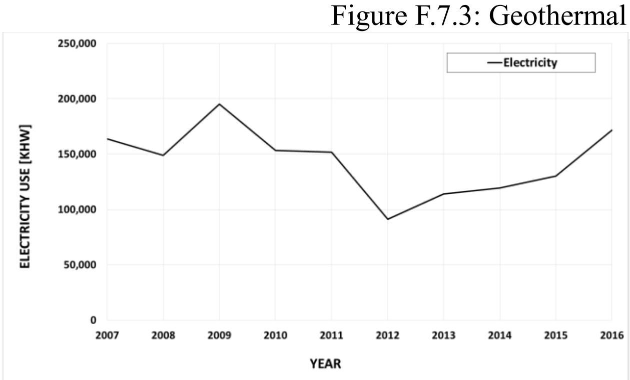


Figure F.7.4: Yearly energy use between 2007 and 2016

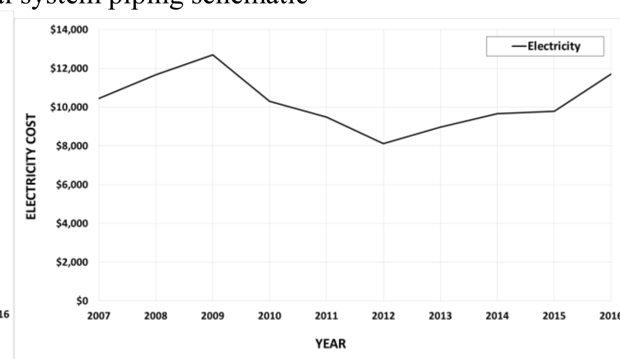


Figure F.7.5: Yearly energy cost between 2007 and 2016

❖ System Performance

The yearly energy use of the LREC building between 2007 and 2016 has been provided by the building owner, where the differences/savings in terms of energy consumption and utility costs before and after the system upgrade can be identified, which are shown in Figure F.7.4 and F.7.5.

As shown in these two figures, a significant decrease is observed in terms of energy usage and expense after the installation and use of the GHP system since 2010. Thereafter, the energy usage and expense were increased gradually, which could be caused by many reasons. The possible reasons for that are listed below, but a detailed analysis and on-site investigation are needed in order to identify the real problems that cause this increase.

- Variable weather – a warmer summer and/or a colder winter
- Performance degradation of building construction materials, such as insulation
- Inappropriate control and operation strategies.
- The low operational efficiency of the GHP system, due to the change of the ground temperature (Ground Temperature Penalty), the lack of regular maintenance services, the short borehole separation distance (less than 15 feet), and/or defective parts in the system.

Table F.7.1: Energy Performance Comparison

	Actual GHP System after 2010	Previous Air-Cooled Condensing Units with Electric Heat before 2010	Similar Building*
	Actual Utilities of 2016	Actual Utilities of 2009	Estimated as an office building (the national median)*
Electricity Usage (kwh/yr)	171,799	195,040	126,616
Electricity Cost ($/yr)	11698.9	12691.0	8693.1
Natural Gas Usage (therm/yr)	0	0	0
Natural Gas Cost ($/yr)	0	0	0
Actual Site Energy Usage (MMBTU/yr)	586	665	431.7
Estimated Source Energy Usage (MMBTU/yr)*	1,840.6	2,089.6	1,355.7
Total Actual Energy Cost ($/yr)	11,698.9	12,691.0**	8,693.08**
Actual Site EUI (kBtu/ft^2/yr)	78.1	88.7	57.6
Estimated Source EUI (kBtu/ft^2/yr)*	245.4	278.6	180.8
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	111.7	126.8	82.3
Energy Savings Compared to Conventional System	12%		
Energy Cost Savings Compared to Conventional System	8%		
Energy Savings Compared to Similar EPA Buildings	-36%		
Energy Cost Savings Compared to Similar EPA Buildings	-35%		

* Based on Energy Star Target Finder results
** Determined by using the actual average annual utility rates, i.e. 6.81 cents per kwh

In looking at the most current year, i.e. 2016, the actual site EUI of the building is 78.1 kBtu/ft^2/yr, which is about 12% lower compared to the energy usage of this building in 2009 when the original system was used. However, its energy consumption is 36% higher in 2016 than that of a similar building (EUI of 57.6 kBtu/ft^2/yr) based on the EPA's Energy Star Target Finder result for a national median property, as shown in Table F.7.1. The EUI of this building is also higher than that of another similar NDSU research center, i.e. Dickinson Research Extension Center (DREC), which has the EUI of 49 kBtu/ft^2/yr in 2016.

The corresponding monthly electricity consumption and its associated cost of this building for the year of 2016 are displayed in Figure F.7.6 and F.7.7. The total energy cost in that year is $11,698.58, i.e. $1.56/ft^2/yr, which is 8% lower than the energy cost of this building in 2009 but is higher than the DREC building that has the energy cost of $1.2/ft^2/yr in 2016.

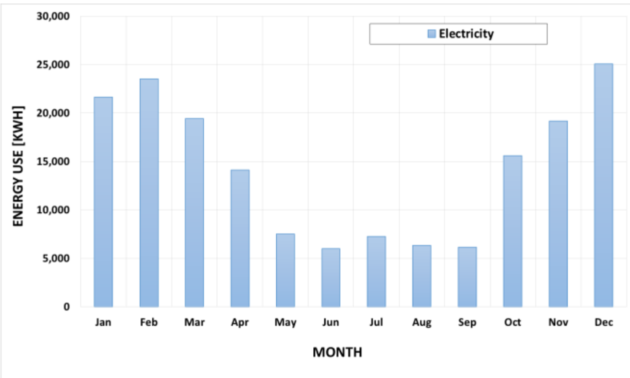


Figure F.7.6: Monthly energy use in 2016

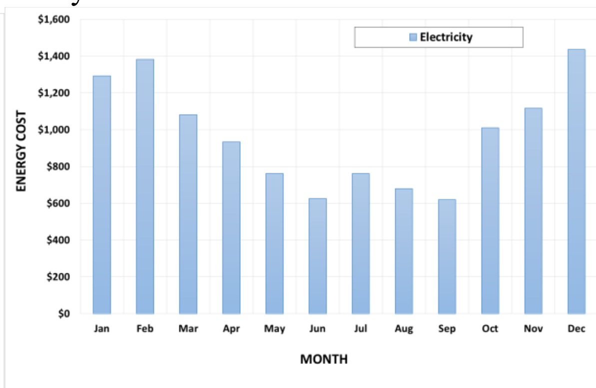


Figure F.7.7: Monthly energy cost in 2016

Table F.7.2: Cost Comparison and Analysis

Actual GHP System			Conventional System	
GHP system:	$144,000.00		Air-Cooled Condensing Units with Electric Heat:	$50,000.00*
Yearly energy cost:	$8,115.9 for 2012	$11,698.9 for 2016	Yearly energy cost:	$12,691.03
HVAC System Average Annual Repair and Maintenance Cost ($)	Not provided		HVAC System Average Annual Repair and Maintenance Cost ($)	-
Simple payback period (Year):	20.5	94.7	-	

* Estimated by using [1], [2], [3], and/or [4]

❖ Project Costs

The original capital cost of the building was given, i.e. $810,000, and the total cost for the GHP system is $144,000[5]. The cost comparative analysis and the simple payback period calculation for this building are shown in Table F.7.2, where the actual GHP system is compared with another alternative, i.e. Air-Cooled Condensing Units with Electric Heat, which is similar as the original system used before 2010. The simple payback periods are calculated, i.e. 20.5 and 94.7 years based on the yearly energy cost of 2012 and 2016, respectively. The difference between two simple payback periods is due to the increase of the yearly energy cost since 2012 (Figure F.7.5). If the current trend continues, it would be not worth installing and using a GHP system in this building (regardless of other factors or considerations, such as thermal comfort, environmental issues, etc.). Therefore, it is suggested for the building owner to look into the system carefully and identify the

1 RS Means data. https://www.rsmeans.com/

2 Climatemaster System Selling Binder. climatemaster.com/downloads/06RepMtg-selling%20wshp-LM.ppt

3 Steve Kavanaugh and Kevin Rafferty. 2014. Geothermal Heating and Cooling Design of Ground-source Heat Pump Systems. ASHRAE. ISBN 978-1-936504855. 1791 Tullie Circle, NE, Atlanta, GA 30329.

4 Bloomquist, R.G., 2001. The economics of geothermal heat pump systems for commercial and institutional buildings. Proceedings of the International Course on Geothermal Heat Pumps, Bad Urach, Germany.

5 2009-2011 Budget Address to the North Dakota Legislative Assembly

problems in order to further lower the energy usage and utility bills. If necessary, a building energy auditing service is suggested.

The basic building information is summarized in Table F.7.3 below.

Table F.7.3: Building Summary

Building Information

Building Name	NDSU Langdon Learning Center
Building Address	Langdon
Building Type	College Building/Office
Building Construction Year	2004
Building Total Area (ft^2)	7,500
Total Number of Floor	Above ground: 1 + Mezzanine
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2010 for Upgrade
Installation Type	Retrofit/Upgrade
GHP system type	Vertical closed loop
Number of Boreholes for Vertical GHP	26
Borehole Depth (ft)	200
Borehole Separation Distance (ft)	10~15
Borehole Length (ft)	5,200
Underground Pipe Length (ft)	10,400
Borehole Length per ton (ft/ton)	224
Underground Pipe Length per ton (ft/ton)	449
GHP water flow rate per ton (gpm/ton)	3.6
Number of Heat Pump Units	Water-to-Air Heat Pump: 7
Total Capacity of Heat Pump Units (tons)	23
Total Capacity of the entire HVAC System (tons)	23
Heat Pump Efficiency Range	Cooling: 16.2 EER Heating: 3.3 COP

Cost Information

Capital Cost of the Building ($)	810,000
Total Cost of the HVAC System ($)	144,000
HVAC System Average Annual Repair and Maintenance Cost ($)	Not Provided
Government Incentives for the Use of GHP	No
Utility Incentives for the Use of GHP	No

Question & Answer

Questions answered by	Randy Mehlhoff Director Tel: 701-256-2582 Cell: 701-305-0276 Fax: 701-256-2580 randall.mehlhoff@ndsu.edu
1. Why did you decide to install the geothermal heat pump system in your building?	Reduce cooling and heating bills More environmentally friendly Were experiencing significant problems with the original system
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Yes
3. As you know, are there any operating difficulties of the geothermal heat pump system?	No
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes

#8. University of North Dakota Gorecki Alumni Center

❖ Background

The Gorecki Alumni Center (GAC) (Figure F.8.1) is located in the University of North Dakota (UND) in Grand Forks, North Dakota. This building has an area of about 38,000 ft^2 with administration areas, a ballroom, conference rooms, etc. for development and alumni services. It was built in late 2012 and is the first LEED Platinum building (LEED BD+C: New Construction v3) in the State of North Dakota. Other features include a GHP system for space cooling and heating, 207 solar photovoltaic (PV) panels for electricity production, VSD fans and water pumps, Air Handling Units (AHUs) with energy recovery, Demand Control Ventilation (DCV) with CO_2 sensors, etc.

Figure F.8.1: Front view of Gorecki Alumni Center
(Source: https://www.obernel.com/portfolio-item/und-gorecki-alumni-center/)

❖ System Description

In the GAC, the space cooling and heating are provided by a vertical closed-loop GHP system with 142 boreholes under a nearby parking lot with a depth of 210 feet (Figure F.8.2) and a separation distance of 15 feet. At the beginning of the design stage, a thermal response test was performed on site during the summer of 2011, in which two test wells (Well 1 and 2) were drilled in order to obtain the accurate knowledge of the thermal characteristics of the local geologic formations. The test results in terms of vertical ground temperature distribution are shown in Figure F.8.3. The depth of the test wells was 200 feet with a test duration of 36 hours. The results in terms of thermal conductivity for Well 1 and 2 were 0.94 and 0.99 Btu/(hr.ft.^{o}F), respectively, which were used to design the vertical closed-loop system.

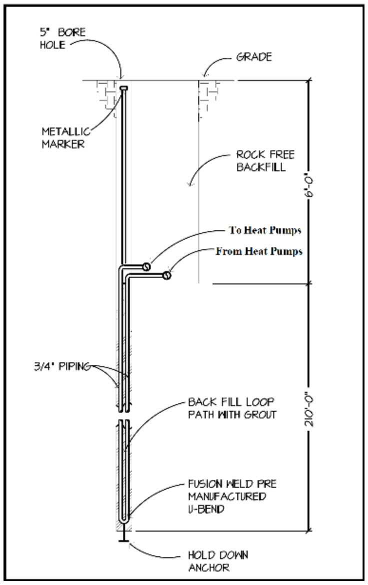


Figure F.8.2: Borehole section

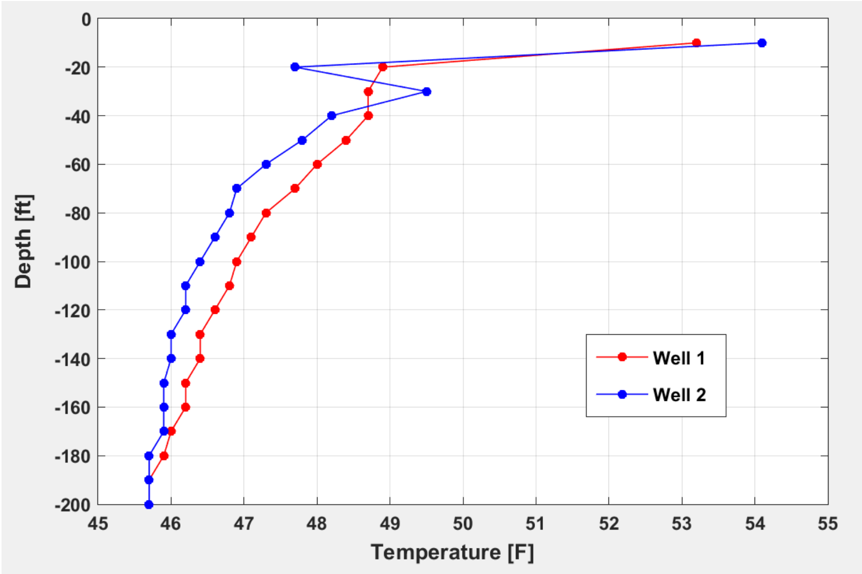


Figure F.8.3: Vertical underground temperatures of Test well 1 & 2

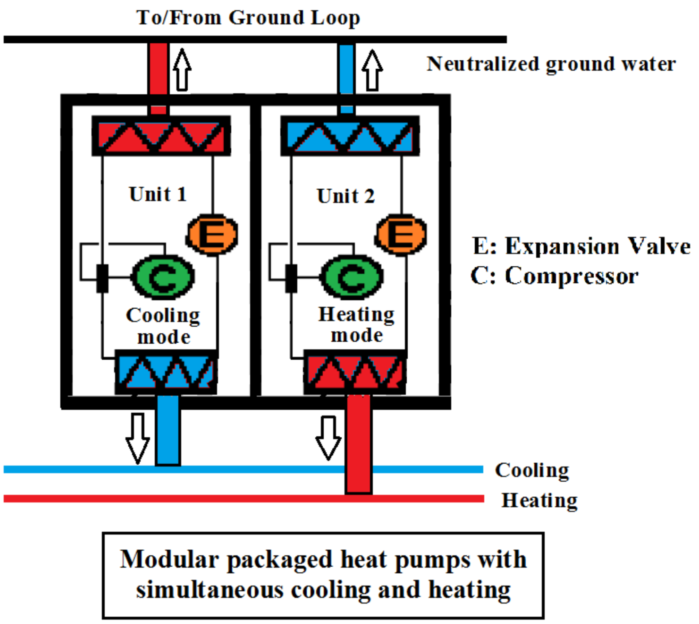


Figure F.8.4: Modular packaged heat pump units with simultaneous cooling and heating (Source: ClimaCool Corp.)

At the water side of the indoor distribution system, simultaneous cold and hot water is provided to terminals by four modular packaged water-to-water heat pumps (similar to Figure F.8.4). This design is intended to achieve a high system performance, and it is reported by the manufacturer's catalog that, in summer, the cooling efficiency at full load is 20.3 EER with a heating mode efficiency (the use of reheat coils) of up to 6.93 COP. Figure F.8.5 shows the detailed design piping schematics for both the outdoor and indoor loops. The water-to-water heat pumps are controlled to maintain 120°F and 44°F supply water temperatures in both heating and cooling modes, respectively, by cycling all module compressors as necessary.

At the air side, three AHUs are connected with multiple VAV boxes (with hot-water reheat coils) through ductwork to deliver conditioned air to each space.

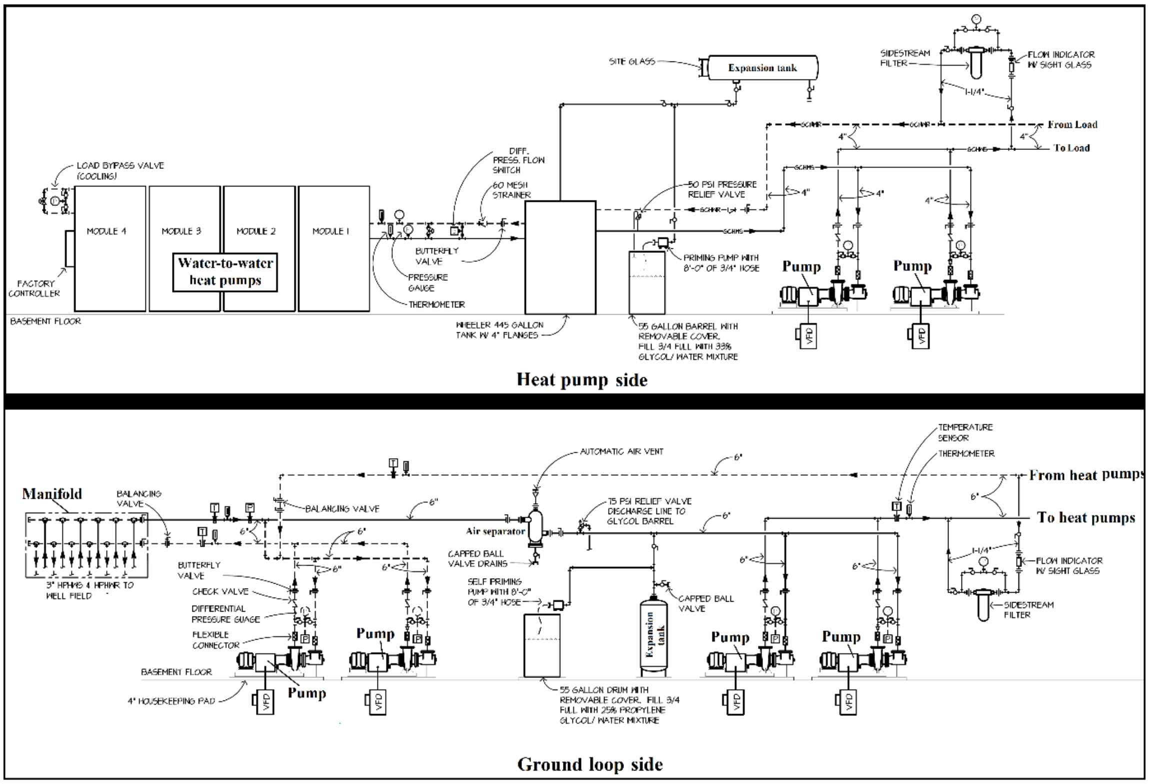


Figure F.8.5: Piping schematic of GAC

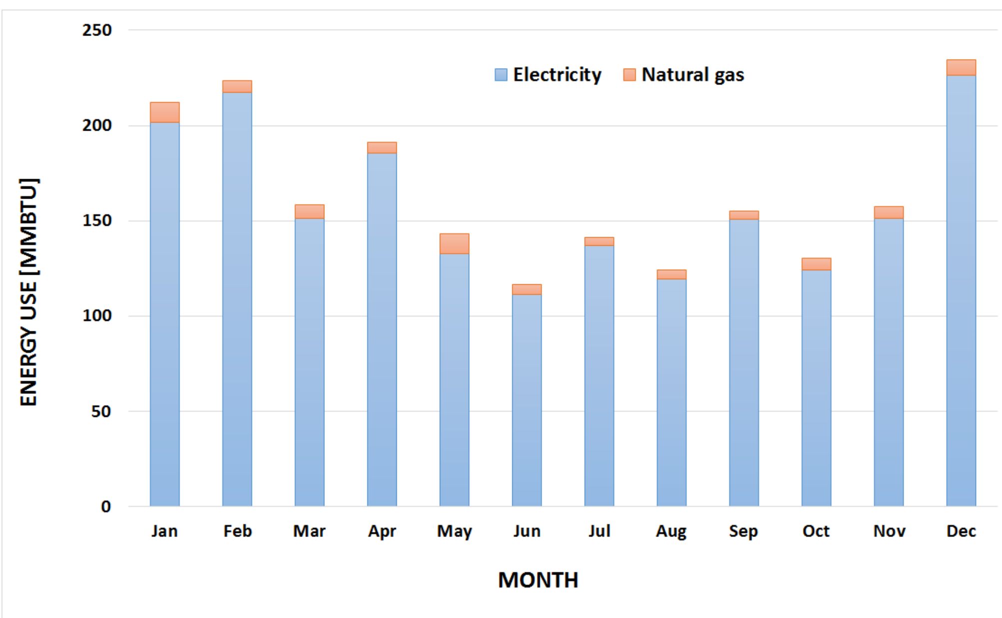


Figure F.8.6: Monthly energy use of 2015

❖ System Performance

The monthly energy use of the GAC for the year of 2015 is shown in Figure F.8.6, and the corresponding actual site EUI of the building is 52.3 kBtu/ft^2/yr, which is about 39% lower compared to a similar building with a site EUI of 85.9 kBtu/ft^2/yr (the EPA's Energy Star Target Finder result for the median property, as shown in Table F.8.1). As shown in Figure F.8.6, electricity is the major energy use, due to the heavy use of GHPs for both space cooling and heating.

Table F.8.1: Energy Performance Comparison

	Actual GHP System	Similar Building*
	Actual Utilities	Estimated (the national median)*
Electricity Usage (kwh/yr)	724,759	-
Electricity Cost ($/yr)	52,994.37	-
Natural Gas Usage (therm/yr)	1,018	-
Natural Gas Cost ($/yr)	Not Provided	-
Actual Site Energy Usage (MMBTU/yr)	1,988	3,264
Estimated Source Energy Usage (MMBTU/yr)*	6,077.2	9,978.4
Total Actual Energy Cost ($/yr)	Not Provided	-
Actual Site EUI (kBtu/ft^2/yr)	52.3	85.9
Estimated Source EUI (kBtu/ft^2/yr)*	159.9	262.6
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	367.9	604.1
Energy Savings Compared to Similar EPA Buildings	39%	

* Based on Energy Star Target Finder results

** Determined by using the actual average annual utility rates, i.e. 7.31 cents per kwh and $0.526 per therm

The cost comparative analysis and the simple payback period calculation for this building were not conducted due to the limited cost information received from the building owner. The basic building information is summarized in Table F.8.2 below.

Table F.8.2: Building Summary

Building Information

Building Name	UND Gorecki Alumni Center
Building Address	Grand Forks
Building Type	College
Building Construction Year	2012
Building Total Area (ft^2)	38,000
Total Number of Floor	Above ground: 3 Below ground: 1
LEED Building	Yes - LEED Platinum

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2012
Installation Type	New
GHP system type	Vertical closed loop
Number of Boreholes for Vertical GHP	142
Borehole Depth (ft)	210
Borehole Separation Distance (ft)	15
Borehole Length (ft)	29,820
Underground Pipe Length (ft)	59,640
Borehole Length per ton (ft/ton)	216
Underground Pipe Length per ton (ft/ton)	432
GHP water flow rate per ton (gpm/ton)	3.6
Number of Heat Pump Units	Water-to-Air Heat Pump: 4 Water-to-Water Heat Pump: 1
Total Capacity of Heat Pump Units (tons)	138
Total Capacity of the entire HVAC System (tons)	224

Heat Pump Efficiency Range	Cooling: 15.4~20.1 EER Heating: 3.4·3.5 COP

Cost Information

Capital Cost of the Building ($)	12,000,000
HVAC System Average Annual Repair and Maintenance Cost ($)	Not Provided
Government Incentives for the Use of GHP	No
Utility Incentives for the Use of GHP	No

Question & Answer

Questions answered by	Robert S. Knutson Chief Operating Officer of UND Gorecki Alumni Center (800) 543-8764 (701) 777-4665 bobk@undalumni.net
1. Why did you decide to install the geothermal heat pump system in your building?	Green product environment concerns
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Yes and no complaint.
3. As you know, are there any operating difficulties of the geothermal heat pump system?	No
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes, if they can afford it.

#9. Williston State College (WSC) Frontier Residence Hall

❖ Background

The WSC Frontier Residence Hall (Figure F.9.1) is located in Williston, North Dakota. This building was built in 2011, and has an area of about 60,841 ft^2, mainly consisting of dormitory rooms for students. It is the primary dormitory on the WSC campus. It can hold up to 171 students in four bedroom suites. Other features include a GHP system for space cooling and heating, VSD fans and water pumps, an ERU to provide ventilation, etc.

Figure F.9.1: WSC Frontier Residence Hall
(Source: https://architizer.com/projects/williston-state-college-frontier-residence-hall/)

❖ System Description

In the WSC Frontier Residence Hall, 42 water-to-air heat pump units are used to condition the indoor occupied spaces. Heat rejection and extraction take place through 120 vertical boreholes with the depth of about 300 feet below the ground and a minimum separation distance of 20 feet, as shown in Figure F.9.2. Water in this system is circulated between the heat pumps and the ground loops through VSD water pumps, as shown in Figure F.9.3. Ventilation requirement for this building is met by one ERU with the total design air flow rate of 6,705 cfm. Ducts from this ERU are tied to each heat pump to supply fresh air to each occupied space.

