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Geothermal Heating and Cooling at the Massachusetts General Hospital

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Abstract

Geothermal heating and