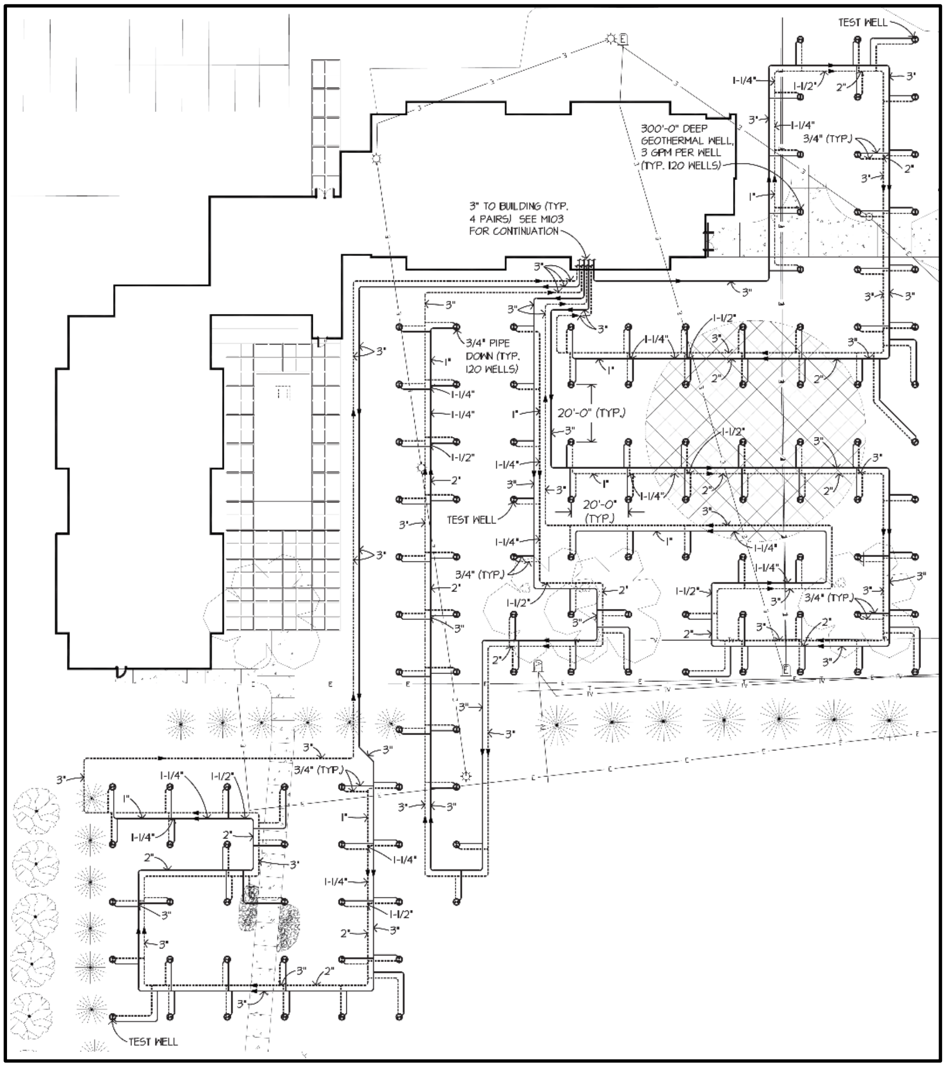


Figure F.9.2: WSC Frontier Residence Hall underground boreholes

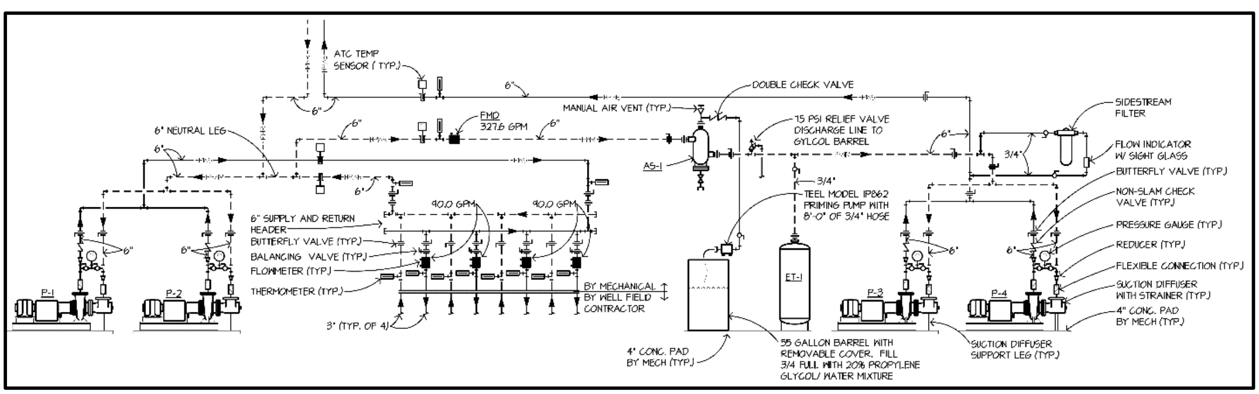


Figure F.9.3: WSC Frontier Residence Hall heat pump piping detail

❖ System Performance

The utility bills of the building were not provided. Therefore, the energy performance analysis of this residence hall was not conducted due to the lack of such necessary information. The performance of a similar building, however, is given in Table F.9.1, which is based on the EPA's Energy Star Target Finder result for a national median property.

Table F.9.1: Energy Performance Comparison

	Similar Building*
	Estimated (the national median)*
Electricity Usage (kwh/yr)	-
Electricity Cost ($/yr)	-
Natural Gas Usage (therm/yr)	-
Natural Gas Cost ($/yr)	-
Actual Site Energy Usage (MMBTU/yr)	7,190.2
Estimated Source Energy Usage (MMBTU/yr)*	13,702.6
Total Actual Energy Cost ($/yr)	104,850.03**
Actual Site EUI (kBtu/ft^2/yr)	118.2
Estimated Source EUI (kBtu/ft^2/yr)*	225.2
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	786.4

* Based on Energy Star Target Finder results
** Determined by using the 2016 average electricity and natural gas rates for the state of North Dakota, i.e. 8.96 cents per kwh and $0.526 per therm [1]

❖ Project Costs

The total capital cost of the building is known as $9,875,000, where the construction cost is about $8,188,158, including foundation and building construction, infrastructure and utilities, mechanical and electrical systems, etc. The information regarding the total HVAC cost, however, was not given. Therefore, the cost comparative analysis and the simple payback period calculation for this building were not conducted, due to the lack of such cost information about this building.

The basic building information is summarized in Table F.9.2 below.

Table F.9.2: Building Summary

Building Information

Building Name	Williston State College - Frontier Residence Hall
Building Address	Williston
Building Type	College/Dormitory
Building Construction Year	2011
Building Total Area (ft^2)	60,841
Total Number of Floor	Above ground: 4 Below ground: 1
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2011
Installation Type	New
GHP system type	Vertical closed loop
Number of Boreholes for Horizontal GHP	120
Borehole Depth (ft)	300
Borehole Separation Distance (ft)	20
Borehole Length (ft)	36,000

[1] https://www.eia.gov/dnav/ng/ng_pri_sum_dcu_SND_a.htm

Underground Pipe Length (ft)	72,000
Borehole Length per ton (ft/ton)	235
Underground Pipe Length per ton (ft/ton)	471
GHP water flow rate per ton (gpm/ton)	3.1
Number of Heat Pump Units	Water-to-Air Heat Pump: 42
Total Capacity of Heat Pump Units (tons)	153
Total Capacity of the entire HVAC System (tons)	188
Heat Pump Efficiency Range	Cooling: 14~17.7 EER Heating: 3.1~3.9 COP

Cost Information

Construction Cost of the Building ($)	8,188,158
Total Cost of the HVAC System ($)	Unknown
HVAC System Average Annual Repair and Maintenance Cost ($)	$46,800 for maintenance person
Government Incentives for the Use of GHP	Unknown
Utility Incentives for the Use of GHP	Unknown

Question & Answer

Questions answered by	Vincent Pachuilo Vice President Tel: 701-774-4250 vincent.pachuilo@willistonstate.edu
1. Why did you decide to install the geothermal heat pump system in your building?	Frontier Hall and its geothermal system were completed prior to my arrival at Williston State College in October of 2014. My first assignment at the college was as the Director for Campus Services/ Facilities, so I am familiar with the building.
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Not Provided
3. As you know, are there any operating difficulties of the geothermal heat pump system?	We have not had issue with the geothermal system, although the air handlers have been problematic. Frontier Hall's HVAC system is controlled by Johnson Control's Metasys System which Aaron Shapiro, our Assistant Director of Campus Services has been trained to utilize.
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Not Provided

#10. Discovery Middle School

❖ Background

The Discovery Middle School (Figure F.10.1) is located in Fargo, North Dakota. This building has an area of about 205,000 ft^2 with gyms, multipurpose rooms, classrooms, locker rooms, offices, conference rooms, libraries, dining areas, studios, a kitchen, and an auditorium (Figure F.10.2 and F.10.3). It was built in 1992 and finished in 1994. This facility was installed with a vertical closed-loop GHP system to provide space heating and cooling. The total number of vertical boreholes is 688 with the depth of about 150 feet underground. It was the first large school that was installed with this type of system at that time in North Dakota[1]. This GHP system has been used for more than 20 years and has provided this school with great and reliable services, as mentioned by Jim Frueh, the director of Fargo schools maintenance and operations.

Figure F.10.1: Discovery Middle School
(Source: www.fargo.k12.nd.us/cms/lib/ND01911460/Centricity/ModuleInstance/458/Discovery_building_850.jpg)

❖ System Description

In the Discovery Middle School building, 173 water-to-air heat pump units were originally installed to condition the indoor occupied spaces. In 2013, the school started to replace the old heat pump units that are about 20 years old and now reaching the end of their lifespan. The replacement heat pump units have higher efficiencies (26~30 EER) compared to the old ones with the cooling efficiency between 12~15 EER. The original underground loops have been still used for heat rejection and extraction, whose lifespan is usually about 40 ~50 years. The underground loop has 688 vertical boreholes with the depth of about 150 feet below the ground surface and a minimum separation distance of 10 feet, as shown in Figure F.10.4. It seems this building has not had the issue of warm ground due to the short borehole separation distance (10 feet) less than the minimum requirement, i.e. 15 feet (like the National Energy Center of Excellence building does). Although there are no negative complaints or issues reported by the building owner regarding warm ground/low heat pump efficiency/high utility cost, the expected savings, because of the use of

[1] https://www.fargo.k12.nd.us/cms/lib/ND01911460/Centricity/domain/94/journey/directors%20columns/20160225%20-%20Frueh%20-%20Heat%20Pumps.pdf

GHPs in terms of energy and energy cost, are not achieved (see the following section). Ventilation requirement for this building is met by multiple Dedicated Outdoor Air Systems (DOASs) that duct fresh air to each heat pump unit, which is then supplied to occupied spaces after mixing with return air.

Figure F.10.2: Discovery Middle School – First Floor

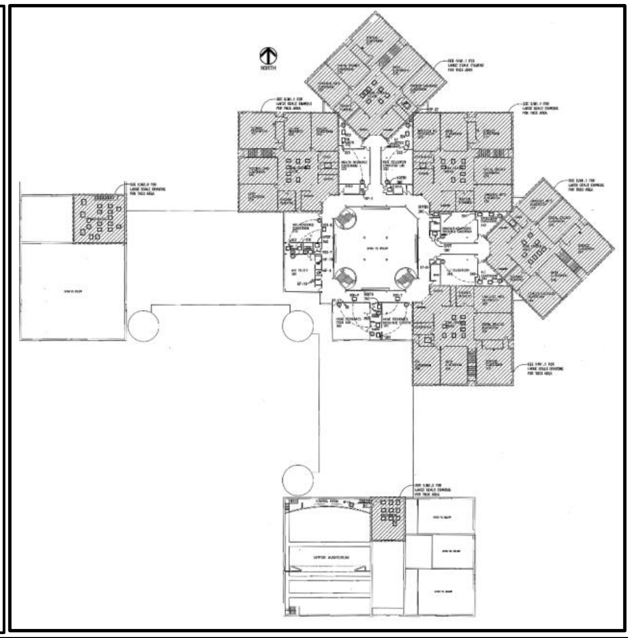


Figure F.10.3 Discovery Middle School – Second Floor

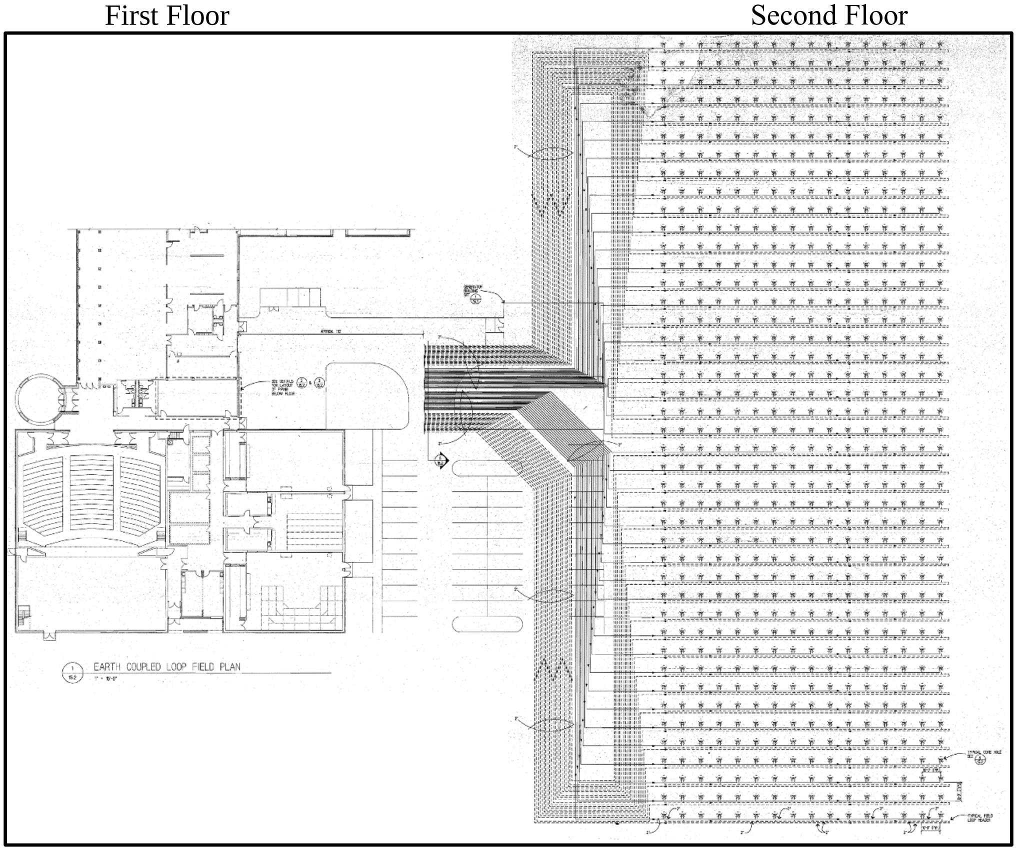


Figure F.10.4: Discovery Middle School – Underground Loop

❖ System Performance

The monthly energy use of the Discovery Middle School building for the year of 2016 was given and is displayed in Figure F.10.5, F.10.6, and F.10.7 with the total energy use of 11,590 MMBTU, i.e. 57 kBtu/ft^2/yr (EUI). The corresponding monthly energy cost of this building is shown in Figure F.10.8 with the total yearly energy cost of $210,700.27 (Electricity: $206,025; Natural gas: $4,675.27), i.e. $1.03/ft^2/yr.

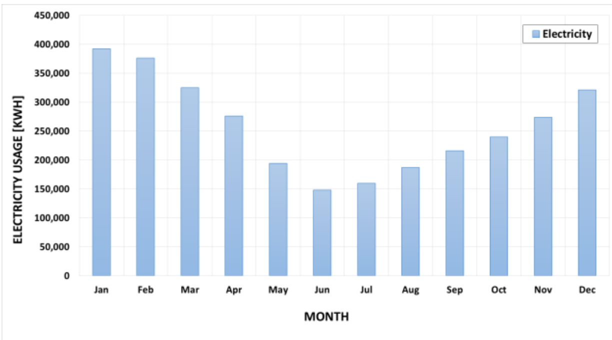


Figure F.10.5: Electricity usage during 2016

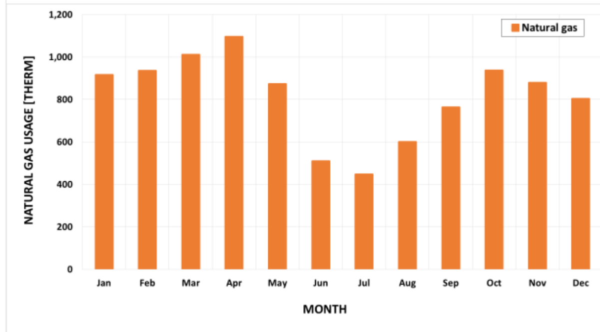


Figure F.10.6: Natural gas usage during 2016

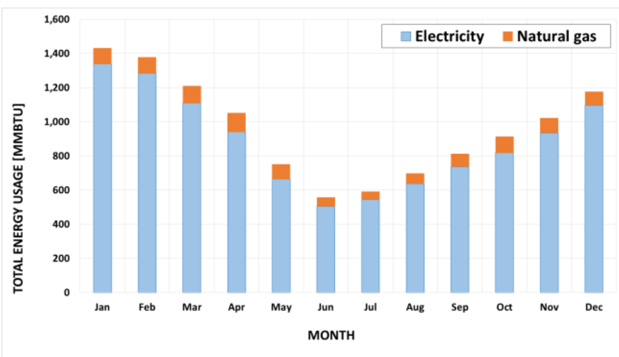


Figure F.10.7: Total energy usage during 2016

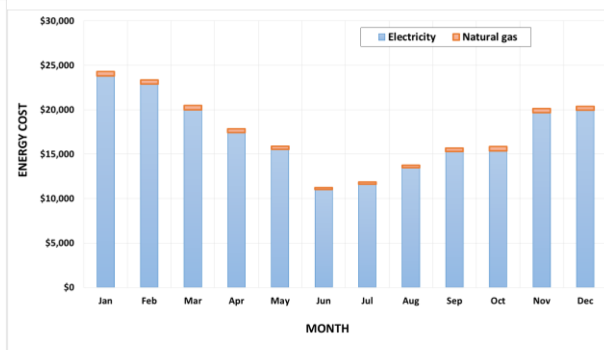


Figure F.10.8: Monthly energy cost during 2016

In order to identify the potential energy and energy cost savings of the building, the actual energy consumption result of this building was eventually compared with the EPA's Energy Star Target Finder result which represents the national median of the energy performance of similar buildings in the U.S. These results are shown in Table F.10.1, which indicate that this building consumes 34% more energy than a similar school building per the Energy Star Target Finder result. The higher energy usage may be caused by many factors, e.g. the design flaw of the short separation distance (10 feet) between boreholes, which may result in the reduction of heat pump efficiency due to warm return water temperatures from the ground loop during winter seasons. Therefore, a detailed analysis and on-site investigation are suggested in order to identify the real problems that cause the high energy use.

Table F.10.1: Energy Performance Comparison

	Actual GHP System	Similar Building*
	Actual Utilities	Estimated (the national median)*
Electricity Usage (kwh/yr)	3,110,180	-
Electricity Cost ($/yr)	206,025.00	-
Natural Gas Usage (therm/yr)	9,776	-
Natural Gas Cost ($/yr)	4,675.27	-
Actual Site Energy Usage (MMBTU/yr)	11,590	8,676.3
Estimated Source Energy Usage (MMBTU/yr)*	34,348.0	25,714.1
Total Actual Energy Cost ($/yr)	210,700.27	157,737.11**
Actual Site EUI (kBtu/ft^2/yr)	57	42.3
Estimated Source EUI (kBtu/ft^2/yr)*	167.6	125.4
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	2,073.8	1,552.5
Energy Savings Compared to Similar EPA Buildings	-34%	
Energy Cost Savings Compared to Similar EPA Buildings	-34%	

* Based on Energy Star Target Finder results
** Determined by using the actual average annual utility rates, i.e. 6.624 cents per kwh and $0.478 per therm

❖ Project Costs

The total capital cost of the building was given, i.e. $12,890,949, but the information regarding the total HVAC cost was unknown. Therefore, the cost comparative analysis and the simple payback period calculation for this building were not conducted, due to the lack of such cost information about this building.

The basic summary information of this building is shown in Table F.10.2 below.

Table F.10.2: Building Summary

Building Information

Building Name	Discovery Middle School
Building Address	Fargo
Building Type	School
Building Construction Year	1994
Building Total Area (ft^2)	205,000
Total Number of Floor	Above ground: 2
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	Ground loop and heat pumps: 1994 73 replacement heat pumps: 2013
Installation Type	Retrofit
GHP system type	Vertical closed loop
Number of Boreholes for Vertical GHP	688
Borehole Depth (ft)	150
Borehole Separation Distance (ft)	10
Borehole Length (ft)	103,200
Underground Pipe Length (ft)	206,400
Borehole Length per ton (ft/ton)	-
Underground Pipe Length per ton (ft/ton)	-
GHP water flow rate per ton (gpm/ton)	-
Number of Heat Pump Units	Old Water-to-Air Heat Pump: 173 Replacement Water-to-Air Heat Pump: 73 for classrooms in 2013

Total Capacity of Heat Pump Units (tons)	-
Total Capacity of the entire HVAC System (tons)	-
Heat Pump Efficiency Range	Old heat pumps for cooling: 12~15 EER Replacement heat pumps for cooling: 26~30 EER

Cost Information

Capital Cost of the Building ($)	12,890,949
Total Cost of the HVAC System ($)	Not Provided
HVAC System Average Annual Repair and Maintenance Cost ($)	100,000 (Heat pump upgrade/replacement)
Government Incentives for the Use of GHP	Unknown
Utility Incentives for the Use of GHP	Unknown

Question & Answer

Questions answered by	Jim Frueh Maintenance & Operations Director Tel: 701-446-1023 Fax: 701-446-1200 fruehj@fargo.k12.nd.us
1. Why did you decide to install the geothermal heat pump system in your building?	Green product environment concerns
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Heat pump replacement costs are expensive
3. As you know, are there any operating difficulties of the geothermal heat pump system?	1. When heat pumps are out, there is no heating in rooms. So we must supplement electric units. 2. Heat pump was sized for heating, but typically it is too big for cooling (overcooling).
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes

#11. Kennedy Elementary School

❖ Background

The Kennedy Elementary School (Figure F.11.1) is located in Fargo, North Dakota. This building has an area of about 89,667 ft^2 with gyms, multipurpose rooms, classrooms, computer rooms, offices, conference rooms, dining areas, a media center, a kitchen, etc. (Figure F.11.2). It was built in 2007, and in 2012 several classrooms were added to the existing building (Figure F.11.3) with the installation and use of 9 additional heat pump units to condition these new areas. This entire facility was installed with a vertical closed-loop GHP system to provide space heating and cooling. The total number of vertical boreholes is 288 with the depth of about 150~200 feet underground.

Figure F.11.1: Kennedy Elementary School
(Source: http://fargocityguide.com/kennedy-elementary-school/)

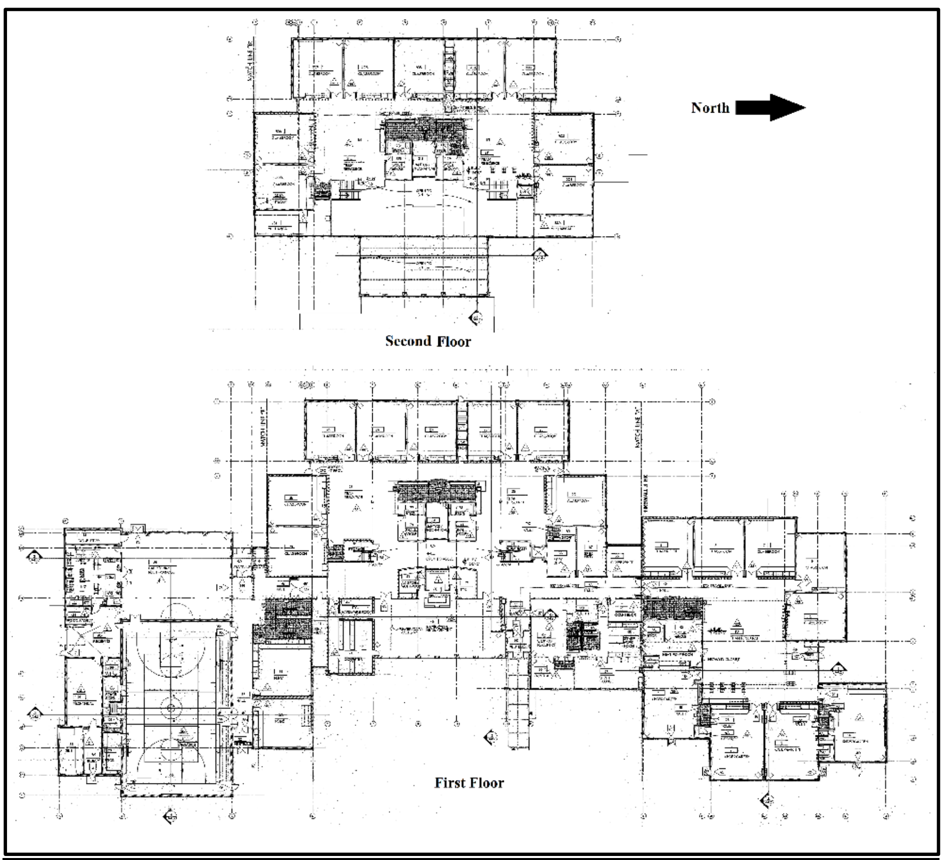


Figure F.11.2: Kennedy Elementary School Floor Plan

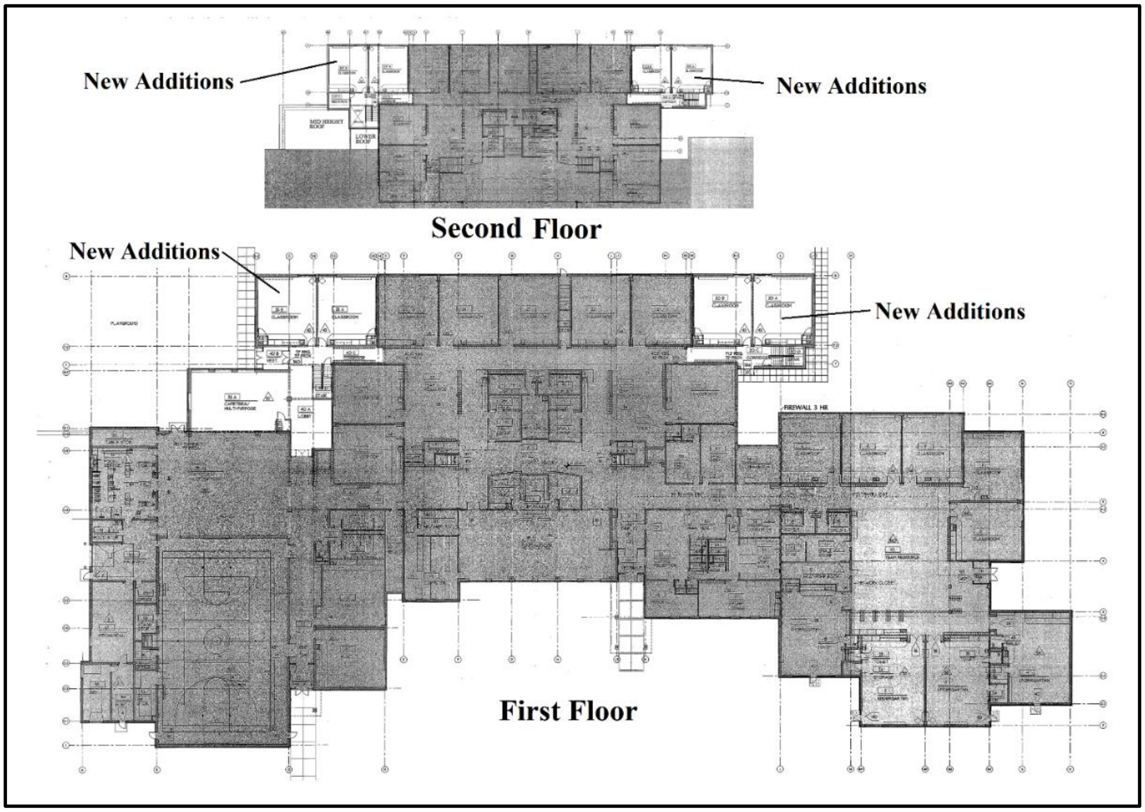


Figure F.11.3: Kennedy Elementary School Floor Plan with New Additions

❖ System Description

In the Kennedy Elementary School building, 49 water-to-air heat pump units were originally installed to condition the indoor occupied spaces (including two ERUs with heat pump cooling and heating modes). Another water-to-water heat pump is used to provide cold and hot water to an AHU. In 2012, several new classrooms were added to the existing building as shown in Figure F.11.3. Therefore, 9 additional water-to-air heat pump units were installed at that time. These new heat pumps share the same ground loop with other existing heat pump units. The efficiencies of these heat pump units used in this building are between 13.7 ~ 16.4 EER for cooling and 3.2 ~ 3.9 COP for heating. Heat rejection and extraction take place through 288 vertical boreholes with the depth of about 150~200 feet below the ground and a separation distance of between 8 and 12 feet, as shown in Figure F.11.4. Water in this system is circulated between the heat pumps and the ground loops through two VSD pumps (one is for backup). Ventilation requirement for this building is met by two ERUs with the total design air flow rate of 15,600 cfm. Ducts from these units are tied to each heat pump to supply fresh air to each occupied space. Other features include, VSD fans, Demand Control Ventilation (DCV) with CO_2 sensors in classrooms, occupancy and daylighting sensors, etc.

It seems this building has not had the issue of warm ground (Ground Temperature Penalty) due to the fact that the design separation distance (8~12 feet) between boreholes is less than the minimum requirement, i.e. 15 feet. Although there are no negative complaints or issues reported regarding warm ground/low heat pump efficiency/high utility cost, more savings could be achieved if the minimum separation distance requirement would be met in the original design.

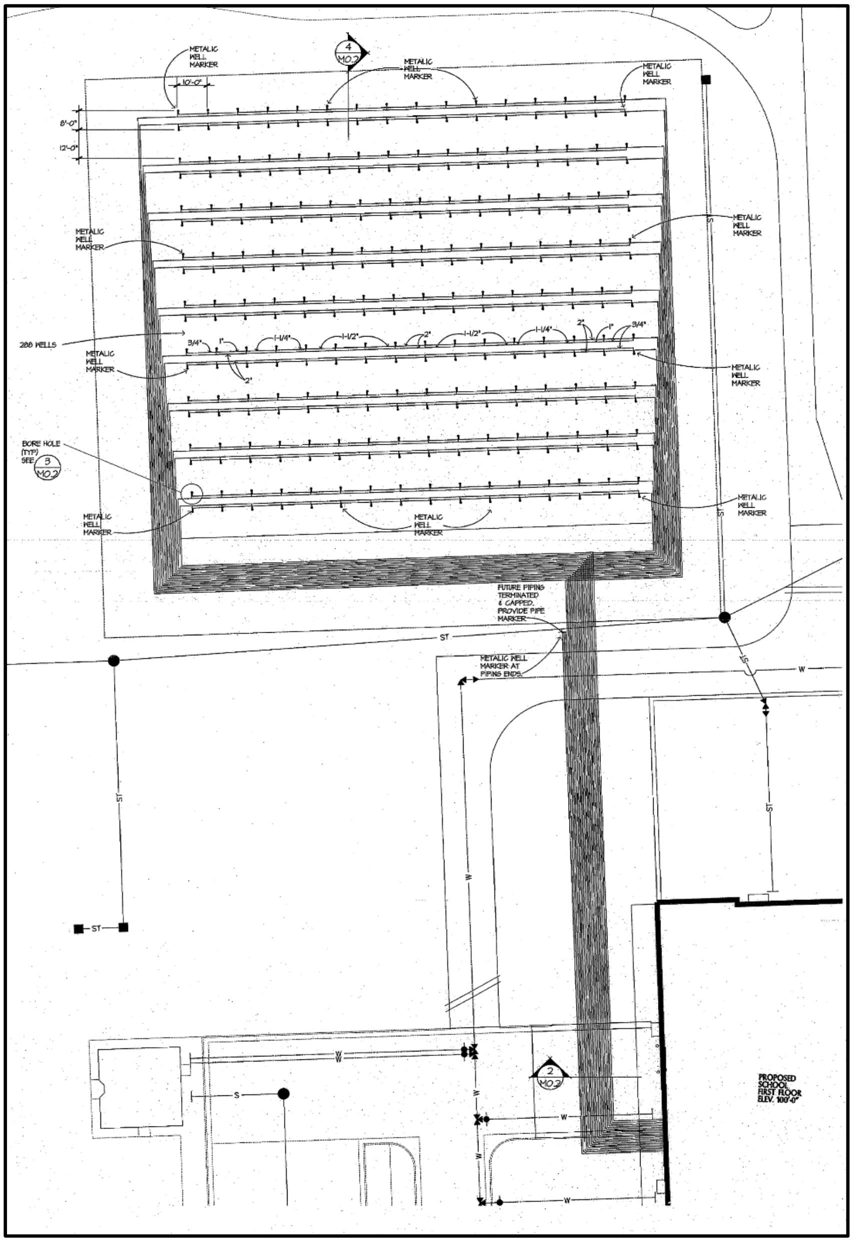
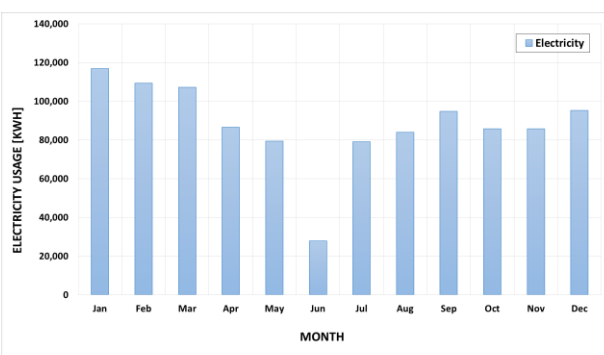


Figure F.11.4: Kennedy Elementary School – Underground Loop



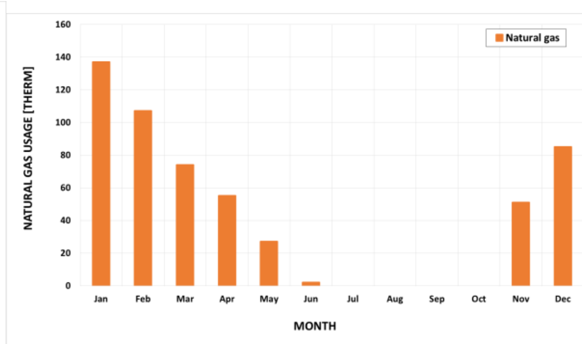


Figure F.11.5: Electricity usage during 2016

Figure F.11.6: Natural gas usage during 2016

❖ System Performance

The monthly energy use of the Kennedy Elementary School building for the year of 2016 was given and is displayed in Figure F.11.5, F.11.6, and F.11.7 with the total energy use of 3,643 MMBTU, i.e. 41 kBtu/ft^2/yr (EUI). The corresponding monthly energy cost of this building is shown in Figure F.11.8 with the total yearly energy cost of $78,915.72 (Electricity: $78,300; Natural gas: $615.72), i.e. $0.88/ft^2/yr.

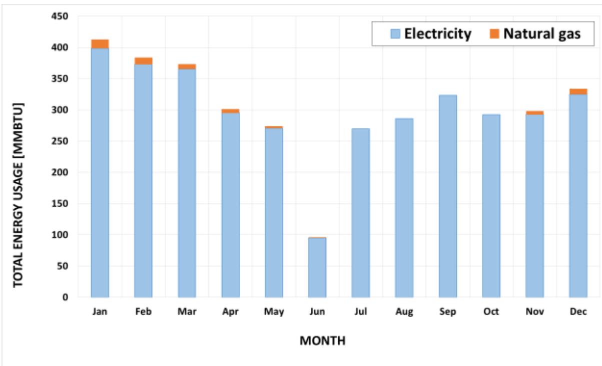


Figure F.11.7: Total energy usage during 2016

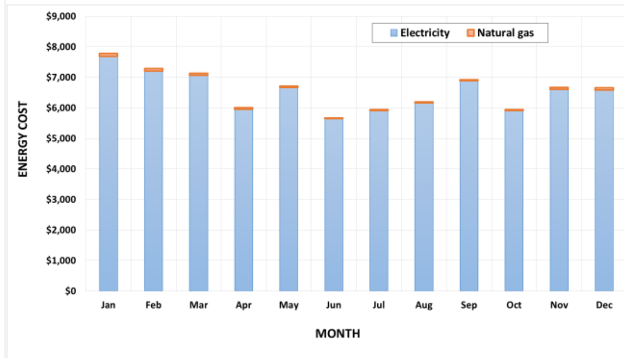


Figure F.11.8: Monthly energy cost during 2016

In order to identify the potential energy and energy cost savings of the building, the actual energy consumption result of this building was eventually compared with the EPA's Energy Star Target Finder result which represents the national median of the energy performance of similar buildings in the U.S. These results are shown in Table F.11.1, which indicate that this building consumes 10% less energy than a similar school building per the Energy Star Target Finder result. The corresponding energy cost savings is 11%, due to the use of the GHP system.

Table F.11.1: Energy Performance Comparison

	Actual GHP System	Similar Building*
	Actual Utilities	Estimated (the national median)*
Electricity Usage (kwh/yr)	1,052,040	-
Electricity Cost ($/yr)	78,300.00	-
Natural Gas Usage (therm/yr)	538	-
Natural Gas Cost ($/yr)	615.72	-
Actual Site Energy Usage (MMBTU/yr)	3,643	4,039.1
Estimated Source Energy Usage (MMBTU/yr)*	11,327.7	12,558.1
Total Actual Energy Cost ($/yr)	78,915.72	88,455.88**
Actual Site EUI (kBtu/ft^2/yr)	41	45.0
Estimated Source EUI (kBtu/ft^2/yr)*	126.3	140.1
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	686.8	761.4
Energy Savings Compared to Similar EPA Buildings	10%	
Energy Cost Savings Compared to Similar EPA Buildings	11%	

* Based on Energy Star Target Finder results
** Determined by using the actual average annual utility rates, i.e. 7.44 cents per kwh and $1.145 per therm

❖ Project Costs

The total capital cost of the building was given, i.e. $12,204,623.17, but the information regarding the total HVAC cost was unknown. Therefore, the cost comparative analysis and the simple payback period calculation for this building were not conducted, due to the lack of such cost information about this building.

The basic summary information of this building is shown in Table F.11.2 below.

Table F.11.2: Building Summary

Building Information

Building Name	Kennedy Elementary School
Building Address	Fargo
Building Type	School
Building Construction Year	2007 2012 for New Addition
Building Total Area (ft^2)	89,667
Total Number of Floor	Above ground: 2
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2007 with 50 heat pumps 2012 for New Addition with 9 new heat pumps
Installation Type	New
GHP system type	Vertical closed loop
Number of Boreholes for Vertical GHP	288
Borehole Depth (ft)	Unknown (Approximately 150~200)
Borehole Separation Distance (ft)	8~12
Borehole Length (ft)	43,200
Underground Pipe Length (ft)	86,400
Borehole Length per ton (ft/ton)	198
Underground Pipe Length per ton (ft/ton)	395
GHP water flow rate per ton (gpm/ton)	4.0
Number of Heat Pump Units	Water-to-Air Heat Pump: 49 with two heat pump ERUs Water-to-Water Heat Pump: 1 for serving AHU-1 Additional Water-to-Air Heat Pump: 9 for building addition in 2012
Total Capacity of Heat Pump Units (tons)	219
Total Capacity of the entire HVAC System (tons)	219
Heat Pump Efficiency Range	Cooling: 13.7~16.4 EER Heating: 3.2~3.9 COP

Cost Information

Capital Cost of the Building ($)	10,663,790.23 for 2007 1,540,832.94 for 2012 (additional)
Total Cost of the HVAC System ($)	Not Provided
HVAC System Average Annual Repair and Maintenance Cost ($)	10,000
Government Incentives for the Use of GHP	Unknown
Utility Incentives for the Use of GHP	Unknown

Question & Answer

Questions answered by	Jim Frueh Maintenance & Operations Director Tel: 701-446-1023 Fax: 701-446-1200 fruehj@fargo.k12.nd.us
1. Why did you decide to install the geothermal heat pump system in your building?	Green product environment concerns
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Not Provided
3. As you know, are there any operating difficulties of the geothermal heat pump system?	Not Provided
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes

#12. Judge Ronald N. Davies High School

❖ Background

The Judge Ronald N. Davies High School (Figure F.12.1) is located in Fargo, North Dakota. This building has an area of about 279,000 ft^2 with gyms/fitness rooms, labs, multipurpose rooms, locker rooms, classrooms, computer rooms, offices, conference rooms, dining areas, a media studio, a natatorium, an auditorium, a kitchen, etc. (Figure F.12.2 and F.12.3). This building was built in 2011, and was installed with a vertical closed-loop GHP system to provide space heating and cooling. The total number of vertical boreholes is 928 with the depth of about 200 feet underground.

Figure F.12.1: Judge Ronald N. Davies High School
(Source: http://zerrbergarchitects.com/work/work_item/126/1)

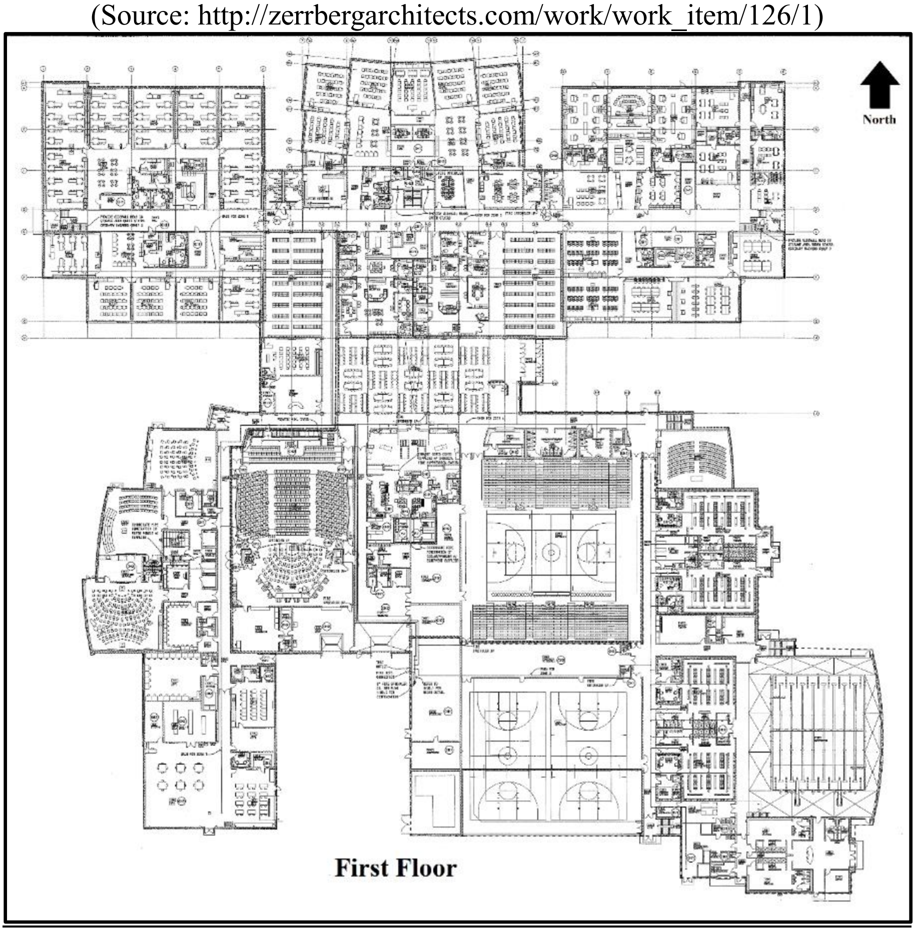


Figure F.12.2: Judge Ronald N. Davies High School 1st Floor Plan

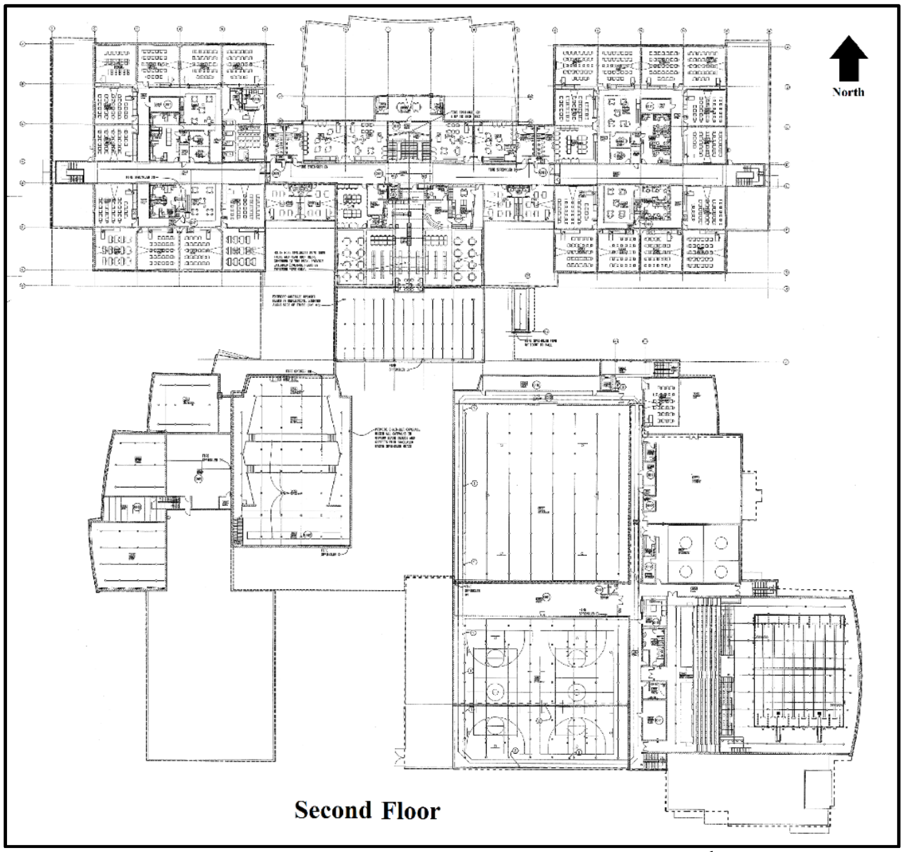


Figure F.12.3: Judge Ronald N. Davies High School 2nd Floor Plan

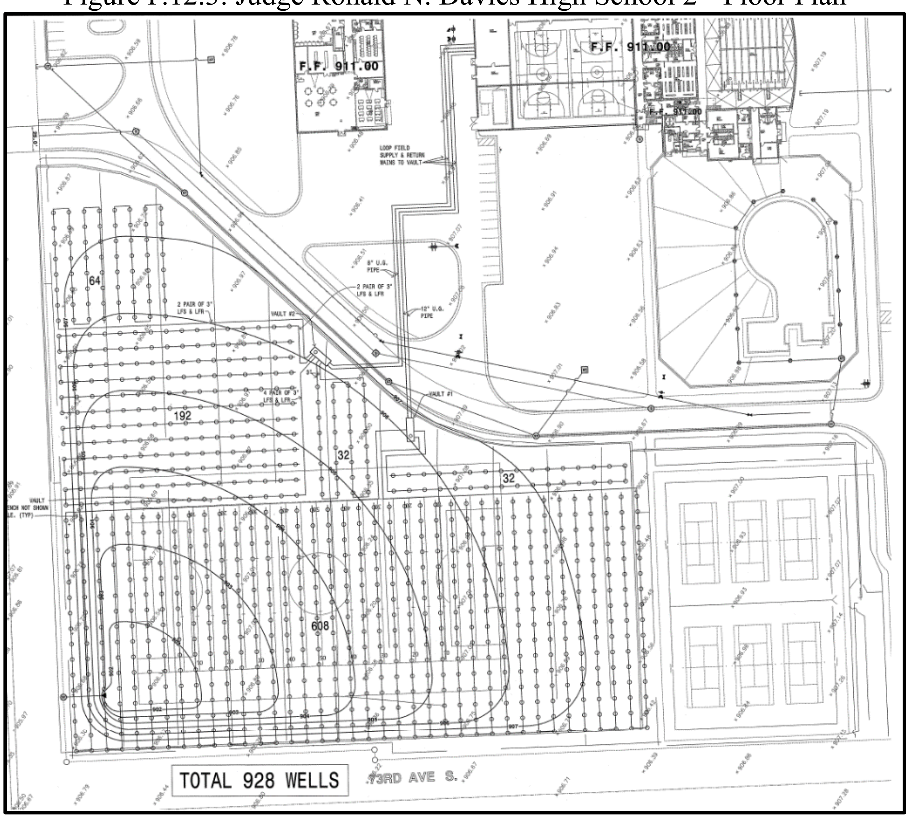


Figure F.12.4: Judge Ronald N. Davies High School – Underground Loop

❖ System Description

In the Judge Ronald N. Davies High School building, 167 water-to-air heat pump units were originally installed to condition the indoor occupied spaces (including four ERUs with heat pump cooling and heating modes). Another water-to-water heat pump is used to provide heating effect to the natatorium and the locker rooms through a floor radiation system. The efficiencies of these heat pump units used in this building are up to 18.5 EER for cooling and 3.0 ~ 6.4 COP for heating. Heat rejection and extraction take place through 928 vertical boreholes with the depth of about 200 feet below the ground surface, as shown in Figure F.12.4. Water in this system is circulated between the heat pumps and the ground loops through four VSD pumps (two are for backup). Ventilation requirement for this building is mainly met by eight ERUs with the total design air flow rate of 46,710 cfm. Ducts from these units are tied to each heat pump to supply fresh air to each occupied space. Other features include, VSD fans, occupancy and daylighting sensors, a separate dehumidification unit to remove moisture from the natatorium, etc.

❖ System Performance

The monthly energy use of the Judge Ronald N. Davies High School building for the year of 2016 was given and is displayed in Figure F.12.5, F.12.6, and F.12.7 with the total energy use of 15,547 MMBTU, i.e. 56 kBtu/ft^2/yr (EUI). The corresponding monthly energy cost of this building is shown in Figure F.12.7 with the total yearly energy cost of $346,730.95 (Electricity: $343,697; Natural gas: $3,033.95), i.e. $1.24/ft^2/yr.

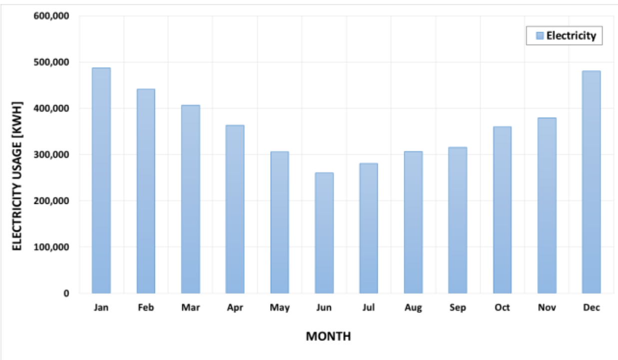


Figure F.12.5: Electricity usage during 2016

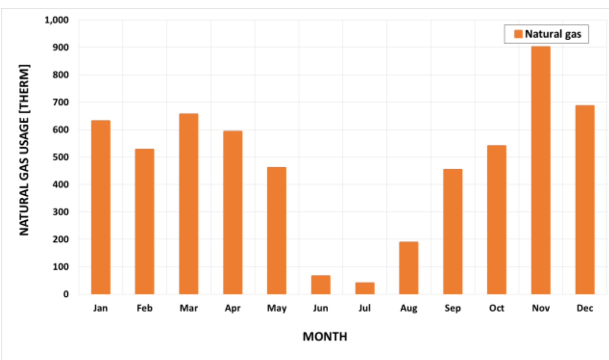


Figure F.12.6: Natural gas usage during 2016

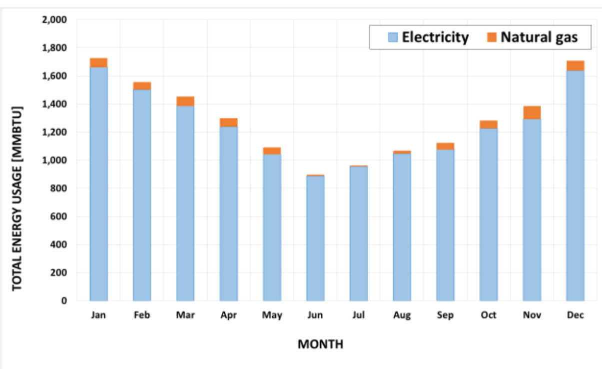


Figure F.12.7: Total energy usage during 2016

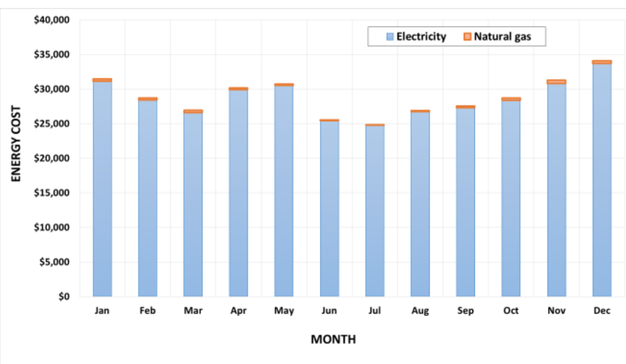


Figure F.12.8: Monthly energy cost during 2016

In order to identify the potential energy and energy cost savings of the building, the actual energy consumption result of this building was eventually compared with the EPA's Energy Star Target Finder result which represents the national median of the energy performance of similar buildings in the U.S. These results are shown in Table F.12.1, which indicate that this building consumes 28% more energy than a similar school building per the Energy Star Target Finder result, and the corresponding energy cost is 28% higher than a similar school building.

Table F.12.1: Energy Performance Comparison

	Actual GHP System	Similar Building*
	Actual Utilities	Estimated (the national median)*
Electricity Usage (kwh/yr)	4,388,282	-
Electricity Cost ($/yr)	343,697.00	-
Natural Gas Usage (therm/yr)	5,746	-
Natural Gas Cost ($/yr)	3,033.95	-
Actual Site Energy Usage (MMBTU/yr)	15,547	12,138.2
Estimated Source Energy Usage (MMBTU/yr)*	47,618.0	37,176.3
Total Actual Energy Cost ($/yr)	346,730.95	270,626.01**
Actual Site EUI (kBtu/ft^2/yr)	56	44
Estimated Source EUI (kBtu/ft^2/yr)*	170.7	133.2
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	2,883.3	2,251.0
Energy Savings Compared to Similar EPA Buildings	-28%	
Energy Cost Savings Compared to Similar EPA Buildings	-28%	

* Based on Energy Star Target Finder results

** Determined by using the actual average annual utility rates, i.e. 7.83 cents per kwh and $0.528 per therm

❖ Project Costs

The total capital cost of the building was given, i.e. $47,473,177, but the information regarding the total HVAC cost was unknown. Therefore, the cost comparative analysis and the simple payback period calculation for this building were not conducted, due to the lack of such cost information about this building.

The basic summary information of this building is shown in Table F.12.2 below.

Table F.12.2: Building Summary

Building Information

Building Name	Judge Ronald N. Davies High School
Building Address	Fargo
Building Type	School
Building Construction Year	2011
Building Total Area (ft^2)	279,000
Total Number of Floor	Above ground: 2
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2011
Installation Type	New
GHP system type	Vertical closed loop
Number of Boreholes for Vertical GHP	928
Borehole Depth (ft)	200
Borehole Separation Distance (ft)	Unknown
Borehole Length (ft)	185,600
Underground Pipe Length (ft)	371,200

Borehole Length per ton (ft/ton)	231
Underground Pipe Length per ton (ft/ton)	462
GHP water flow rate per ton (gpm/ton)	2.9
Number of Heat Pump Units	Water-to-Air Heat Pump: 167 with four heat pump ERUs Water-to-Water Heat Pump: 1
Total Capacity of Heat Pump Units (tons)	803
Total Capacity of the entire HVAC System (tons)	845
Heat Pump Efficiency Range	Cooling: 18.5 or less EER Heating: 3.0~6.4 COP

Cost Information

Capital Cost of the Building ($)	47,473,177
Total Cost of the HVAC System ($)	Not Provided
HVAC System Average Annual Repair and Maintenance Cost ($)	20,000
Government Incentives for the Use of GHP	No
Utility Incentives for the Use of GHP	Yes

Question & Answer

Questions answered by	Jim Frueh Maintenance & Operations Director Tel: 701-446-1023 Fax: 701-446-1200 fruehj@fargo.k12.nd.us
1. Why did you decide to install the geothermal heat pump system in your building?	Green product environment concerns
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Not Provided
3. As you know, are there any operating difficulties of the geothermal heat pump system?	Not Provided
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes

#13. Bennett Elementary School

❖ Background

The Bennett Elementary School (Figure F.13.1) is located in Fargo, North Dakota. This building has an area of about 90,268 ft^2 with gyms, multipurpose rooms, classrooms, offices, conference rooms, cafeteria/dining areas, a media center, a kitchen, etc. (Figure F.13.2). It was built in 1999 and in 2009, several classrooms were added to the existing building (Figure F.13.3) with the installation and use of 3 additional heat pump units to condition these new areas. This facility was equipped with a vertical closed-loop GHP system to provide space heating and cooling. The total number of vertical boreholes is 320 with the depth of about 150 feet underground.

Figure F.13.1: Bennett Elementary School
(Source: https://en.wikipedia.org/wiki/File:Bennett_elementary.jpg)

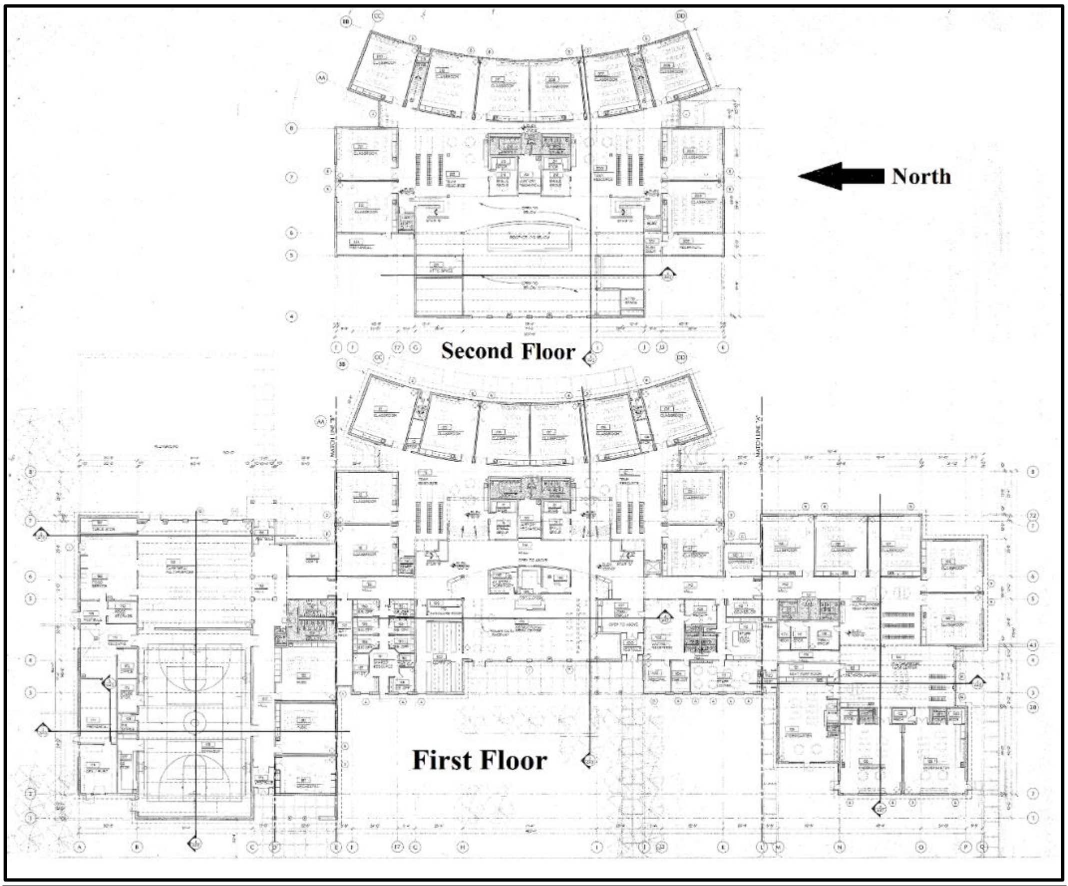


Figure F.13.2: Bennett Elementary School Floor Plan

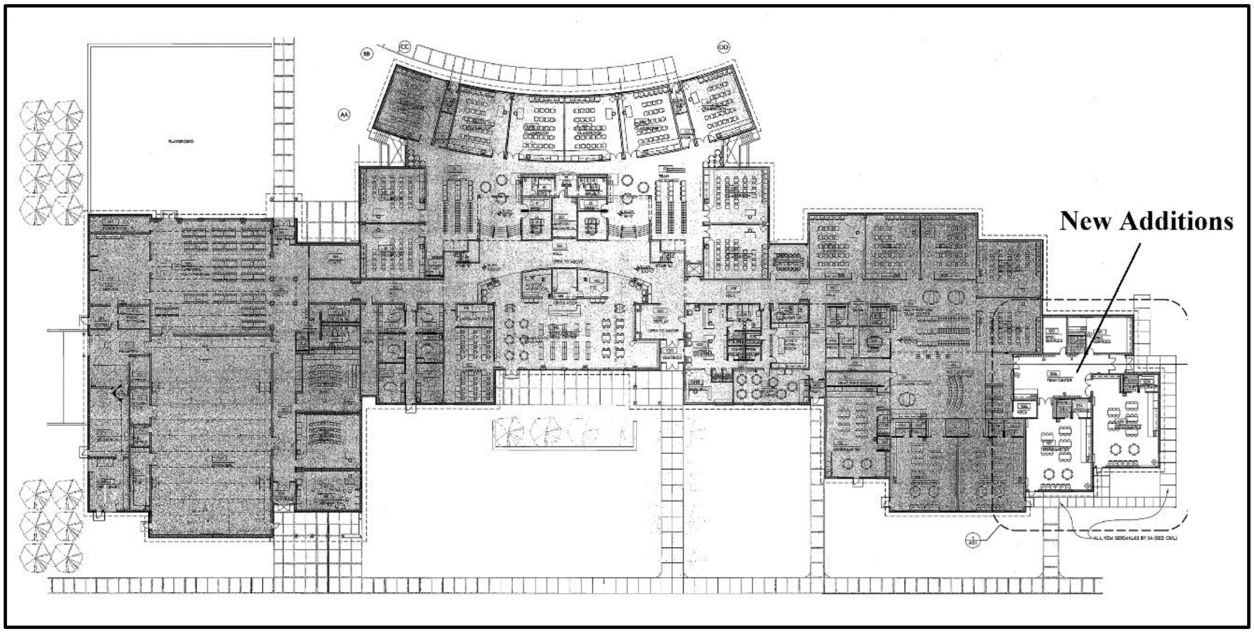


Figure F.13.3: Bennett Elementary School 1st Floor Plan with New Additions

❖ System Description

In the Bennett Elementary School building, 54 water-to-air heat pump units were originally installed in 1999 to condition the indoor occupied spaces. In 2009, two new kindergarten classrooms were added to the existing building as shown in Figure F.13.3. Therefore, 3 additional water-to-air heat pump units were installed at that time to condition these new classrooms. These new heat pumps share the same ground loop with other existing heat pump units. The efficiencies of these heat pump units used in this building are between 11.6 ~ 18.9 EER for cooling and 3.3 ~ 3.6 COP for heating. Heat rejection and extraction take place through 320 vertical boreholes with the depth of about 150 feet below the ground and a separation distance of between 8 and 12 feet, as shown in Figure F.13.4. Water in this system is circulated between heat pumps and ground loops through four pumps (two for the well field and two for the building loop). Ventilation requirement for this building is met by four energy recovery units (ERU) with total design cfm of about 20,000. Ducts from these units are tied to each heat pump to supply fresh air to each occupied space.

It seems this building did not have the issue of warm ground (Ground Temperature Penalty) that could be derived from the fact that the designed separation distance (8~12 feet) between boreholes is less than the minimum requirement, i.e. 15 feet. Although there are no negative complaints or issues reported regarding warm ground/low heat pump efficiency/high utility cost, more savings could be achieved if the minimum separation distance requirement would be met in the original design, since this type of building is usually cooling-dominated even in the cold climate, due to the large amount of internal gains resulting from the large number of occupants (students).

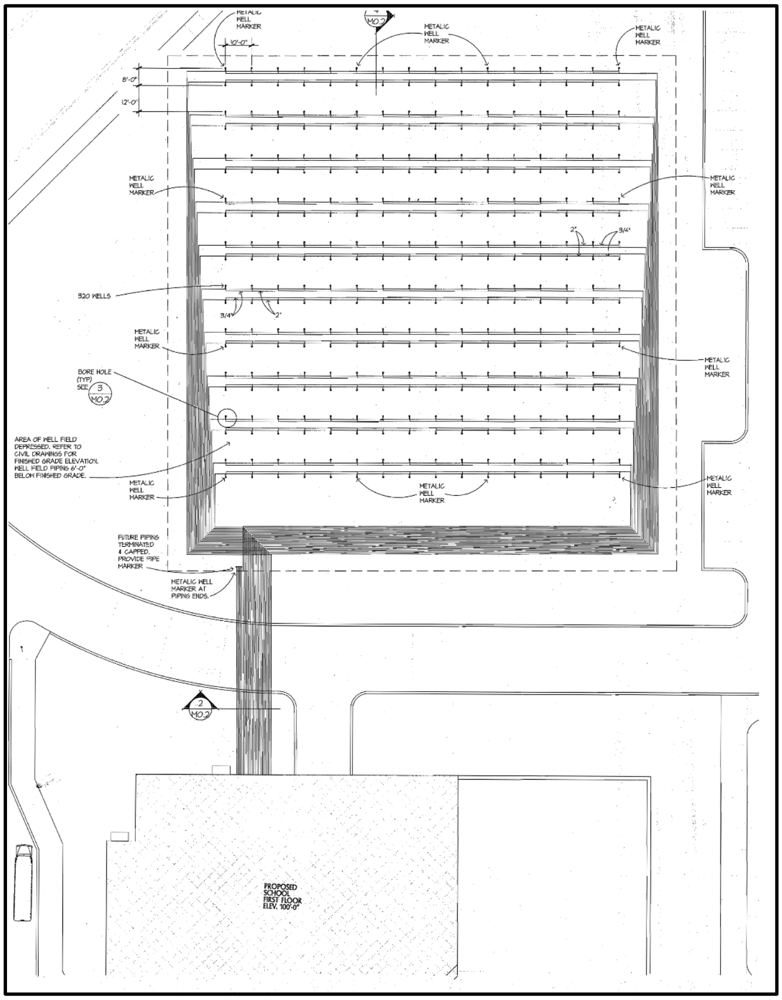


Figure F.13.4: Bennett Elementary School – Underground Loop

❖ System Performance

The monthly energy use of the Kennedy Elementary School building for the year of 2016 was given and is displayed in Figure F.13.5, and F.13.6 with the total energy use of 4,492 MMBTU, i.e. 50 kBtu/ft^2/yr (EUI). The corresponding monthly energy cost of this building is shown in Figure F.13.7 with the total yearly energy cost of $95,211 (Electricity: $95,211 - electricity is the only energy source for this building.), i.e. $1.06/ft^2/yr.

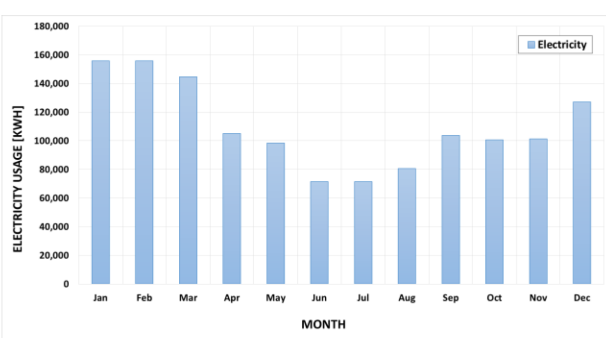


Figure F.13.5: Electricity usage during 2016

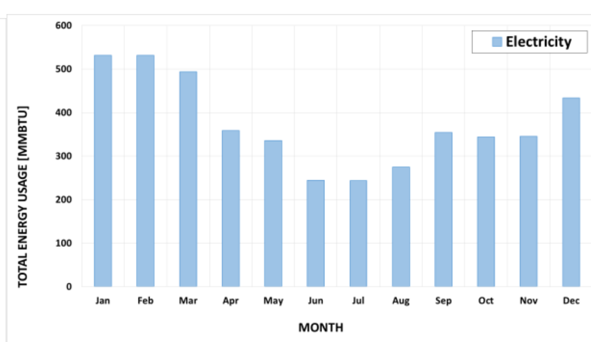


Figure F.13.6 Total energy usage during 2016

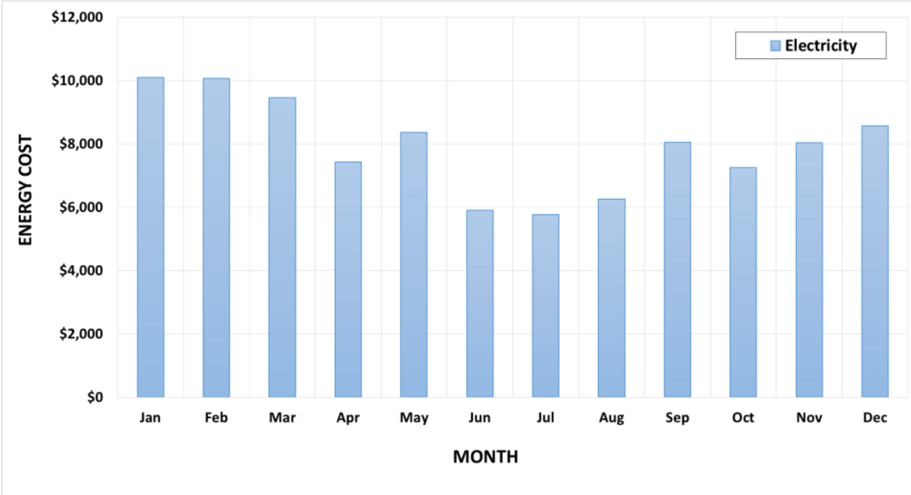


Figure F.13.7: Monthly energy cost during 2016

In order to identify the potential energy and energy cost savings of the building, the actual energy consumption result of this building was eventually compared with the EPA's Energy Star Target Finder result which represents the national median of the energy performance of similar buildings in the U.S. These results are shown in Table F.13.1, which indicate that this building consumes 4% less energy than a similar school building per the Energy Star Target Finder result. The corresponding energy cost savings is also 4%, due to the use of GHP system.

Table F.13.1: Energy Performance Comparison

	Actual GHP System	Similar Building*
	Actual Utilities	Estimated (the national median)*
Electricity Usage (kwh/yr)	1,316,600	1,376,137
Electricity Cost ($/yr)	95,211.00	99,449.65
Natural Gas Usage (therm/yr)	0	0
Natural Gas Cost ($/yr)	0	0
Actual Site Energy Usage (MMBTU/yr)	4,492	4,692.0
Estimated Source Energy Usage (MMBTU/yr)*	14,105.6	14,732.7
Total Actual Energy Cost ($/yr)	95,211.00	99,449.65**
Actual Site EUI (kBtu/ft^2/yr)	50	52
Estimated Source EUI (kBtu/ft^2/yr)*	156.3	163.2
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	855.9	894.0
Energy Savings Compared to Similar EPA Buildings	4%	
Energy Cost Savings Compared to Similar EPA Buildings	4%	

* Based on Energy Star Target Finder results
** Determined by using the actual average annual utility rates, i.e. 7.232 cents per kwh.

❖ Project Costs

The total capital cost of the building was given, i.e. $7,995,863.24, but the information regarding the total HVAC cost was unknown. Therefore, the cost comparative analysis and the simple payback period calculation for this building were not conducted, due to the lack of such cost information about this building.

The basic summary information of this building is shown in Table F.13.2 below.

Table F.13.2: Building Summary

Building Information

Building Name	Bennett Elementary School
Building Address	Fargo
Building Type	School
Building Construction Year	1999 2009 for New Addition
Building Total Area (ft^2)	90,268
Total Number of Floor	Above ground: 2
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	1999 with 54 heat pumps 2009 for New Addition with 3 new heat pumps
Installation Type	New
GHP system type	Vertical closed loop
Number of Boreholes for Vertical GHP	320
Borehole Depth (ft)	150
Borehole Separation Distance (ft)	8~12
Borehole Length (ft)	48,000
Underground Pipe Length (ft)	96,000
Borehole Length per ton (ft/ton)	209
Underground Pipe Length per ton (ft/ton)	417
GHP water flow rate per ton (gpm/ton)	3.8
Number of Heat Pump Units	Water-to-Air Heat Pump: 54 Additional Water-to-Air Heat Pump: 3 for building addition in 2009
Total Capacity of Heat Pump Units (tons)	230
Total Capacity of the entire HVAC System (tons)	230
Heat Pump Efficiency Range	Cooling: 11.6~18.9 EER Heating: 3.3~3.6 COP

Cost Information

Capital Cost of the Building ($)	7,199,212.45 for 1999 796,650.79 for 2009 (additional)
Total Cost of the HVAC System ($)	Not Provided
HVAC System Average Annual Repair and Maintenance Cost ($)	10,000
Government Incentives for the Use of GHP	Unknown
Utility Incentives for the Use of GHP	Unknown

Question & Answer

Questions answered by	Jim Frueh Maintenance & Operations Director Tel: 701-446-1023 Fax: 701-446-1200 fruehj@fargo.k12.nd.us
1. Why did you decide to install the geothermal heat pump system in your building?	Green product environment concerns
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Not Provided
3. As you know, are there any operating difficulties of the geothermal heat pump system?	Not Provided
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes

#14. Northwood Public School

❖ Background

The Northwood Public School (Figure F.14.1) is located in Northwood, North Dakota. This building has an area of about 103,000 ft^2 with gyms, classrooms, science labs, locker rooms, computer labs, offices, conference rooms, a kitchen, a library, etc. The previous Northwood Public School building was hit by a tornado and severely damaged in 2007. The new school was built after two years and was equipped with a closed-loop GHP system to provide space heating and cooling. The total number of vertical boreholes is 384 with the depth of 200 feet underground.

Figure F.14.1: Northwood Public School
(Source: http://gstspecialedition.com/gmedia/northwood_public_school-jpg/)

❖ System Description

In the Northwood Public School building, 68 water-to-air heat pump units are currently used to condition the indoor occupied spaces, including 3 HRUs with heat pump cooling and heating modes. Additionally, 8 water-to-water heat pumps are used to provide cold and hot water to four AHUs and one floor radiation system. These heat pump units have the efficiencies between 12.7 ~ 20 EER for cooling and 2.7 ~ 3.4 COP for heating. Heat rejection and extraction take place through 384 vertical boreholes with the depth of about 200 feet below the ground surface and a minimum separation distance of 15 feet, as shown in Figure F.14.2. Water in this system is transferred to the ground loops through two pumps (P-1 and P-2) (one is for backup), as shown in Figure F.14.3. The other two pumps (P-3 and P-4 shown in Figure F.14.3) are the ones used to convey the water to each heat pump unit inside the building. Ventilation requirement for this building is met by three HRUs with the total design air flow rate of 14,050 cfm. Ducts from this unit are tied to each heat pump to supply fresh air to each occupied space.

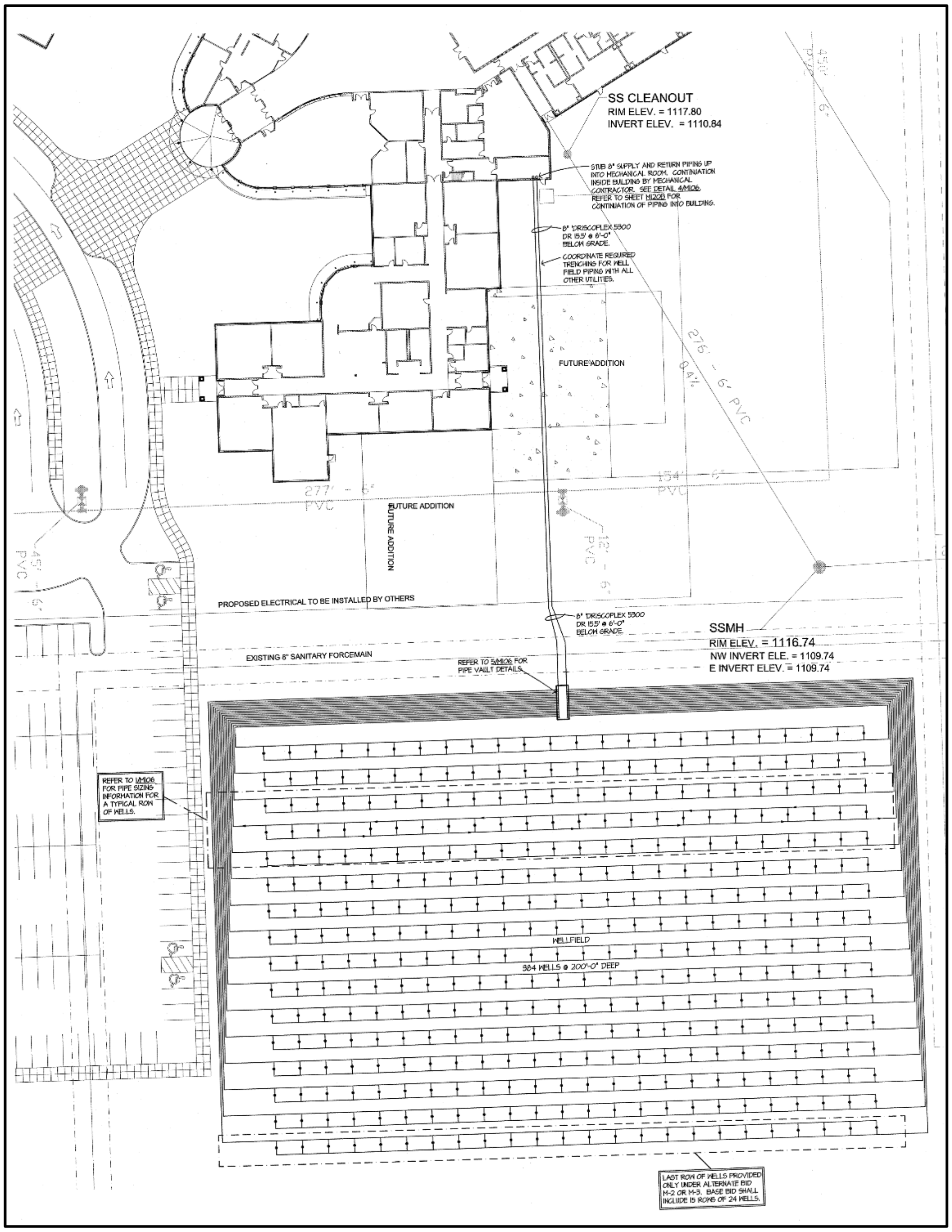


Figure F.14.2: Northwood Public School – Underground Loop

The building experienced a lightning strike in 2010, which nearly destroyed the entire electrical system. According to the building owner, the problems for the mechanical system after the lightning strike may include

- pump seals were broken which caused leaking issues;
- the failure of water pumps;
- several heat pump units were damaged and had to be replaced.

Additionally, the owner believes that the building water circulation system in the heat pump loop was oversized with more-than-enough water flow rates, which could be the reason that caused the failure of water pumps. Other problems and impacts of the lightning strike on the GHP system are unknown, and a further in-depth investigation is needed in the future.

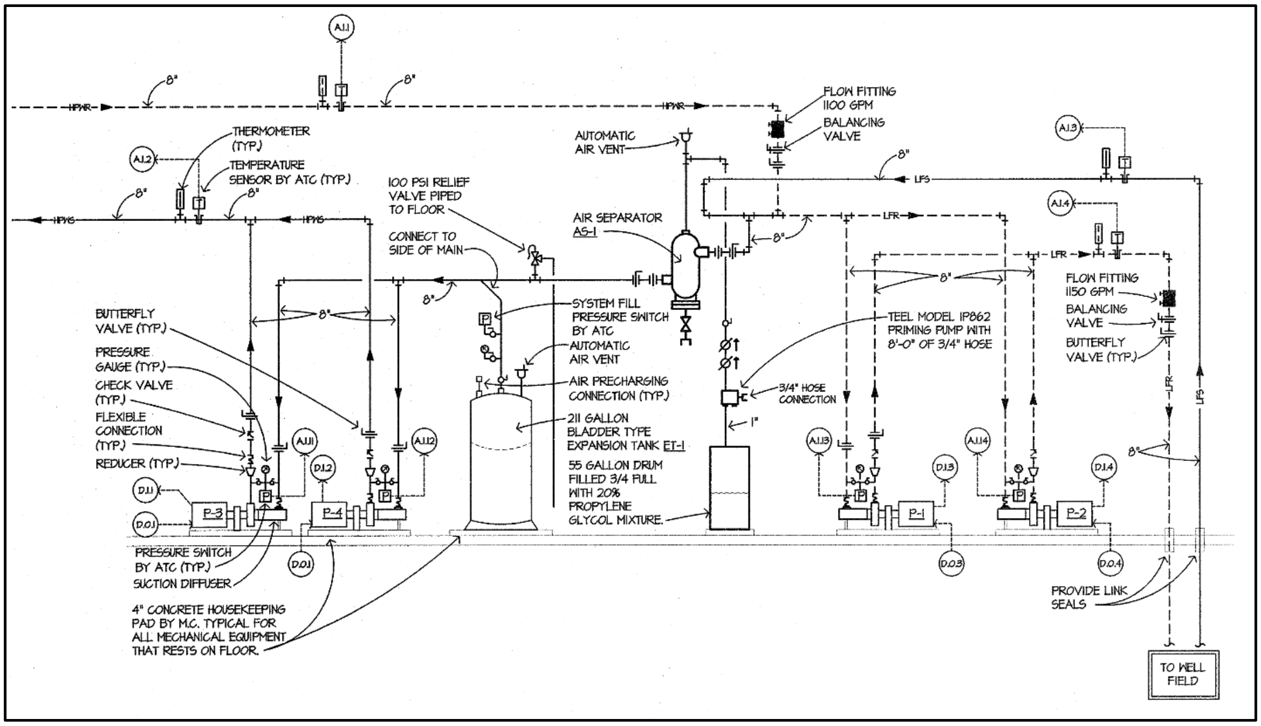


Figure F.14.3: Heat pump piping detail

❖ System Performance

The monthly energy use of the Northwood Public School building was not provided. Therefore, the energy performance analysis of this school building was not conducted, due to the lack of such necessary information. The performance of a similar building, however, is given in Table F.14.1, which is based on the EPA's Energy Star Target Finder result for a national median property.

Table F.14.1: Energy Performance Comparison

	Similar Building*
	Estimated (the national median)*
Electricity Usage (kwh/yr)	-
Electricity Cost ($/yr)	-
Natural Gas Usage (therm/yr)	-
Natural Gas Cost ($/yr)	-
Actual Site Energy Usage (MMBTU/yr)	7,065.5
Estimated Source Energy Usage (MMBTU/yr)*	12,020.1
Total Actual Energy Cost ($/yr)	91,141**
Actual Site EUI (kBtu/ft^2/yr)	68.6
Estimated Source EUI (kBtu/ft^2/yr)*	116.7
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	677.8

* Based on Energy Star Target Finder results
** Determined by using the 2016 average electricity and natural gas rates for the state of North Dakota, i.e. 8.96 cents per kwh and $0.526 per therm [1]

❖ Project Costs

The total capital cost of the building was given, i.e. $14,000,000. The total cost of the HVAC system is $2,140,627, i.e. $20.78/ft^2, where the exterior ground-loop installation and component

[1] https://www.eia.gov/dnav/ng/ng_pri_sum_dcu_SND_a.htm

cost (including borehole drilling, headers, piping, etc.) is $631,391, and the interior HVAC/GHP system installation and component cost (including heat pump units, ducting, controls, etc.) is $1,509,236. Since the actual energy cost information was not provided, the cost comparative analysis and the simple payback period calculation for this building were not able to be conducted, due to the lack of such information.

The basic summary information of this building is shown in Table F.14.2 below.

Table F.14.2: Building Summary

Building Information

Building Name	Northwood Public School
Building Address	Northwood
Building Type	School
Building Construction Year	2008
Building Total Area (ft^2)	103,000
Total Number of Floor	Above ground: 1
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2008
Installation Type	New
GHP system type	Vertical closed loop
Number of Boreholes for Vertical GHP	384
Borehole Depth (ft)	200
Borehole Separation Distance (ft)	15
Borehole Length (ft)	76,800
Underground Pipe Length (ft)	153,600
Borehole Length per ton (ft/ton)	241
Underground Pipe Length per ton (ft/ton)	482
GHP water flow rate per ton (gpm/ton)	3.6
Number of Heat Pump Units	Water-to-Air Heat Pump: 65 Water-to-Water Heat Pump: 8 HRU with Heat Pump Mode: 3
Total Capacity of Heat Pump Units (tons)	319
Total Capacity of the entire HVAC System (tons)	319
Heat Pump Efficiency Range	Cooling: 12.7~20.0 EER Heating: 2.7~3.4 COP

Cost Information

Capital Cost of the Building ($)	14,000,000
Total Cost of the HVAC System ($)	2,140,627
Cost Breakdown ($)	• Exterior Ground-loop installation and component cost (including borehole drilling, headers, piping, etc.): $631,391
	• Interior HVAC/GHP System installation and component cost (including heat pump units, ducting, controls, etc.): $1,509,236
HVAC System Average Annual Repair and Maintenance Cost ($)	Unknown
Government Incentives for the Use of GHP	Yes - $50,000
Utility Incentives for the Use of GHP	No

Question & Answer

Questions answered by	Keith Arneson Superintendent Tel: 701-587-5221 Fax: 701-587-5423 Keith.Arneson@northwoodk12.com
1. Why did you decide to install the geothermal heat pump system in your building?	Unknown
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Yes, we are very satisfied with the comfort and noise levels.
3. As you know, are there any operating difficulties of the geothermal heat pump system?	Yes, we experienced a lightning strike that grounded throughout geothermal equipment in 2010. The problems caused by the lightning strike: > Several heat pump units were broken > Pump seals were broken and caused leaking > Failure of pumps (we believe the system was over designed and built with more than enough circulating water flow rate)
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Maybe.

#15. Rugby High School

❖ Background

The Rugby High School (Figure F.15.1) is located in Rugby, North Dakota. This building has an area of about 99,000 ft^2 with gyms, fitness rooms, multipurpose rooms, classrooms, locker rooms, computer labs, offices, conference rooms, wood shops, dining areas, an auditorium, a media center, a kitchen, etc. (Figure F.15.2). It was built in 1956, and in 2012 the building was retrofitted with the installation of a closed-loop GHP system to provide space heating and cooling. The total number of vertical boreholes is 72 with the depth of 250 feet underground.

Figure F.15.1: Rugby High School (Source: http://www.rugby.k12.nd.us/)

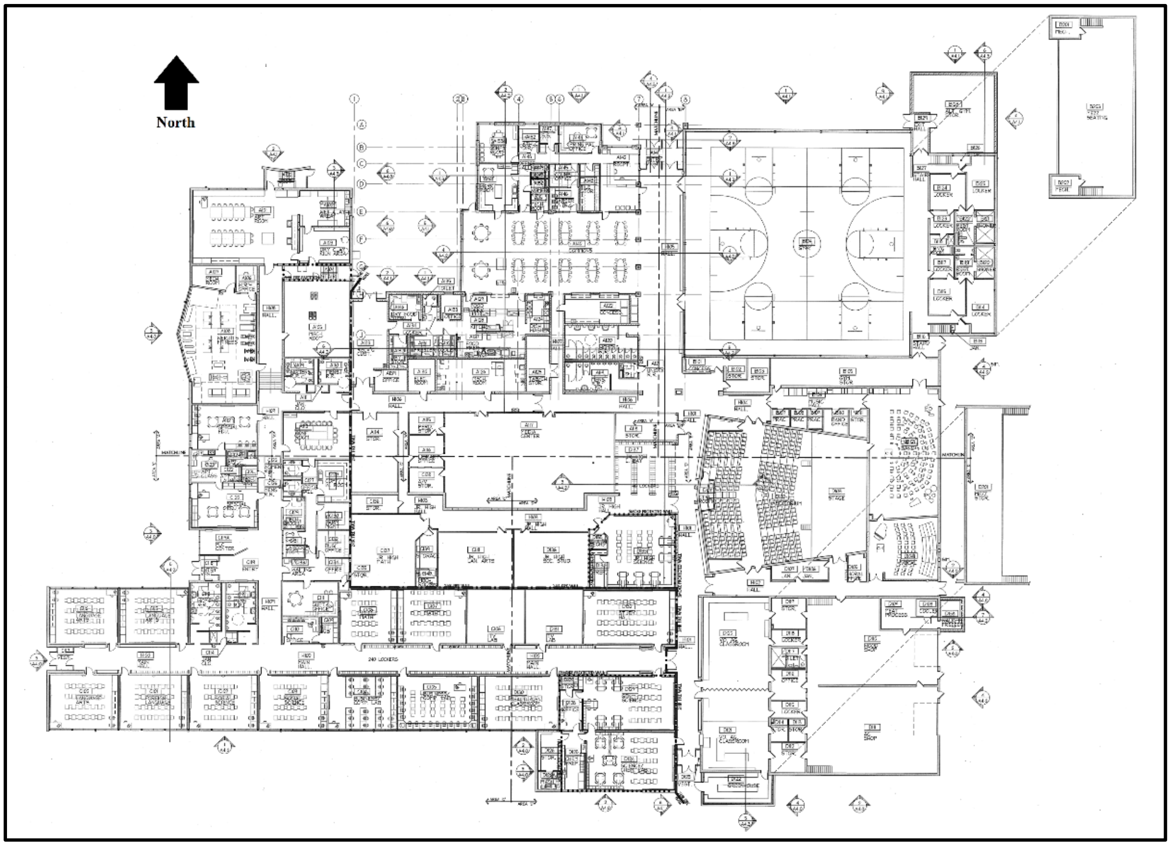


Figure F.15.2: Rugby High School Floor Plan

❖ System Description

In the Rugby High School building, 53 water-to-air heat pump units are currently used to condition the indoor occupied spaces. Heat rejection and extraction take place through 72 vertical boreholes with the depth of 250 feet below the ground surface and a separation distance of 20 feet, as shown in Figure F.15.3. Water in this system is circulated between the heat pumps and the ground loops through two water pumps (one is for backup). Ventilation requirement for this building is met by 9 ERUs with the total design air flow rate of 13,410 cfm. Ducts from these units are tied to each heat pump to supply fresh air to each occupied space.

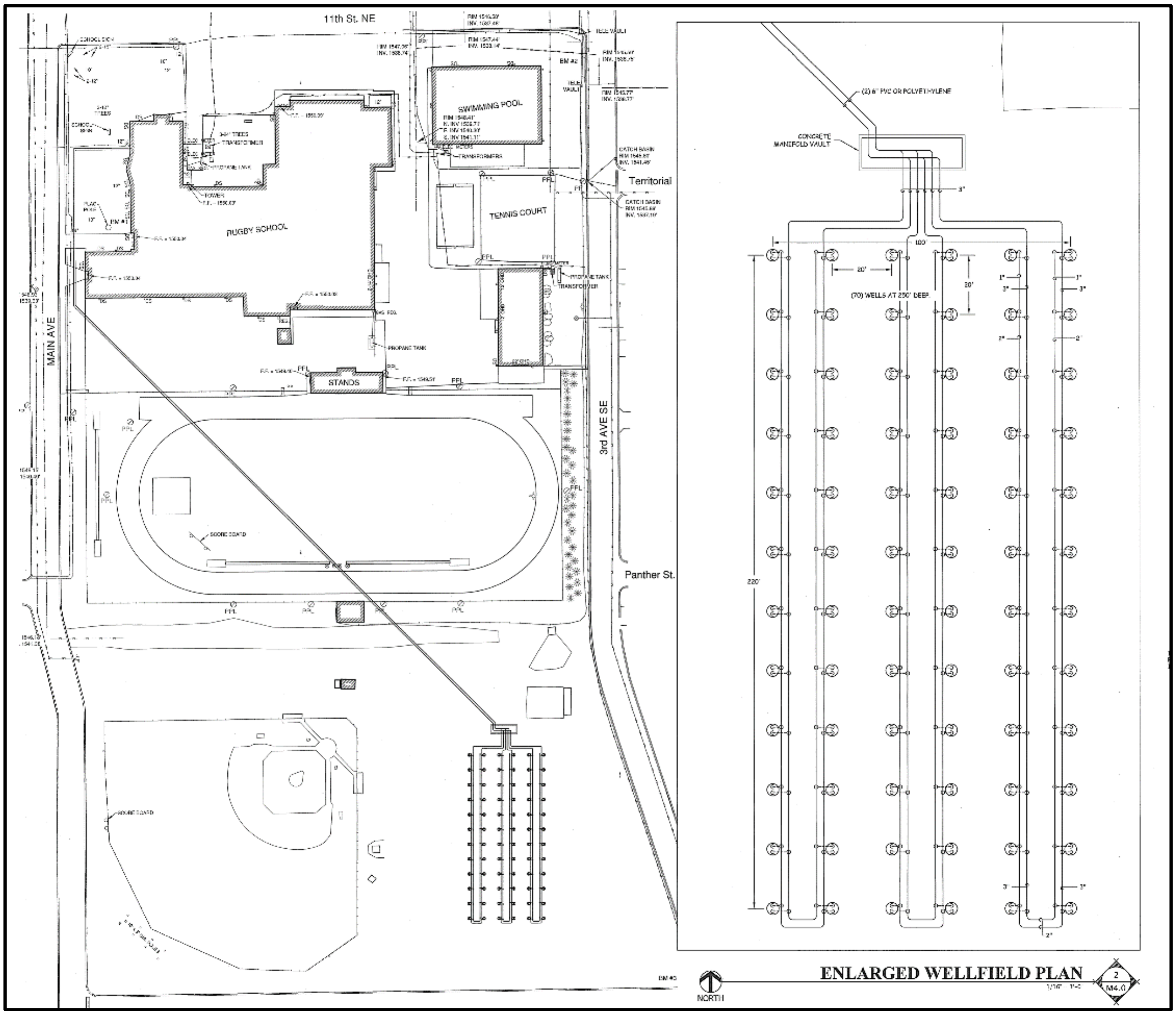


Figure F.15.3: Rugby High School – Underground Loop

❖ System Performance

The monthly energy use of the Rugby High School building for the year of 2016 was given and is displayed in Figure F.15.4, F.15.5, and F.15.6 with the total energy use of 4,252 MMBTU, i.e. 43 kBtu/ft^2/yr (EUI). The corresponding monthly energy cost of this building is shown in Figure F.15.7 with the total yearly energy cost of $80,308.57 (Electricity: $75,691.57; Propane: $4,617), i.e. $0.81/ft^2/yr.

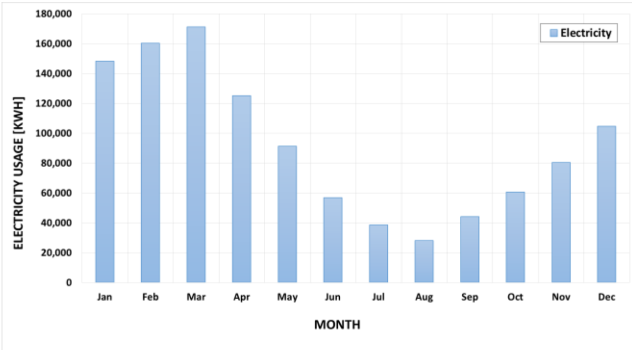


Figure F.15.4: Electricity usage during 2016

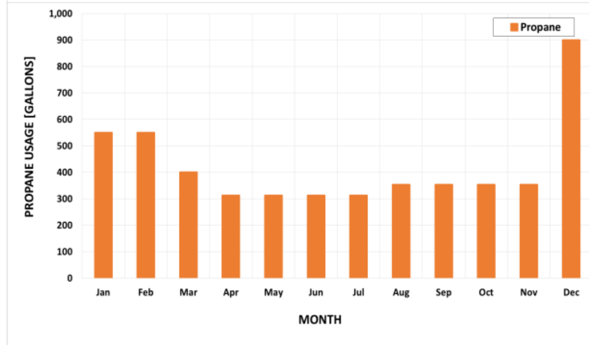


Figure F.15.5: Propane usage during 2016

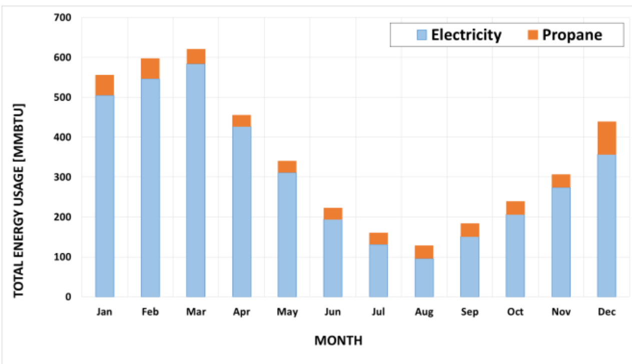


Figure F.15.6: Total energy usage during 2016

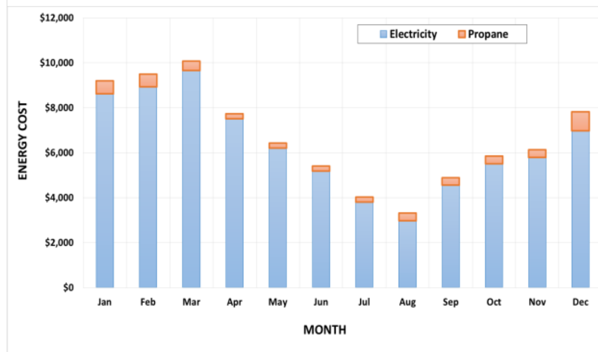


Figure F.15.7: Monthly energy cost during 2016

In order to identify the potential energy and energy cost savings of the building, the actual energy consumption result of this building was eventually compared with the EPA's Energy Star Target Finder result which represents the national median of the energy performance of similar buildings in the U.S. These results are shown in Table F.15.1, which indicate that this building consumes 7% less energy than a similar school building per the Energy Star Target Finder result. The corresponding energy cost savings is also 7%, due to the use of the GHP system.

Table F.15.1: Energy Performance Comparison

	Actual GHP System	Similar Building*
	Actual Utilities	Estimated (the national median)*
Electricity Usage (kwh/yr)	1,109,700	-
Electricity Cost ($/yr)	75,691.57	-
Natural Gas Usage (therm/yr)	5,065	-
Natural Gas Cost ($/yr)	4,617.00	-
Actual Site Energy Usage (MMBTU/yr)	4,252	4,568.6
Estimated Source Energy Usage (MMBTU/yr)*	12,359.6	13,279.1
Total Actual Energy Cost ($/yr)	80,308.57	86,272.26**
Actual Site EUI (kBtu/ft^2/yr)	43	46
Estimated Source EUI (kBtu/ft^2/yr)*	124.8	134.1
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	751.3	807.2
Energy Savings Compared to Similar EPA Buildings	7%	
Energy Cost Savings Compared to Similar EPA Buildings	7%	

* Based on Energy Star Target Finder results
** Determined by using the actual average annual utility rates, i.e. 6.82 cents per kwh and $0.9115 per gallon for propane

❖ Project Costs

The total capital cost of the building was given, i.e. $8,000,000. The total cost of the HVAC system is $1,214,500, i.e. $12.27/ft^2. Since the actual design documents, such as architectural drawings, were not provided, the cost comparative analysis and the simple payback period calculation for this building were not able to be conducted due to the lack of such information about this building.

The basic summary information of this building is shown in Table F.15.2 below.

Table F.15.2: Building Summary

Building Information

Building Name	Rugby High School
Building Address	Rugby
Building Type	School
Building Construction Year	1956
Building Total Area (ft^2)	99,000
Total Number of Floor	Above ground: 1
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2012
Installation Type	Retrofit
GHP system type	Vertical closed loop
Number of Boreholes for Vertical GHP	72
Borehole Depth (ft)	250
Borehole Separation Distance (ft)	20
Borehole Length (ft)	18,000
Underground Pipe Length (ft)	36,000
Borehole Length per ton (ft/ton)	154
Underground Pipe Length per ton (ft/ton)	307
GHP water flow rate per ton (gpm/ton)	2.1
Number of Heat Pump Units	Water-to-Air Heat Pump: 53
Total Capacity of Heat Pump Units (tons)	117
Total Capacity of the entire HVAC System (tons)	Unknown (information regarding previous cooling equipment is not provided)
Heat Pump Efficiency Range	Unknown

Cost Information

Capital Cost of the Building ($)	8,000,000
Total Cost of the HVAC System ($)	1,214,500
HVAC System Average Annual Repair and Maintenance Cost ($)	10,000
Government Incentives for the Use of GHP	No
Utility Incentives for the Use of GHP	No

Question & Answer

Questions answered by	Mike McNeff Superintendent Tel: 701-776-5201 Fax: 701-776-5091 mike.mcneff@k12.nd.us
1. Why did you decide to install the geothermal heat pump system in your building?	Outdated HVAC system. Added cooling to create a better learning environment.
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Yes, no complaints.
3. As you know, are there any operating difficulties of the geothermal heat pump system?	It is working well.
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes

#16. Zion Lutheran Church

❖ Background

The Zion Lutheran Church (Figure F.16.1) is located in Minot, North Dakota, and was built in 2006. This building has an area of about 24,000 ft^2 and mainly consists of a sanctuary, conference/meeting rooms, dining areas, a kitchen, family rooms, nursery rooms, offices, classrooms, etc. This facility is using a vertical closed-loop GHP system to provide space heating and cooling. The total number of vertical boreholes is 48 with the depth of about 200 feet underground. Other features include a floor heating radiation system, three ERUs, etc. The owner is happy with the current system, and would like to suggest GHP systems to other building owners or end users. The only concern from the building owner is the slow response of this system, so the system is usually started and operates at least one or two hours early before an event.

Figure F.16.1: Zion Lutheran Church (Source: http://hightconstruction.com/project-gallery/)

❖ System Description

In the Zion Lutheran Church building, 13 water-to-air heat pump units are used to condition the indoor occupied spaces. Another water-to-water heat pump is used only to provide heating effect to several perimeter zones of the building through a floor radiation system. Heat rejection and extraction take place through 48 vertical boreholes with the depth of about 200 feet below the ground surface and a minimum separation distance of 15 feet, as shown in Figure F.16.2. Water in this system is circulated between the heat pumps and the ground loops through two water pumps (one is for backup). Ventilation requirement for this building is met by three ERUs with the total design air flow rate of 3,240 cfm. Ducts from these units are tied to each heat pump to supply fresh air to each occupied space. In addition, a makeup air unit is used to provide makeup fresh air to the kitchen area when the kitchen exhaust fans are operating and taking air out of the building. This makeup air unit is equipped with a gas-fired heating device to heat the cold outside air up to 70^{o}F before supplying it to the indoor kitchen space.

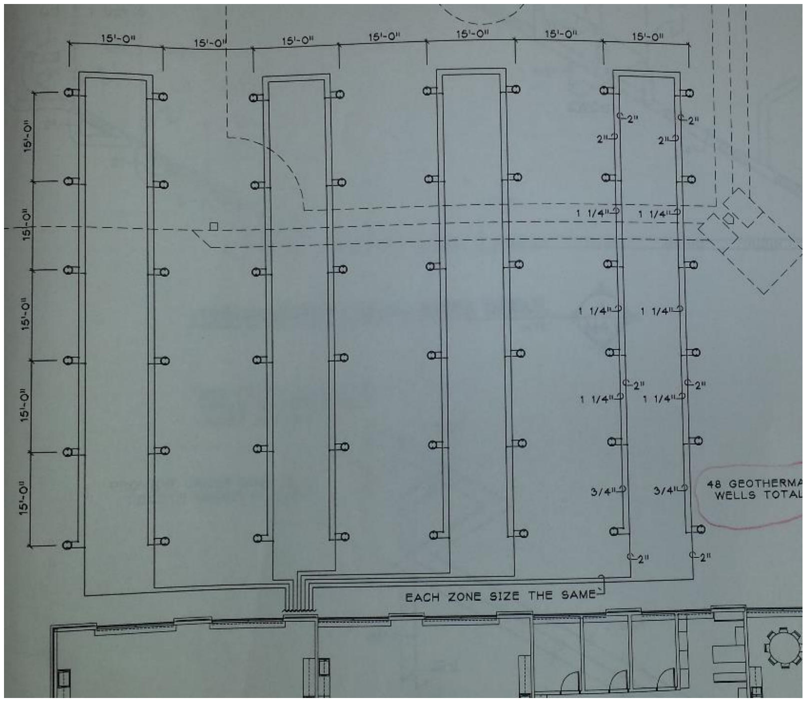


Figure F.16.2: Zion Lutheran Church underground boreholes

❖ System Performance

The monthly electricity use of the Zion Lutheran Church building for the year of 2016 was given and is displayed in Figure F.16.3 with the total electricity consumption of 177,120 kWh. The natural gas consumption of this building was not provided, which will be estimated by using a computer model and will be discussed later. The corresponding electricity cost is shown in Figure F.16.4 with the total cost of $18,216.91 per year, i.e. $0.79/ft^2/yr. In order to determine the potential energy and energy cost savings between the actual building with a GHP system and a similar building with a conventional air-conditioning system, an energy simulation model was established as described in Figure 3.4. To enhance the reliability of the simulation results, the model with the actual building design was calibrated by using the actual energy usage. Figure F.16.5 shows the calibration result, i.e. the comparison of electricity consumption between the simulation model and the actual building data for the year of 2016.

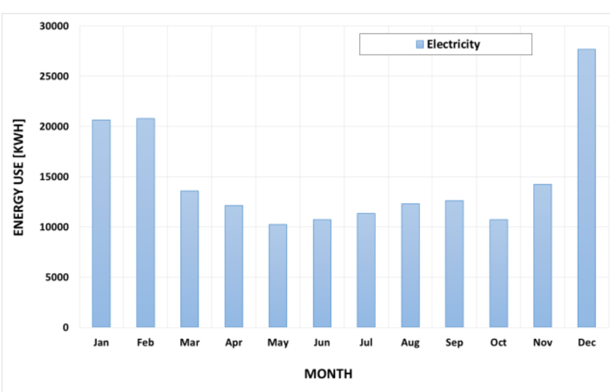


Figure F.16.3: Electricity use in 2016

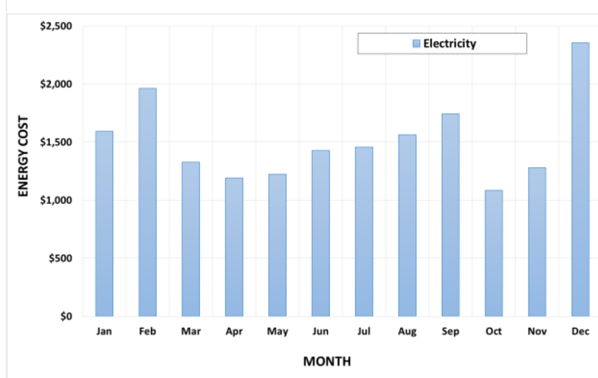


Figure F.16.4: Electricity cost in 2016

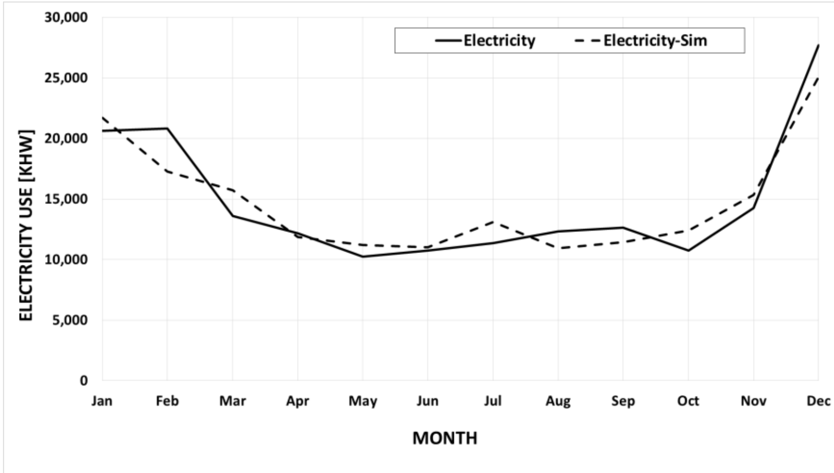


Figure F.16.5: Electricity use comparison

A baseline model for a similar building with a conventional air-conditioning system design was established based on the calibrated model. The difference between these two models is shown in Table F.16.1 below.

Table F.16.1: Model difference

Model with the actual GHP system	Model with a conventional air-conditioning system
Geothermal heat pump systems as designed	Packaged rooftop air conditioner with constant volume fan control, direct expansion (DX) cooling and fossil fuel furnace heating (others are the same as the actual system).

Once these simulation models have been established successfully, the energy and energy cost savings can be identified, which are shown in Table F.16.2. Please note, in this figure the natural gas usage and cost of the actual GHP system were estimated, due to the absence of such utility information. As shown in Table F.16.2, the monthly energy use of the building for the year of 2016 is 2,036.8 MMBTU (EUI = 30.7 kBtu/ft^2/yr). The energy and energy cost savings are summarized below:

- 46.5% of energy savings is achieved between the actual building and a similar building with a conventional air-conditioning system, and this high energy savings is due to the high efficiencies (around 3.0 COP, i.e. 300%) of the heat pump units, compared to the heating efficiencies (80%) of gas-fired furnaces during winter seasons, especially during weekdays when the church is not fully occupied.
- 1.0 % of energy saving is achieved between the actual building and a similar building based on the EPA's Energy Star Target Finder result for a national median property, which means that the energy performance of this church building is very similar as other churches in the U.S.
- Energy cost savings between the actual building and a similar building with a conventional air-conditioning system or based on the Energy Star Target Finder result are shown as 2.2% and 1.0%, respectively.

Such low energy cost savings (2.2%) (compared to the 46.5% energy savings) is caused by the extremely low utility rate for natural gas compared to electricity. The conventional air-conditioning system primarily uses natural gas (furnaces) to provide heating effect, while the actual geothermal system uses electricity (heat pumps).

Table F.16.2: Energy Performance Comparison

	Actual GHP System		ASHRAE Conventional System	Similar Building*
	Actual Utilities	Simulated	Simulated	Estimated (the national median)*
Electricity Usage (kwh/yr)	177,120	177,057	142,176	-
Electricity Cost ($/yr)	18,216.91	18,210.00	14,623.00	-
Natural Gas Usage (therm/yr)	1,326	1,326	8,923	-
Natural Gas Cost ($/yr)	700.00**	700.00**	4,712.00	-
Actual Site Energy Usage (MMBTU/yr)	737	736.7	1,377.5	744.1
Estimated Source Energy Usage (MMBTU/yr)*	2,036.8	2,036.2	2,460.1	2,056.5
Total Actual Energy Cost ($/yr)	18,916.9	18,910.0**	19,335.0**	19,100.27**
Actual Site EUI (kBtu/ft^2/yr)	30.7	30.7	57.4	31.0
Estimated Source EUI (kBtu/ft^2/yr)*	84.9	84.8	102.5	85.7
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	122.2	122.1	139.8	123.4
Energy Savings Compared to Conventional System	46.5%			
Energy Savings Compared to Similar EPA Buildings	1.0%			
Energy Cost Savings Compared to Conventional System	2.2%			
Energy Cost Savings Compared to Similar EPA Buildings	1.0%			

* Based on Energy Star Target Finder results

** Determined by using the actual average annual utility rates,, i.e. 10.2851 cents per kwh and $0.5281 per therm

- Project Costs

The total capital cost of the building as well as the information regarding the total HVAC cost was not given. Therefore, the cost comparative analysis and the simple payback period calculation for this building were not conducted, due to the lack of such cost information about this building.

The basic building information is summarized in Table F.16.3 below.

Table F.16.3: Building Summary

Building Information

Building Name	Zion Lutheran Church
Building Address	Minot
Building Type	Church
Building Construction Year	2006
Building Total Area (ft^2)	24,000
Total Number of Floor	Above ground: 1 + Mezzanine
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2006
Installation Type	New
GHP system type	Vertical closed loop
Number of Boreholes for Horizontal GHP	48
Borehole Depth (ft)	200
Borehole Separation Distance (ft)	15
Borehole Length (ft)	9,600
Underground Pipe Length (ft)	19,200

Borehole Length per ton (ft/ton)	192
Underground Pipe Length per ton (ft/ton)	384
GHP water flow rate per ton (gpm/ton)	3.1
Number of Heat Pump Units	Water-to-Air Heat Pump: 13 Water-to-Water Heat Pump (Heating Only): 1
Total Capacity of Heat Pump Units (tons)	50
Total Capacity of the entire HVAC System (tons)	50
Heat Pump Efficiency Range	Unknown

Cost Information

Capital Cost of the Building ($)	Unknown
Total Cost of the HVAC System ($)	Unknown
HVAC System Average Annual Repair and Maintenance Cost ($)	Unknown
Government Incentives for the Use of GHP	Unknown
Utility Incentives for the Use of GHP	Unknown

Question & Answer

Questions answered by	Pastor John Streccius Tel: 701-852-1872 Fax: 701-852-1873 johnstreccius@gmail.com
1. Why did you decide to install the geothermal heat pump system in your building?	Design of new building to be more efficient
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	We are satisfied. Slow to respond due to nature of the system.
3. As you know, are there any operating difficulties of the geothermal heat pump system?	Costly to repair when a pump goes out.
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes

#17. St. Anthony of Padua Church

❖ Background

The St. Anthony of Padua Church (Figure F.17.1) is located in Fargo, North Dakota, and was built about 100 years ago (between 1917 and 1932). This building has an area of about 50,000 ft^2 with the full occupancy capacity of 400 people. This facility is using a vertical closed-loop GHP system to provide heating and cooling. The total number of vertical boreholes is 100 with the depth of about 150 feet underground.

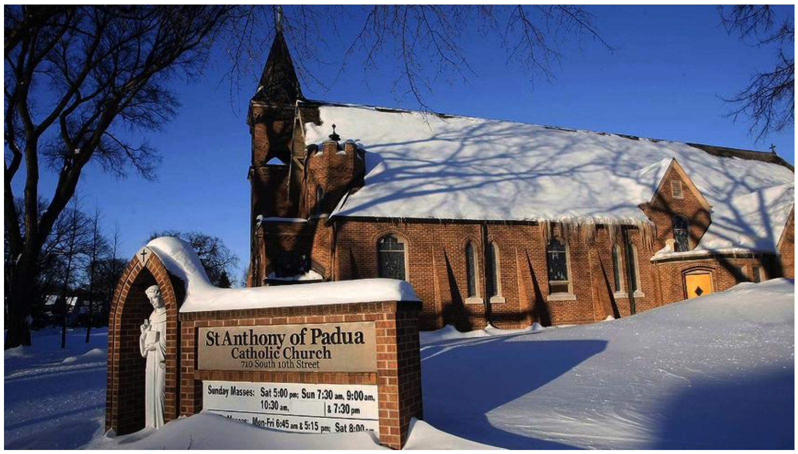


Figure F.17.1: St. Anthony of Padua Church (Source: http://www.inforum.com/taxonomy/term/19714)

❖ System Performance

The yearly energy costs (including electricity and natural gas) are known as $32,739, i.e. $0.65/ft^2/yr.

Table F.17.1 shows the performance result of this building in terms of energy and energy cost, where the performance of the existing design is compared with the estimated result of a similar building based on the EPA's Energy Star Target Finder calculation for a national median property. As shown in the table, this church is operating as efficiently as other similar worship facilities nationwide, in comparison of the total energy costs.

Table F.17.1: Energy Performance Comparison

	Actual GHP System	Similar Building*
	Actual Utilities	Estimated (the national median)*
Electricity Usage (kwh/yr)	Not Provided	-
Electricity Cost ($/yr)	Not Provided	-
Natural Gas Usage (therm/yr)	Not Provided	-
Natural Gas Cost ($/yr)	Not Provided	-
Actual Site Energy Usage (MMBTU/yr)	Not Provided	2,567.6
Estimated Source Energy Usage (MMBTU/yr)*	-	4,247.6
Total Actual Energy Cost ($/yr)	32,739.00	32,129.00**
Actual Site EUI (kBtu/ft^2/yr)	Not Provided	51.4
Estimated Source EUI (kBtu/ft^2/yr)*	-	85.0
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	-	238.4

* Based on Energy Star Target Finder results

** Determined by using the 2016 average electricity and natural gas rates for the state of North Dakota, i.e. 8.96 cents per kwh and $0.526 per therm [1]

[1] https://www.eia.gov/dnav/ng/ng_pri_sum_dcu_SND_a.htm

The cost comparative analysis and the simple payback period calculation for this building were not conducted, due to the limited cost information received from the building owner. The basic summary information of this building is shown in Table F.17.2 below.

Table F.17.2: Building Summary

Building Information

Building Name	St. Anthony of Padua Church
Building Address	Fargo
Building Type	Church
Building Construction Year	1917-1932
Building Total Area (ft^2)	50,000
Total Number of Floor	Above ground: 2 Below ground: 1
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2005
Installation Type	Retrofit
GHP system type	Vertical closed loop
Number of Boreholes for Vertical GHP	100
Borehole Depth (ft)	150
Borehole Separation Distance (ft)	Unknown
Borehole Length (ft)	15,000
Underground Pipe Length (ft)	30,000

Cost Information

Capital Cost of the Building ($)	-
Total Cost of the HVAC System ($)	546,000
HVAC System Average Annual Repair and Maintenance Cost ($)	3,000
Government Incentives for the Use of GHP	Unknown
Utility Incentives for the Use of GHP	Unknown

Question & Answer

Questions answered by	Frank Jaumen Tel: 701-237-6063
1. Why did you decide to install the geothermal heat pump system in your building?	Lower heating and cooling bills
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Yes, satisfied No complaints
3. As you know, are there any operating difficulties of the geothermal heat pump system?	No
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes

#18. Grand Forks Airport International Terminal

❖ Background

The Grand Forks Airport International Terminal (Figure F.18.1) is located in Grand Forks, North Dakota, and was built in 2011. This building has an area of about 53,548 ft^2 having 48 rooms with the full occupancy of 808. This facility was originally designed to use a vertical closed-loop GHP system (96 boreholes with the depth of about 200 feet) to provide space heating and cooling. A new type of horizontal borehole, however, was planned for use after finding the unusual high water table during construction. Up to $40,000 were added on the original budget for the horizontal borehole drilling. Auxiliary heating devices are used, including gas-fired unit heaters and a hot water floor radiation system. Other features include two DOASs with heat pump cooling and heating modes that connect to the ground loop with other heat pump units, VSD water pumps and fans, occupancy and daylighting sensors, Building Automation System (BAS), etc. This building achieved the LEED Silver certification in 2013 and was one of only five international airport terminals that achieved LEED certification in the U.S. as of 2013.

Figure F.18.1: Grand Forks Airport International Terminal (Source: http://gfkairport.com/)

❖ System Description

In the Grand Forks Airport International Terminal building, 33 water-to-air heat pump units are used to condition the indoor occupied spaces. Another water-to-water heat pump is used only to provide heating effect to the large open space – the lobby through a hot water floor radiation system, as shown in Figure F.18.2. Two DOASs are used to provide necessary ventilation (total 6,355 cfm). Ducts from these two units are tied to each heat pump to supply fresh air to each occupied space. Energy recovery wheels are equipped in these two DOASs respectively to exchange the heat between exhaust and intake air. These DOASs are in the heat pump mode, which are connected to and share the same ground loops with other heat pump units. These heat pump units have the efficiencies between 8.9 ~ 12.3 EER for cooling and 2.6 ~ 3.7 COP for heating. Heat rejection and extraction take place through 16 horizontal boreholes that are buried underground with the depth of 25 feet and 40 feet (two layers) below the ground surface with a minimum separation distance of 20 feet, as shown in Figure F.18.3. The length of each horizontal borehole is 500 feet. A horizontally bored system is a variant of a conventional horizontal closed-loop system, and can be considered as an intermediate underground heat exchange system between conventional horizontal and vertical closed-loop systems. The development of this type of system benefits from a horizontal drilling technique that allows the installation of horizontal heat exchangers in the deeper ground at different layers. Like a vertical closed-loop system, the horizontal boreholes are typically grouted in order to improve the heat transfer performance.

Water in both of the ground and building loops is circulated between them through four VSD pumps (two for the ground loop and the other two for the building loop).

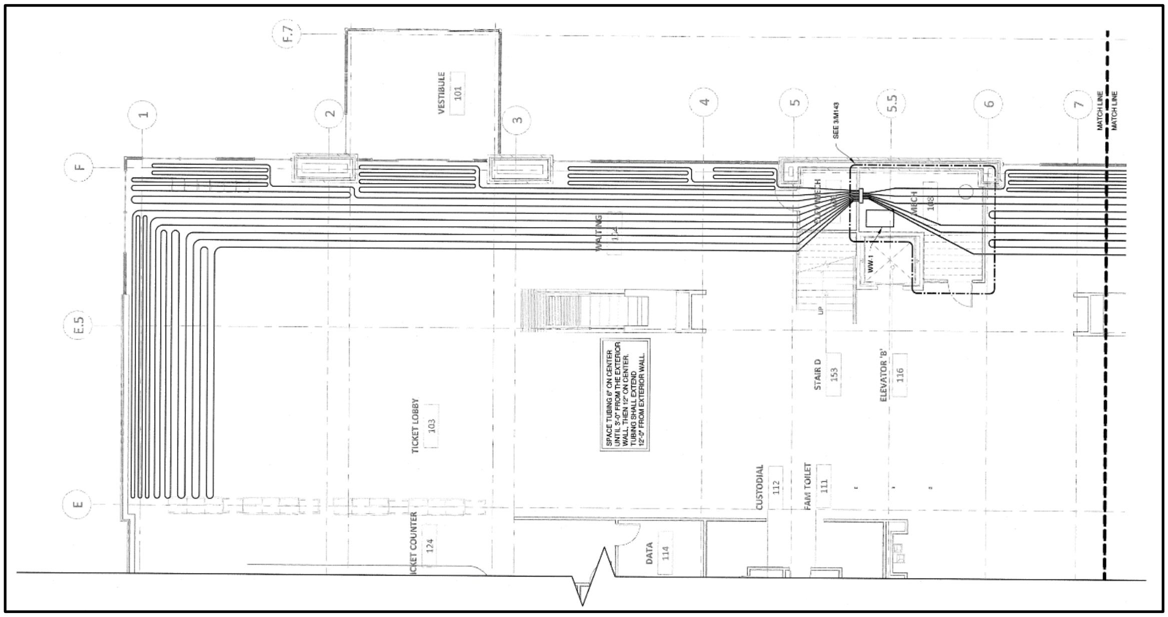


Figure F.18.2: Hot water floor radiation system

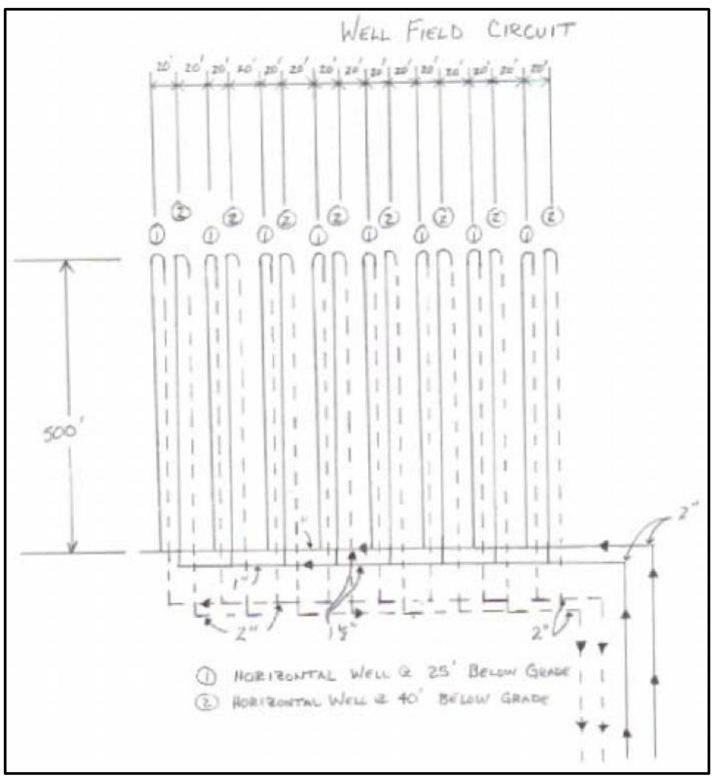


Figure F.18.3: Horizontal underground loop

❖ System Performance

The monthly energy use of the Grand Forks Airport International Terminal building was not provided, but the actual energy cost during 2016 was given and is displayed in Figure F.18.4 with the total cost of $110,331.8 per year, i.e. $2.06/ft^2/yr. The reported actual energy savings is 15.7% compared to other relative buildings[1].

In order to determine the potential energy and energy cost savings between the actual building with a GHP system and a similar building with a conventional air-conditioning system, an energy simulation model was established as described in Figure 3.4. To enhance the reliability of the simulation results, the model with the actual building design was calibrated by using the actual utility costs. Figure F.18.5, Figure F.18.6, and Figure F.18.7 show the calibration results, i.e. the comparison between the simulated energy cost and the actual utility bills for the year 2016.

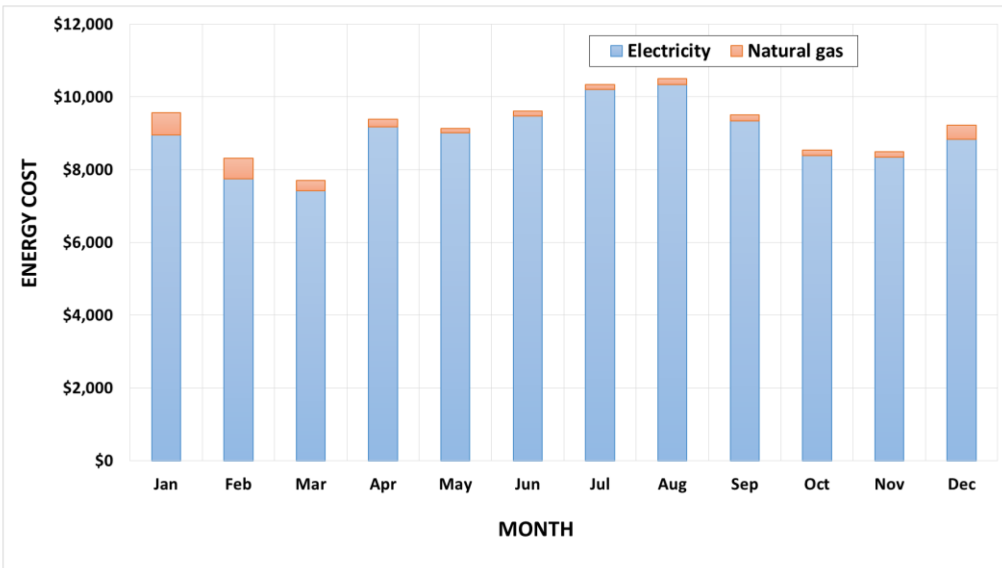


Figure F.18.4: Monthly energy cost during 2016

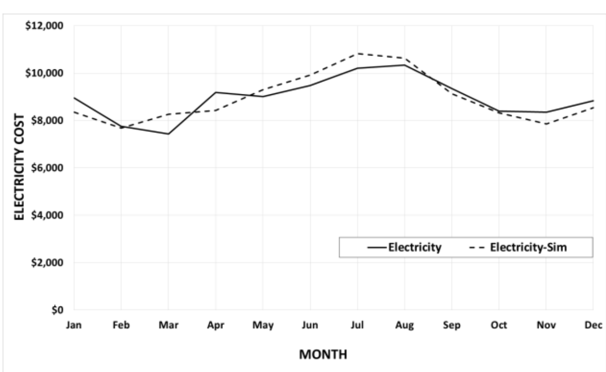


Figure F.18.5: Electricity cost comparison

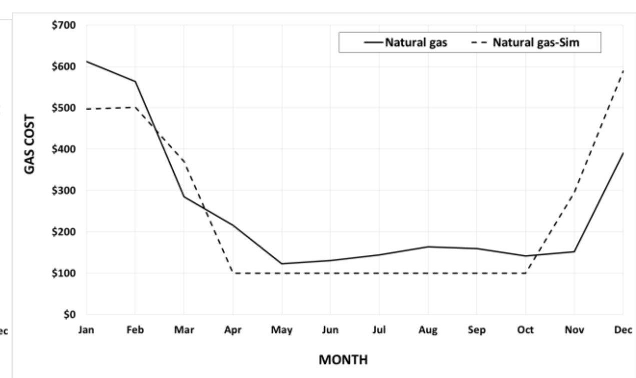


Figure F.18.6: Natural gas cost comparison

[1] http://gfkairport.com/leed/

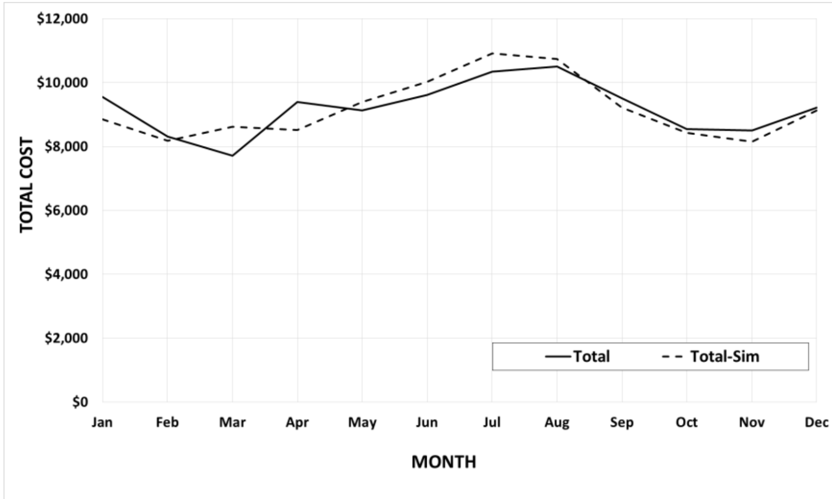


Figure F.18.7: Total utility cost comparison

The baseline model for a similar building with a conventional air-conditioning system design was established based on the calibrated model. The difference between these two models is shown in Table F.18.1 below.

Table F.18.1: Model difference

Model with the actual GHP system	Model with a conventional air-conditioning system
Geothermal heat pump systems as designed	Packaged rooftop air conditioner with constant volume fan control, direct expansion (DX) cooling and fossil fuel furnace heating (others are the same as the actual system)

Table F.18.2: Energy Performance Comparison

	Actual GHP System		ASHRAE Conventional System
	Actual Utilities	Simulated	Simulated
Electricity Usage (kwh/yr)	Not Provided	1,233,728	1,007,035
Electricity Cost ($/yr)	107,248.43	107,211.00	87,511.00
Natural Gas Usage (therm/yr)	Not Provided	4,494	20,948
Natural Gas Cost ($/yr)	3,083.41	2,952.00	11,063.00
Actual Site Energy Usage (MMBTU/yr)	Not Provided	4,660.2	5,531.9
Estimated Source Energy Usage (MMBTU/yr)*	-	13,689.6	12,988.6
Total Actual Energy Cost ($/yr)	110,331.8	110,163.0**	98,574.0**
Actual Site EUI (kBtu/ft^2/yr)	Not Provided	87.0	103.3
Estimated Source EUI (kBtu/ft^2/yr)*	-	255.7	242.6
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	-	825.9	765.9
Energy Savings Compared to Conventional System	16%		
Energy Cost Savings Compared to Conventional System	-12%		

* Based on Energy Star Target Finder results
** Determined by using the 2016 average electricity and natural gas rates for the state of North Dakota, i.e. 8.96 cents per kwh and $0.526 per therm [1]

[1] https://www.eia.gov/dnav/ng/ng_pri_sum_dcu_SND_a.htm

As shown in Table F.18.1, the conventional air-conditioning system was determined by using ASHRAE 90.1 (Appendix G). Please note that, in the model with the conventional air-conditioning system, only the mechanical system was changed according to ASHRAE 90.1 (Appendix G). Other building parameters, such as building wall and roof constructions, light power density of each space, etc., were not changed (see Figure 3.4). Once these simulation models have been established successfully, the energy and energy cost savings can be identified, which are summarized below and also shown in Table F.18.2.

- 16% of energy savings is achieved between the actual building and a similar building with a conventional air-conditioning system;
- Energy cost savings between the actual building and a similar building with a conventional air-conditioning system are not found (-12%), due to the extremely low utility rate for natural gas compared to electricity. The conventional air-conditioning system primarily uses natural gas (furnaces) to provide heating effect, while the actual geothermal system uses electricity (heat pumps).

❖ Project Costs

The total capital cost of the building is approximately $25,000,000 with the total HVAC cost of about $1,200,000, i.e. $22.4/ft^2. The simple payback period was determined, which goes to infinity, since there is no energy cost savings (-12%) identified compared to the corresponding conventional system. Table F.18.3 provides the summary information of this building.

Table F.18.3: Building Summary

Building Information

Building Name	Grand Forks Airport International Terminal
Building Address	Grand Forks
Building Type	Public/Commercial Building
Building Construction Year	2011
Building Total Area (ft^2)	53,548
Total Number of Floor	Above ground: 2
LEED Building	Yes - Silver

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2011
Installation Type	New
GHP system type	Horizontally bored closed loop
Number of Boreholes for Horizontal GHP	16
Borehole Depth (ft)	25 and 40
Borehole Separation Distance (ft)	20
Borehole Length (ft)	500/each Total 8,000
Underground Pipe Length (ft)	16,000
Borehole Length per ton (ft/ton)	83
Underground Pipe Length per ton (ft/ton)	166
GHP water flow rate per ton (gpm/ton)	2.3
Number of Heat Pump Units	Water-to-Air Heat Pump: 33 Water-to-Water Heat Pump (Heating Only): 1 DOAS - Heat Pump: 2
Total Capacity of Heat Pump Units (tons)	96
Total Capacity of the entire HVAC System (tons)	96
Heat Pump Efficiency Range	Cooling: 8.9~12.3 EER Heating: 2.6~3.7 COP

Cost Information

Capital Cost of the Building ($)	25,000,000
Total Cost of the HVAC System ($)	1,200,000
HVAC System Average Annual Repair and Maintenance Cost ($)	4,600
Government Incentives for the Use of GHP	No
Utility Incentives for the Use of GHP	No

Question & Answer

Questions answered by	Rick Audette Operations & Maintenance Manager Tel: 701-738-4644 Fax: 701-795-6979 'raudette@gfkairport.com'
1. Why did you decide to install the geothermal heat pump system in your building?	Lower heating and cooling bills (decision and goal from Architect & Airport Authority Board)
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Yes, except electrical costs. No complaints from users.
3. As you know, are there any operating difficulties of the geothermal heat pump system?	None
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Possibly

#19. Black Gold Corporate Headquarters

❖ Background

The Black Gold Corporate Headquarters (Figure F.19.1) is located in Grand Forks, North Dakota, and was built in 2012. This office building has an area of about 13,445 ft^2 with individual and open offices, conference/meeting rooms, training rooms, etc. This facility is using a vertical closed-loop GHP system to provide space heating and cooling. The total number of vertical boreholes is 26 with the depth of about 200 feet underground. This building is LEED Gold certified. As reported, to achieve this certification, this building was designed to reduce energy consumption by 21.66% and water use by 34%[1]. Other features include one ERU, VSD water pumps, occupancy and daylighting sensors, exterior sunshades, LED lights, etc.

❖ System Description

In the building of Black Gold Corporate Headquarters, 19 water-to-air heat pump units are used to condition the indoor occupied spaces. Another water-to-water heat pump is used only to provide hot water to the perimeter zones of the building through a floor radiation system, as shown in Figure F.19.2. These heat pump units have the efficiencies between 11.5 ~ 15.8 EER for cooling and 3.3 ~ 4.4 COP for heating. Heat rejection and extraction take place through 26 vertical boreholes with the depth of about 200 feet below the ground surface and a minimum separation distance of 15 feet, as shown in Figure F.19.3. Water in this system is circulated between the heat pumps and the ground loops through two VSD pumps (one is for backup), as shown in Figure F.19.4. Ventilation requirement for this building is met by an ERU with the total design air flow rate of 1,800 cfm. Ducts from this unit are tied to each heat pump to supply fresh air to each occupied space.

Figure F.19.1: Black Gold Corporate Headquarters (Source: http://jlgarchitects.com/projects/black-gold)

1 https://www.obernel.com/portfolio-item/black-gold-farms-corporate-headquarters/

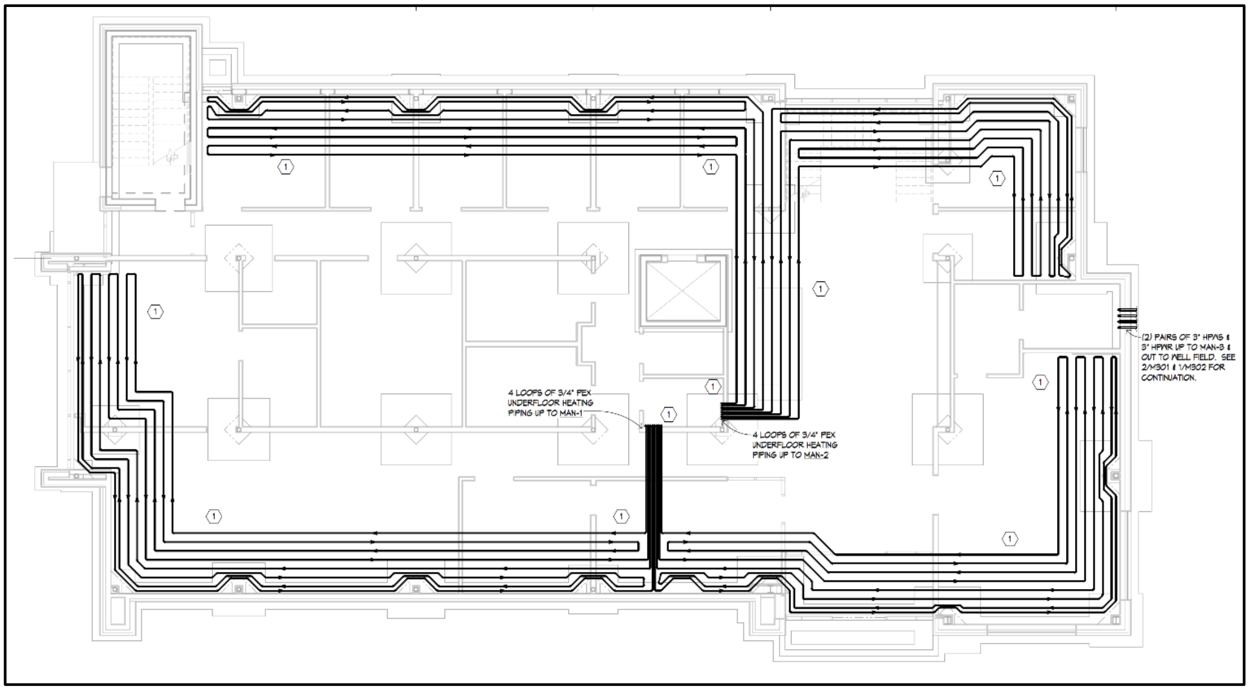


Figure F.19.2: Hot water floor radiation system

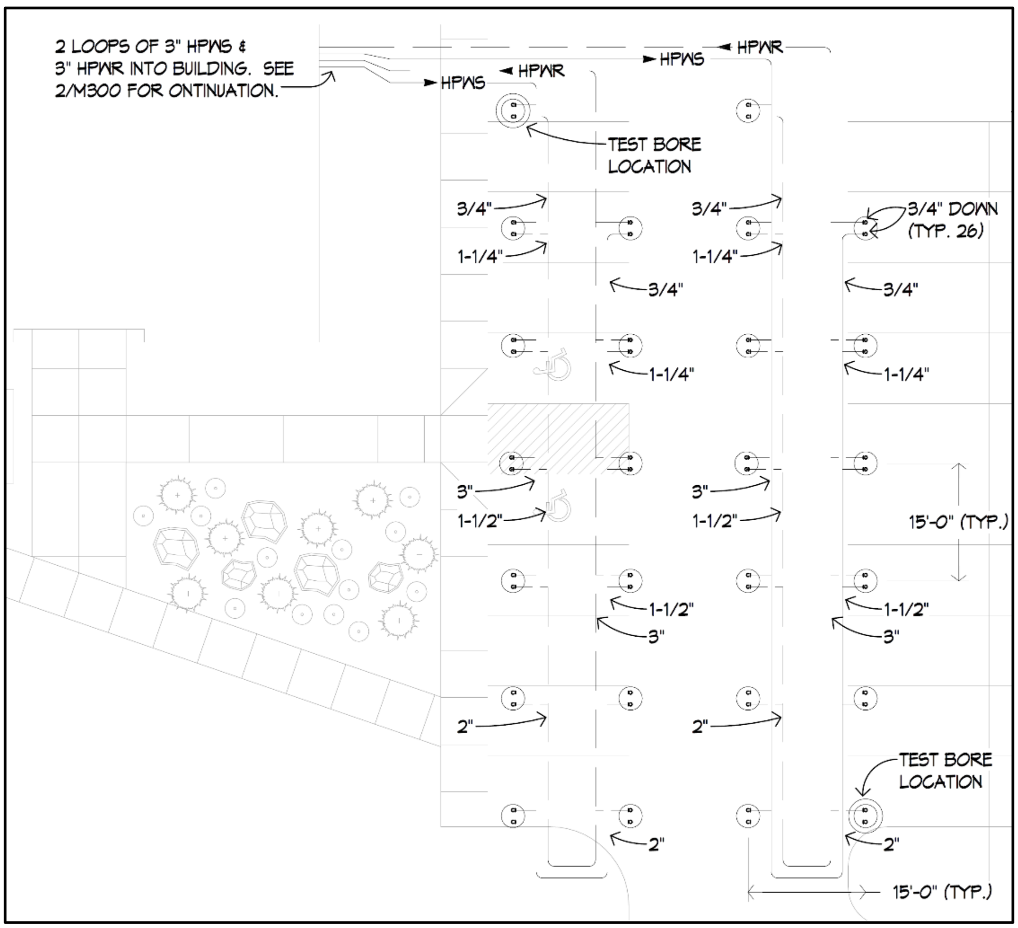


Figure F.19.3: Underground boreholes

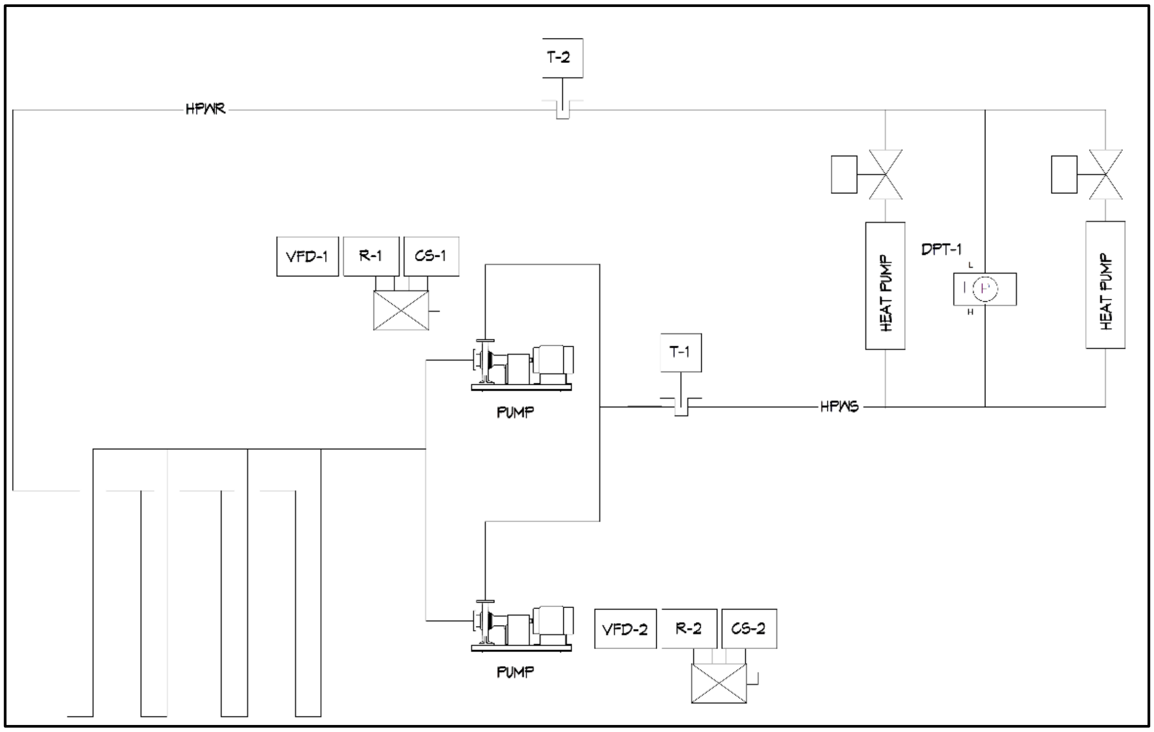


Figure F.19.4: Building and underground loops

❖ System Performance

The monthly energy use of the Black Gold Corporate Headquarters building for the year of 2016 was given and is displayed in Figure F.19.5 with the total energy consumption of 171,040 kwh (EUI = 43.4 kBtu/ft^2/yr). As shown in this figure, electricity is the only energy source for this building. The corresponding energy cost is shown in Figure F.19.6 with the total cost of $17,945.6 per year, i.e. $1.33/ft^2/yr. In order to determine the potential energy and energy cost savings between the actual building with a GHP system and a similar building with a conventional air-conditioning system, an energy simulation model was established as described in Figure 3.4. To enhance the reliability of the simulation results, the model with the actual building design was calibrated by using the actual energy usage and utility cost. Figure F.19.7 and F.19.8 show the calibration results.

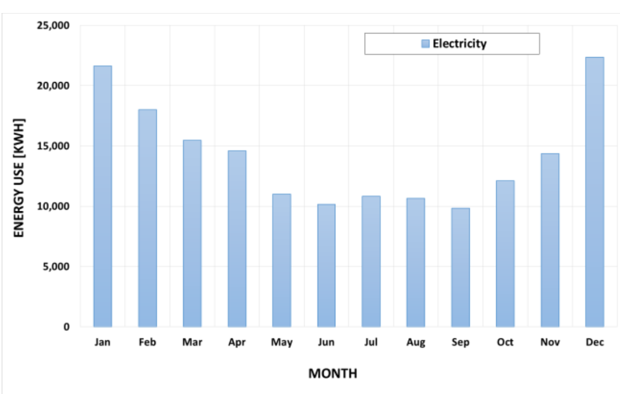


Figure F.19.5: Monthly energy use during 2016

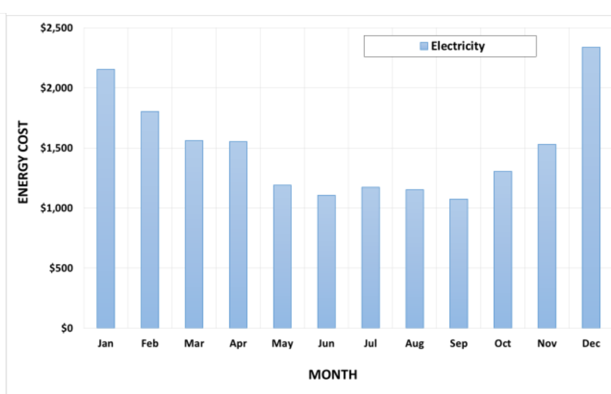


Figure F.19.6: Monthly energy cost during 2016

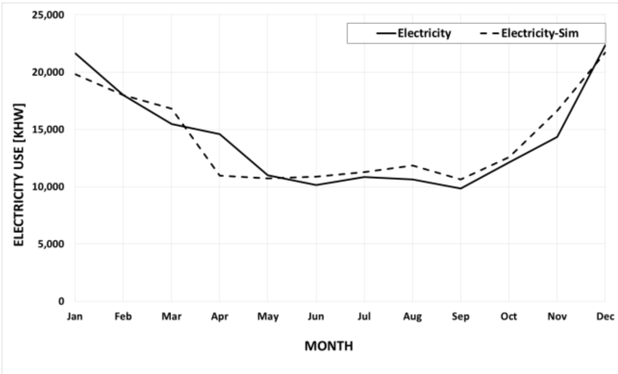


Figure F.19.7: Electricity use comparison

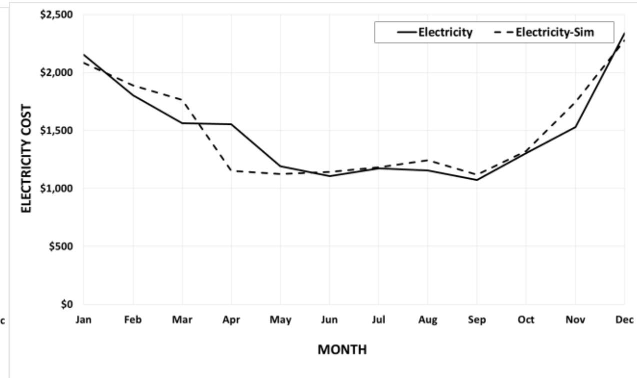


Figure F.19.8: Energy cost comparison

The baseline model for a similar building with a conventional air-conditioning system design was established based on the calibrated model. The difference between these two models is shown in Table F.19.1 below.

Table F.19.1: Model difference

Model with the actual GHP system	Model with a conventional air-conditioning system
Geothermal heat pump systems as designed	Packaged rooftop heat pump with constant volume fan control, direct expansion (DX) cooling and electric heat pump heating (others are the same as the actual system).

As shown in Table F.19.1, the conventional air-conditioning system was determined by using ASHRAE 90.1 (Appendix G). Please note that, in the model with the conventional air-conditioning system, only the mechanical system was changed according to ASHRAE 90.1. Other building parameters, such as building wall and roof constructions, light power density of each space, etc., were not changed (see Figure 3.4). Once these simulation models have been established successfully, the energy and energy cost savings can be identified, which are summarized below and also shown in Table F.19.2.

- 31.8% of energy savings is achieved between the actual building and a similar building with a conventional air-conditioning system;
- 31.7% of energy saving is achieved between the actual building and a similar building based on the EPA's Energy Star Target Finder result for a national median property;
- Energy cost savings between the actual building and a similar building with a conventional air-conditioning system or based on the Energy Star Target Finder result are shown as 31.7% for both, due to the use of the high-efficiency GHP system.

Table F.19.2: Energy Performance Comparison

	Actual GHP System		ASHRAE Conventional System	Similar Building*
	Actual Utilities	Simulated	Simulated	Estimated (the national median)*
Electricity Usage (kwh/yr)	171,040	171,889	250,509	250,563
Electricity Cost ($/yr)	17,945.64	18,041.00	26,293.00	26,269.74
Natural Gas Usage (therm/yr)	-	-	-	-
Natural Gas Cost ($/yr)	-	-	-	-
Actual Site Energy Usage (MMBTU/yr)	583	586.7	855.0	854.3
Estimated Source Energy Usage (MMBTU/yr)*	1,832.5	1,841.6	2,683.9	2,682.5
Total Actual Energy Cost ($/yr)	17,945.6	18,041.0**	26,293.0**	26,269.74**
Actual Site EUI (kBtu/ft^2/yr)	43.4	43.6	63.6	63.5
Estimated Source EUI (kBtu/ft^2/yr)*	136.3	137.0	199.6	199.5
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	111.2	111.7	162.9	162.8
Energy Savings Compared to Conventional System	31.8%			
Energy Savings Compared to EPA Similar Buildings	31.7%			
Energy Cost Savings Compared to Conventional System	31.7%			
Energy Cost Savings Compared to EPA Similar Buildings	31.7%			

* Based on Energy Star Target Finder results
** Determined by using the actual average annual utility rates, i.e. 10.4921 cents per kwh

Up to now, this building has only been operating for 5 years, and considering the lifespan of a heat pump unit with about 20 years, this system is still relatively new and in a good shape. Thus, so far no operational difficulties or significant issues have been reported. Figure F.19.9 and F.19.10 show the actual ground water temperatures of the geothermal system in a typical summer or winter day under either cooling (7/27/2016) or heating (1/10/2016) modes, respectively. In these figures, "Supply" and "Return" represent the temperature of water supplied to the heat pumps or returned to the underground wellfields, respectively.

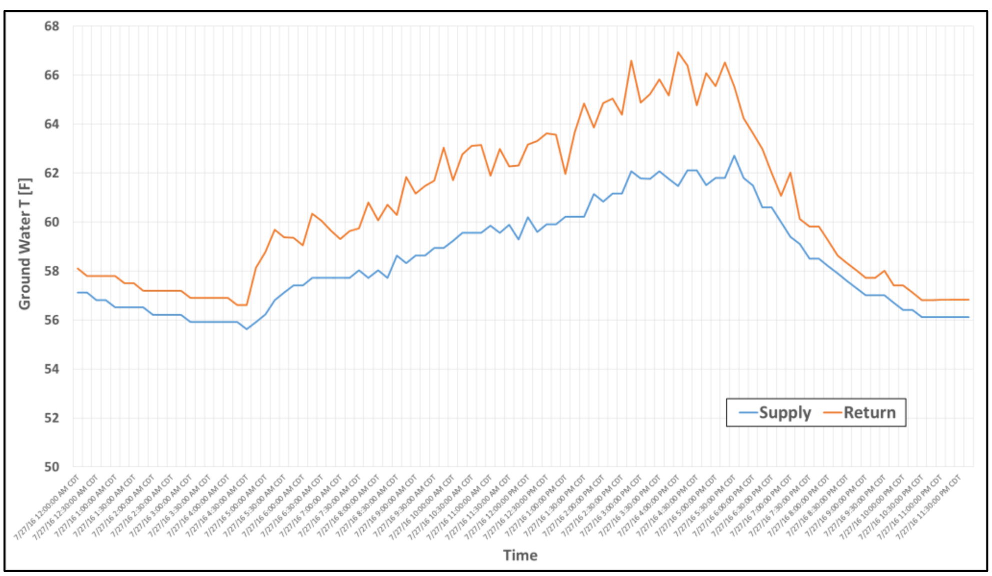


Figure F.19.9: Ground water temperatures in a typical summer day (7/27/2016)

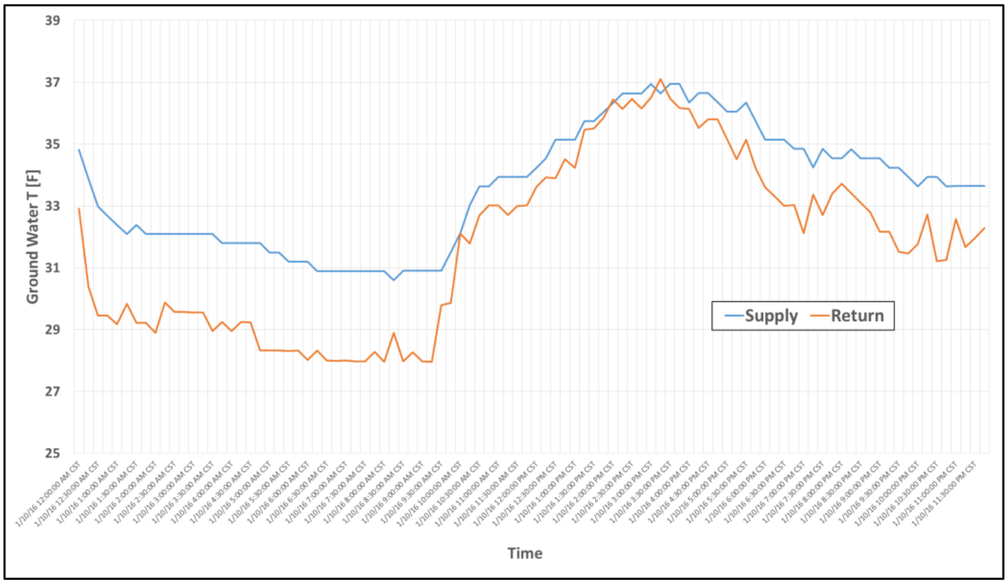


Figure F.19.10: Ground water temperatures in a typical winter day (1/10/2016)

The only issues reported by the operation specialist of this building are shown below.

1. The difficulties for the geothermal system to initially start up during the first winter in 2012, due to the absence of a backup heating system and that the underground region had not absorbed enough building heat during the summer period and thus is too cold and not ready to provide enough heat. So it is reported that temporary auxiliary heating devices were used to heat up the entire building during that winter.
2. The location of one return grill of a heat pump unit is not appropriately designed and located, which results in the ice formation on the cooling coil of that heat pump unit due to the much less return air flow going through that cooling coil.

❖ Project Costs

The total capital cost of the building is approximately $2,973,000 with the total mechanical system cost of about $400,000, i.e. $29.75/ft^2, where $145,000 is for the exterior ground-loop installation and components and $255,000 is for the interior HVAC/GHP system installation and components. Table F.19.3 indicates the mechanical cost comparison between the actual design and the virtual conventional system. As shown in this table, the simple payback period because of the use of the GHP system against the conventional air-conditioning system for this building is 9.3 years.

Table F.19.3: Cost Comparison Analysis

Actual GHP System		Conventional System	
GHP system:	$322,754.00*	Packaged rooftop heat pump with constant volume fan control, direct expansion (DX) cooling and electric heat pump heating (others are the same as the actual system**):	$244,949.40*
Cost of the Mechanical System per Total Building Area ($/ft^2)	24.0	Cost of the Mechanical System per Total Building Area ($/ft^2)	18.2
Yearly energy cost:	$17,945.64	Yearly energy cost:	$26,293.00
HVAC System Average Annual Repair and Maintenance Cost ($)	$700	HVAC System Average Annual Repair and Maintenance Cost ($)	$700
Simple payback period (Years):		9.3	

* Estimated by using [1], [2], [3], and/or [4]
** Others may include sump pumps, energy recovery units, exhaust fans, roof hoods, water heaters, etc.

Table F.9.4 provides the summary information of this building.

Table F.19.4: Building Summary

Building Information

Building Name	Black Gold Corporate Headquarters
Building Address	Grand Forks
Building Type	Office/Commercial Building
Building Construction Year	2012
Building Total Area (ft^2)	13,445
Total Number of Floor	Above ground: 2
LEED Building	Yes - Gold

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2012
Installation Type	New
GHP system type	Vertical closed loop
Number of Boreholes for Horizontal GHP	26
Borehole Depth (ft)	200
Borehole Separation Distance (ft)	15
Borehole Length (ft)	5,200
Underground Pipe Length (ft)	10,400
Borehole Length per ton (ft/ton)	141
Underground Pipe Length per ton (ft/ton)	282
GHP water flow rate per ton (gpm/ton)	2.4
Number of Heat Pump Units	Water-to-Air Heat Pump: 19 Water-to-Water Heat Pump (Heating Only): 1
Total Capacity of Heat Pump Units (tons)	37
Total Capacity of the entire HVAC System (tons)	37
Heat Pump Efficiency Range	Cooling: 11.5~15.8 EER Heating: 3.3~4.4 COP

[1] RS Means data. https://www.rsmeans.com/

[2] Climatemaster System Selling Binder. climatemaster.com/downloads/06RepMtg-selling%20wshp-LM.ppt

[3] Steve Kavanaugh and Kevin Rafferty. 2014. Geothermal Heating and Cooling Design of Ground-source Heat Pump Systems. ASHRAE. ISBN 978-1-936504855. 1791 Tullie Circle, NE, Atlanta, GA 30329.

[4] Bloomquist, R.G., 2001. The economics of geothermal heat pump systems for commercial and institutional buildings. Proceedings of the International Course on Geothermal Heat Pumps, Bad Urach, Germany.

Cost Information

Capital Cost of the Building ($)	2,973,000
Total Cost of the HVAC System ($)	400,000
Cost Breakdown ($)	• Exterior Ground-loop installation and component cost (including borehole drilling, headers, piping, etc.): $145,000
	• Interior HVAC/GHP System installation and component cost (including heat pump units, ducting, controls, etc.): $255,000
HVAC System Average Annual Repair and Maintenance Cost ($)	700 (most spent for filters)
Government Incentives for the Use of GHP	No
Utility Incentives for the Use of GHP	No

Question & Answer

Questions answered by	Joel Horne Operations Specialist Tel: 701-740-2896 Fax: 701-772-0749 joel.horne@blackgoldfarms.com
1. Why did you decide to install the geothermal heat pump system in your building?	To aid in obtaining LEED status, and to be seen a good steward of resources in the eyes of our customers, suppliers, and the general public.
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	There are some comfort issues that can be discussed.
3. As you know, are there any operating difficulties of the geothermal heat pump system?	Aside from the start-up season and learning curve issues, there have been no difficulties other than nuisance items. The caveat to be made is the system has been in operation only five years, and we have not experienced a colder than average winter.
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes, with reservations.

#20. Cass County Electric Cooperative Building

❖ Background

The Cass County Electric Cooperative (CCEC) Office Building (Figure F.20.1) is located in Fargo, North Dakota, and was built in 2008. This office building has an area of about 57,500 ft^2 with two stories above the ground and one basement for parking. This building consists of 32 office spaces (individual or open offices), 3 conference rooms, lobbies, one training room, one board room, one lunch room, one breakroom, a large I.T. room with about 1,700 ft^2 and hundreds of servers, etc. This facility is using a vertical closed-loop GHP system to provide space heating and cooling. The total number of vertical boreholes is 80 with the depth of about 200 feet underground. Other features include one ERU, two make-up air units, four DOASs, VSD fans and water pumps, etc.

Figure F.20.1: Cass County Electric Building
(Source: https://www.obernel.com/portfolio-item/cass-county-electric-office-building/)

❖ System Description

In the CCEC office building, 40 water-to-air heat pump units are used to condition the indoor occupied spaces. These heat pump units have the efficiencies between 8.4 ~ 11.8 EER for cooling and 2.5~ 4.2 COP for heating. Heat rejection and extraction take place through 80 vertical boreholes with the depth of about 200 feet below the ground and a minimum separation distance of 15 feet, as shown in Figure F.20.2. These vertical boreholes were buried under a parking lot located in the west of the building. Water in this system is circulated between the heat pumps and the ground loops through two VSD water pumps (one is for backup). Ventilation requirement (fresh air) for this building is met by an ERU with the total design air flow rate of 5,400 cfm. Ducts from this unit are tied to each heat pump to supply fresh air to each occupied space. An energy recovery wheel is equipped in the energy recovery unit to exchange the heat between exhaust and intake air. This ERU is also using geothermal heat (sharing the same geothermal loop with other water-to-air heat pumps) to precondition the ventilation air. Additionally, the large I.T. server room is cooled down by using four dedicated air-conditioning units (DX cooling only with about 90 tons) which are connected to four dry coolers to provide cooling effect and reject server heat to the outside all year around.

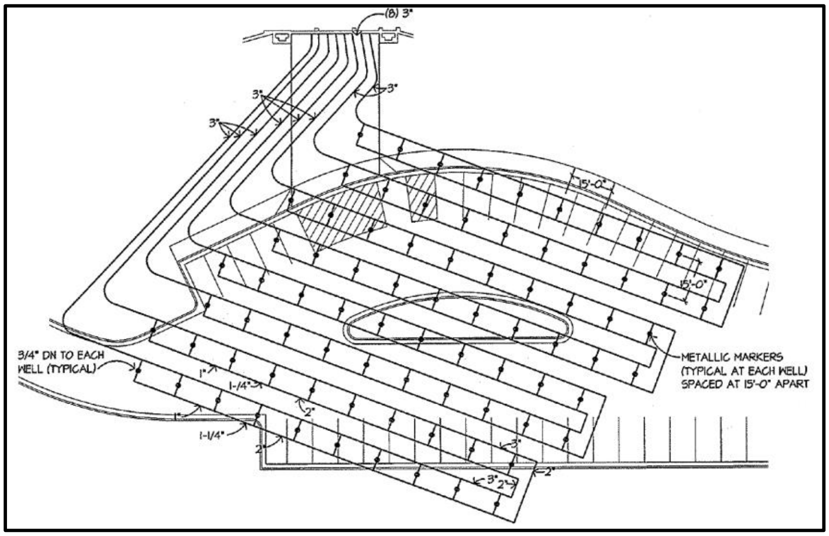


Figure F.20.2: Geothermal loops

❖ System Performance

The actual monthly energy cost of the CCEC office building was not provided, but the monthly energy use during 2016 was given and is displayed in Figure F.20.3. Thus, the corresponding annual energy cost can be estimated ($68,983/yr or $1.2/ft^2/yr) by using the average electricity utility rate for commercial usage in North Dakota in 2016, i.e. 8.96 cents per kWh[1]. In this building, electricity is the only energy source.

In order to identify the potential energy and energy cost savings of the building, the actual energy consumption result of this building was eventually compared with the EPA's Energy Star Target Finder result which represents the national median of the energy performance of similar buildings in the U.S. These results are shown in Table F.20.1, which indicate a 34% of energy and energy cost savings between the actual building and a similar building based on the Energy Star Target Finder result.

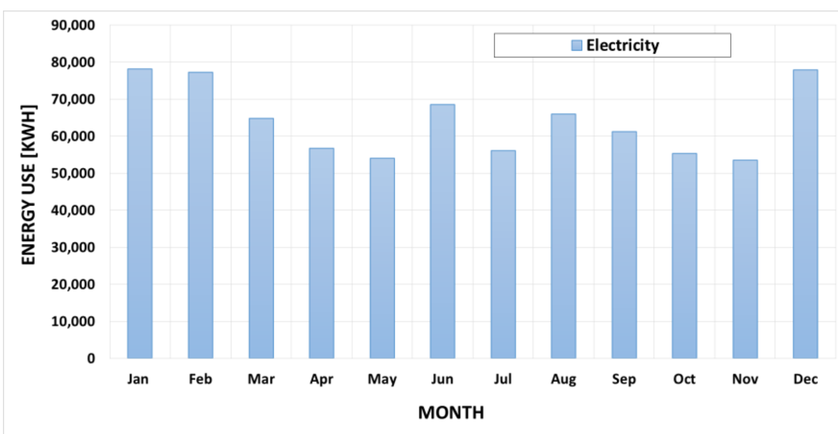


Figure F.20.3: Monthly energy use during 2016

[1] https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a

Table F.20.1: Energy Performance Comparison

	Actual GHP System	Similar Building*
	Actual Utilities	Estimated (the national median)*
Electricity Usage (kwh/yr)	769,900	1,160,636
Electricity Cost ($/yr)	68,983**	103,917**
Natural Gas Usage (therm/yr)	-	-
Natural Gas Cost ($/yr)	-	-
Actual Site Energy Usage (MMBTU/yr)	2,627	3,957.2
Estimated Source Energy Usage (MMBTU/yr)*	8,248.5	12,425.6
Total Actual Energy Cost ($/yr)	68,983**	103,917**
Actual Site EUI (kBtu/ft^2/yr)	46	68.8
Estimated Source EUI (kBtu/ft^2/yr)*	143.5	216.1
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	500.5	754.0
Energy Savings Compared to Similar EPA Buildings	34%	
Energy Cost Savings Compared to Similar EPA Buildings	34%	

* Based on Energy Star Target Finder results
** Determined by using the 2016 average electricity rates for the state of North Dakota, i.e. 8.96 cents per kwh [1]

❖ Project Costs

The total capital cost of the building as well as the information regarding the total HVAC cost was not given. Therefore, the cost comparative analysis and the simple payback period calculation for this building were not conducted, due to the lack of such cost information about this building.

The basic summary information of this building is shown in Table F.20.2 below.

Table F.20.2: Building Summary

Building Information

Building Name	Cass County Electric Cooperative Building
Building Address	Fargo
Building Type	Commercial Building/Office
Building Construction Year	2008
Building Total Area (ft^2)	57,500
Total Number of Floor	Above ground: 2 Below ground: 1
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2008
Installation Type	New
GHP system type	Vertical closed loop
Number of Boreholes for Vertical GHP	80
Borehole Depth (ft)	200
Borehole Separation Distance (ft)	15
Borehole Length (ft)	16,000
Underground Pipe Length (ft)	32,000
Borehole Length per ton (ft/ton)	233
Underground Pipe Length per ton (ft/ton)	466
GHP water flow rate per ton (gpm/ton)	4.2
Number of Heat Pump Units	Water-to-Air Heat Pump: 40
Total Capacity of Heat Pump Units (tons)	69
Total Capacity of the entire HVAC System (tons)	177
Heat Pump Efficiency Range	Cooling: 8.4~11.8 EER Heating: 2.5~4.2 COP

[1] https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a

Cost Information

Capital Cost of the Building ($)	Not Provided
Total Cost of the HVAC System ($)	Not Provided
HVAC System Average Annual Repair and Maintenance Cost ($)	8,000
Government Incentives for the Use of GHP	No
Utility Incentives for the Use of GHP	No

Question & Answer

Questions answered by	Chad Brousseau Manager of Energy Services Office: 701.356.4514 Cell: 701.866.5114 cbrousseau@kwh.com
1. Why did you decide to install the geothermal heat pump system in your building?	Efficient heating system with low operating cost
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Yes
3. As you know, are there any operating difficulties of the geothermal heat pump system?	No difficulties that I am aware of.
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Depending on the application and scale of the project and what other heating systems are available. Geothermal can be a great choice in the right scenario.

#21. Osgood Fire Station 7

❖ Background

The Osgood Fire Station #7 (Figure F.21.1) is located in Fargo, North Dakota, and was built in 2009. This building has an area of about 12,000 ft^2 with 4 sleeping rooms, one laundry space, one wellness/fitness room, one conference room, several office rooms, one large open dinning/kitchen area, and a large garage (apparatus bays). This facility is using a vertical closed-loop GHP system to provide space heating and cooling. Auxiliary heating devices are used in the large garage space, including gas fired unit heaters and a hot water floor radiation system. The total number of vertical boreholes is 18 with the depth of about 200 feet underground. Other features include one ERU, VSD water pumps, occupancy sensors, etc.

Figure F.21.1: Fargo Osgood Fire Station 7 (Source: https://www.facebook.com/pg/FargoFS7/about/)

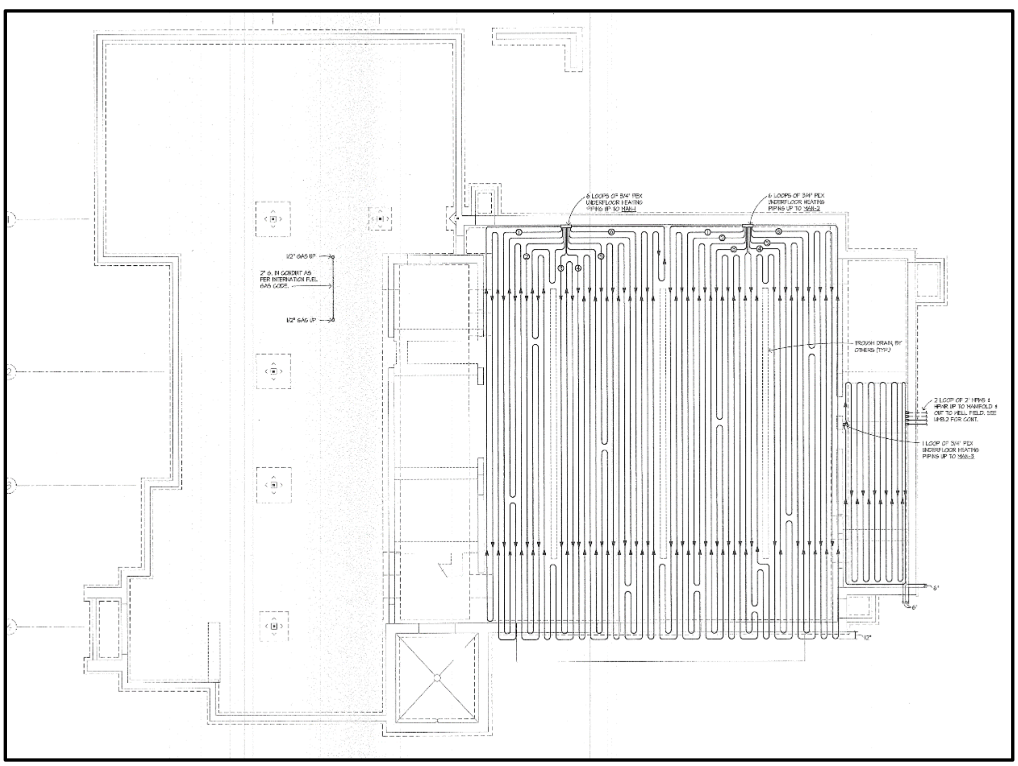


Figure F.21.2: Hot water floor radiation system

❖ System Description

In the Osgood Fire Station #7 building, 6 water-to-air heat pump units are used to condition the indoor occupied spaces. Another water-to-water heat pump is used only to provide heating effect to the large garage through a hot water floor radiation system, as shown in Figure F.21.2. These heat pump units have the efficiencies between 11.5 ~ 14 EER for cooling and 2.9 ~ 3.5 COP for heating. Heat rejection and extraction take place through 18 vertical boreholes with the depth of about 200 feet below the ground surface and a minimum separation distance of 15 feet, as shown in Figure F.21.3. Water in this system is circulated between the heat pumps and the ground loops through two VSD water pumps (one is for backup). Ventilation requirement for this building is met by an ERU with the total design air flow rate of 740 cfm. Ducts from this ERU are tied to each heat pump to supply fresh air to each occupied space. An energy recovery wheel is equipped in the energy recovery unit to exchange the heat between exhaust and intake air. Six gas-fired unit heaters are used to provide additional heating to the large garage space during winter with the heating efficiency of approximately 83%.

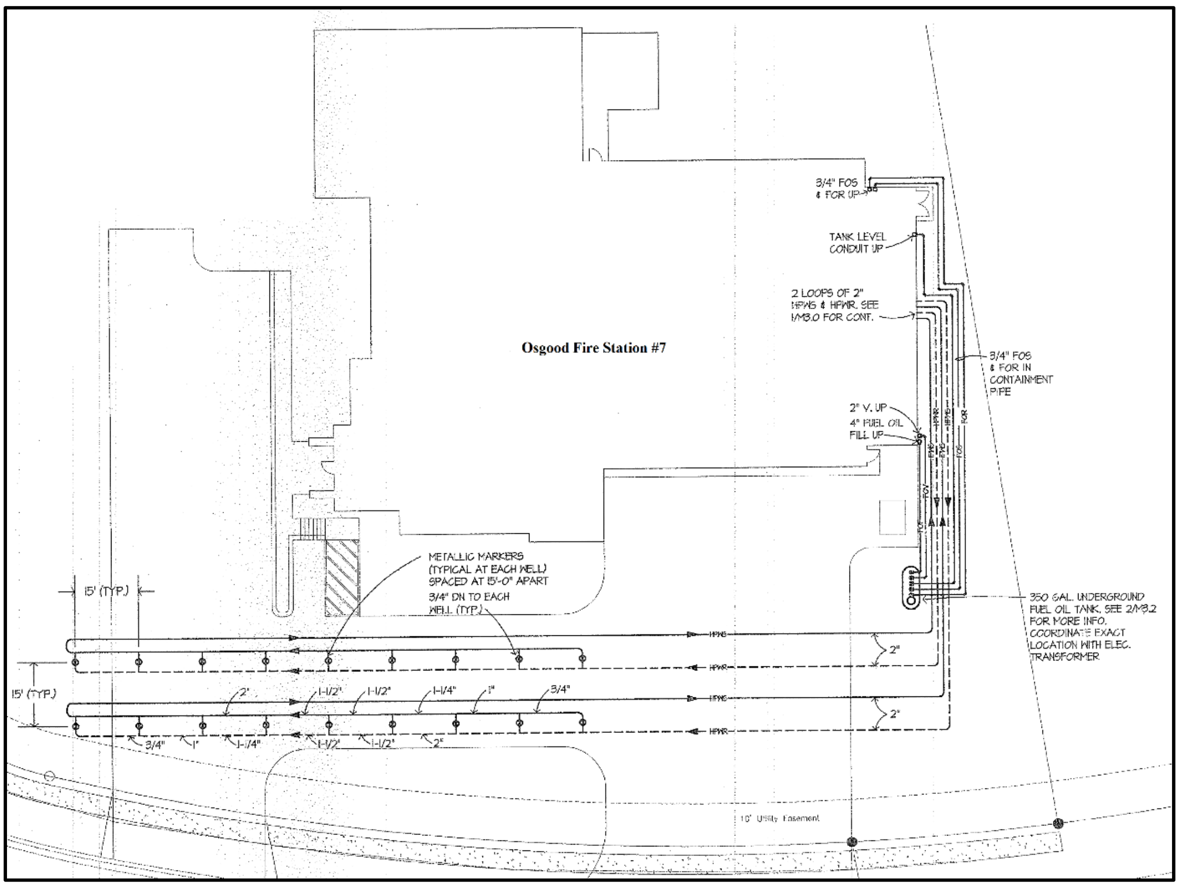


Figure F.21.3: Osgood Fire Station #7 – Underground loops

❖ System Performance

The monthly energy use of the Osgood Fire Station #7 building was not provided, but the actual energy cost during 2016 was given and is displayed in Figure F.21.4 with the total cost of \$15,832.05 per year, i.e. \$1.32/ft^2/yr.

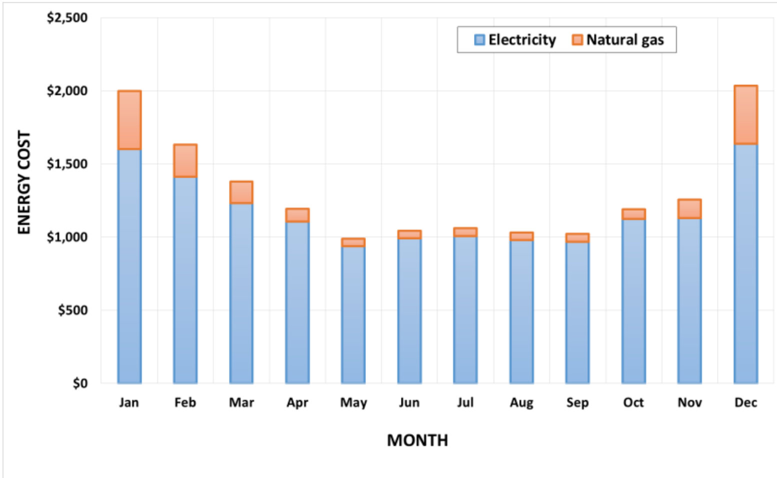


Figure F.21.4: Monthly energy cost during 2016

In order to determine the potential energy and energy cost savings between the actual building with a geothermal heat pump system and a similar building with a conventional air-conditioning system, an energy simulation model was established. To enhance the reliability of the simulation results, the model with the actual building design was calibrated first by using the actual utility costs. Figure F.21.5, F.21.6, and F.21.7 show the calibration results.

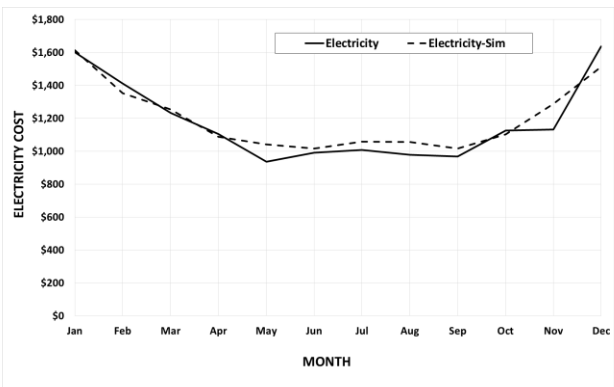


Figure F.21.5: Electricity cost comparison

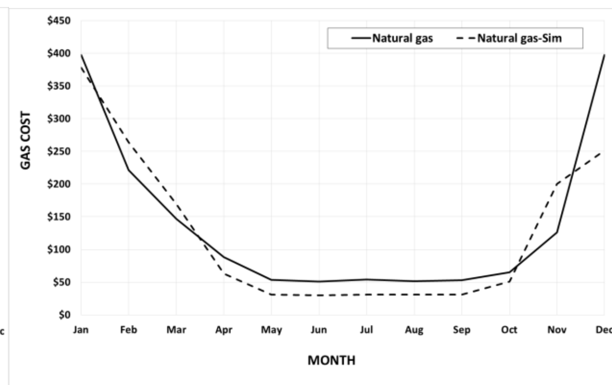


Figure F.21.6: Natural gas cost comparison

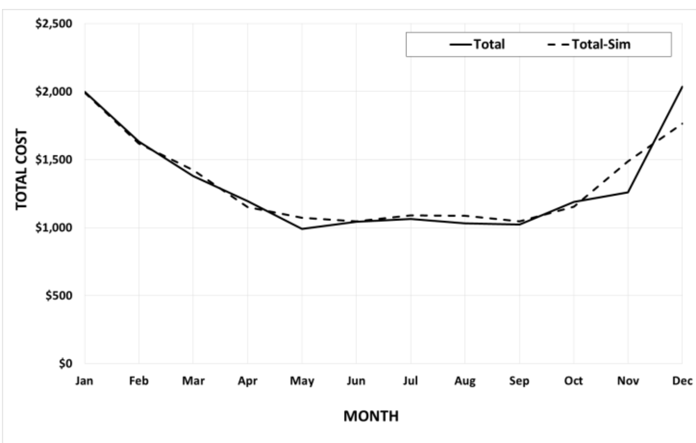


Figure F.21.7: Total utility cost comparison

The baseline model for a similar building with a conventional air-conditioning system design was established based on the calibrated model. The difference between these two models is shown in Table F.21.1 below.

Table F.21.1: Model difference

Model with the actual GHP system	Model with a conventional air-conditioning system
Geothermal heat pump systems as designed	Packaged rooftop air conditioner with constant volume fan control, direct expansion (DX) cooling and fossil fuel furnace heating (others are the same as the actual system)

Table F.21.2: Energy Performance Comparison

	Actual GHP System		ASHRAE Conventional System	Similar Building*
	Actual Utilities	Simulated	Simulated	Estimated (the national median)*
Electricity Usage (kwh/yr)	Not Provided	160,701	153,983	-
Electricity Cost ($/yr)	14,126.67	14,399	13,797	-
Natural Gas Usage (therm/yr)	Not Provided	2,902	3,844	-
Natural Gas Cost ($/yr)	1,705.38	1,532	2,030	-
Actual Site Energy Usage (MMBTU/yr)	Not Provided	838.7	909.9	822.9
Estimated Source Energy Usage (MMBTU/yr)*	-	2,026.4	2,053.3	1,857.2
Total Actual Energy Cost ($/yr)	15,832.05	15,931**	15,827**	14,315**
Actual Site EUI (kBtu/ft^2/yr)	Not Provided	69.7	75.6	68.4
Estimated Source EUI (kBtu/ft^2/yr)*	-	168.4	170.7	154.4
Total Estimated Greenhouse Gas Emissions (Metric Tons CO2e/yr)*	-	119.9	120.5	109.0
Energy Savings Compared to Conventional System	8%			
Energy Cost Savings Compared to Conventional System	-0.03%			
Energy Savings Compared to Similar EPA Buildings	-2%			
Energy Cost Savings Compared to Similar EPA Buildings	-11%			

* Based on Energy Star Target Finder results
** Determined by using the 2016 average electricity and natural gas rates for the state of North Dakota, i.e. 8.96 cents per kwh and $0.526 per therm [1]

As shown in Table F.21.1, the conventional air-conditioning system was determined by using ASHRAE 90.1 (Appendix G). Please note that, in the model with the conventional air-conditioning system, only the mechanical system was changed according to ASHRAE 90.1. Other building parameters, such as building wall and roof constructions, light power density of each space, etc., were not changed (see Figure 3.4). Once these simulation models have been established successfully, the energy and energy cost savings can be identified, which are summarized below and also shown in Table F.21.2.

- 8% of energy savings is achieved between the actual building and a similar building with a conventional air-conditioning system;

[1] https://www.eia.gov/dnav/ng/ng_pri_sum_dcu_SND_a.htm

- -2% of energy saving is achieved between the actual building and a similar building based on the EPA's Energy Star Target Finder result for a national median property;
- Energy cost savings between the actual building and a similar building with a conventional air-conditioning system is not found (-0.03%), due to the extremely low utility rate for natural gas compared to electricity;
- In addition, no energy cost savings is found (-11%) between the actual building and a similar building based on the EPA's Energy Star Target Finder result.

❖ Project Costs

The total capital cost of the building is approximately $2,500,000 with the total HVAC cost of about $430,000, which is around $35.7/ft^2. The simple payback period was determined, which goes to infinity, since there is no energy cost savings (-0.03%) identified compared to the corresponding conventional system. Table F.21.3 provides the summary information of this building.

Table F.21.3: Building Summary

Building Information

Building Name	Osgood Fire Station 7
Building Address	Fargo
Building Type	Public/Government Building
Building Construction Year	2009
Building Total Area (ft^2)	12,032
Total Number of Floor	Above ground: 1 + Mezzanine
LEED Building	No

Geothermal Heat Pump (GHP) Information

HVAC/GHP Installation Year	2009
Installation Type	New
GHP system type	Vertical closed loop
Number of Boreholes for Vertical GHP	18
Borehole Depth (ft)	200
Borehole Separation Distance (ft)	15
Borehole Length (ft)	3,600
Underground Pipe Length (ft)	7,200
Borehole Length per ton (ft/ton)	222
Underground Pipe Length per ton (ft/ton)	444
GHP water flow rate per ton (gpm/ton)	3.7
Number of Heat Pump Units	Water-to-Air Heat Pump: 6 Water-to-Water Heat Pump: 1 (Heating Only)
Total Capacity of Heat Pump Units (tons)	16
Total Capacity of the entire HVAC System (tons)	16
Heat Pump Efficiency Range	Cooling: 11.5~14 EER Heating: 2.9~3.5 COP

Cost Information

Capital Cost of the Building ($)	2,500,000
Total Cost of the HVAC System ($)	430,000
HVAC System Average Annual Repair and Maintenance Cost ($)	Not Provided
Government Incentives for the Use of GHP	No
Utility Incentives for the Use of GHP	Unknown

Question & Answer

Questions answered by	Gary Lorenz Assistant Chief of Operations Fargo Fire Department Tel: 701-241-8132 Fax: 701-241-8125 Glorenz@cityoffargo.com
1. Why did you decide to install the geothermal heat pump system in your building?	Not Provided
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Not Provided
3. As you know, are there any operating difficulties of the geothermal heat pump system?	Not Provided
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Not Provided

#22. Lostwood National Wildlife Refuge (LNWR) Office Building

❖ Background

The LNWR office building is located in Kenmare, North Dakota. This facility was an old pole barn that was remodeled into an office by refuge staffs back in 1992. This office building has been using a GHP system to provide space heating and cooling for about 25 years.

Documents regarding design, construction and the total costs are essentially non-existent. Therefore, in-depth analysis and simulations for this building were not conducted, due to the limited information received from the building owner. The basic summary information of this building is shown in Table F.22.1 below.

Table F.22.1: Building Summary

Building Information

Building Name	Lostwood National Wildlife Refuge (NWR) office building
Building Address	Kenmare
Building Type	Public Building
Building Construction Year	1992
Building Total Area (ft^2)	-
Total Number of Floor	-
LEED Building	No

Cost Information

Capital Cost of the Building ($)	360,000
Total Cost of the HVAC System ($)	-
HVAC System Average Annual Repair and Maintenance Cost ($)	150
Government Incentives for the Use of GHP	No
Utility Incentives for the Use of GHP	$2,000 grant for the system purchase from Burke-Divide Electric

Question & Answer

Questions answered by	Kory Richardson Lostwood NWR Manager Tel: 701-848-2722 Fax: 701-848-2702 kory_richardson@fws.gov
1. Why did you decide to install the geothermal heat pump system in your building?	Lower heating and cooling bills (long term cost savings)
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Yes, very satisfied.
3. As you know, are there any operating difficulties of the geothermal heat pump system?	About 4 years ago, the antifreeze solution and pump system needed to be replaced. It was an old type of fluid that was very corrosive. Old fluid was pumped out of the system and disposed of by Safety Kleen. A new pump system was installed and filled with new, non-corrosive antifreeze. Been working like a charm ever since. Total cost of repair was about $2,600.
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes, if they can afford the initial cost of installation and will be using the system for the long term.

#23. Lostwood National Wildlife Refuge (LNWR) Residence

❖ Background

The LNWR Residence building is located in Kenmare, North Dakota, and was built in 2003. Documents regarding design, construction and the total costs are essentially non-existent. Therefore, in-depth analysis and simulations for this building were not conducted, due to the limited information received from the building owner. The basic summary information of this building is shown in Table F.23.1 below.

Table F.23.1: Building Summary

Building Information

Building Name	Lostwood NWR Residence building
Building Address	Kenmare
Building Type	Residential Building
Building Construction Year	2003
Building Total Area (ft^2)	-
Total Number of Floor	-
LEED Building	No

Cost Information

Capital Cost of the Building ($)	400,000
Total Cost of the HVAC System ($)	-
HVAC System Average Annual Repair and Maintenance Cost ($)	100
Government Incentives for the Use of GHP	No
Utility Incentives for the Use of GHP	No

Question & Answer

Questions answered by	Kory Richardson Lostwood NWR Manager Tel: 701-848-2722 Fax: 701-848-2702 kory_richardson@fws.gov
1. Why did you decide to install the geothermal heat pump system in your building?	Lower heating and cooling bills (long term cost savings)
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Yes, very satisfied.
3. As you know, are there any operating difficulties of the geothermal heat pump system?	None
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes, if they can afford the initial cost of installation and will be using the system for the long term.

#24. Coteau Prairie Residence

❖ Background

The Coteau Prairie Residence building is located in Stanley, North Dakota, and was built in 2002. Documents regarding design, construction and the total costs are essentially non-existent. Therefore, in-depth analysis and simulations for this building were not conducted, due to the limited information received from the building owner. The basic summary information of this building is shown in Table F.24.1 below.

Table F.24.1: Building Summary

Building Information

Building Name	Coteau Prairie Residence building
Building Address	Stanley
Building Type	Residential Building
Building Construction Year	2002
Building Total Area (ft^2)	-
Total Number of Floor	-
LEED Building	No

Cost Information

Capital Cost of the Building ($)	400,000
Total Cost of the HVAC System ($)	-
HVAC System Average Annual Repair and Maintenance Cost ($)	100
Government Incentives for the Use of GHP	No
Utility Incentives for the Use of GHP	No

Question & Answer

Questions answered by	Kory Richardson Lostwood NWR Manager Tel: 701-848-2722 Fax: 701-848-2702 kory_richardson@fws.gov
1. Why did you decide to install the geothermal heat pump system in your building?	Lower heating and cooling bills (long term cost savings)
2. Are you satisfied with the current HVAC system in terms of noise, cost, indoor and comfort? Any complaints from building users?	Yes, very satisfied.
3. As you know, are there any operating difficulties of the geothermal heat pump system?	About 3 years ago, the antifreeze solution and pump system needed to be replaced. It was an old type of fluid that was very corrosive. Old fluid was pumped out of the system and disposed of by Safety Kleen. A new pump system was installed and filled with new, non-corrosive antifreeze. Total cost of repair was about $2,900.
4. Would you like to suggest geothermal heat pump systems to others, like your friends?	Yes, if they can afford the initial cost of installation and will be using the system for the long term.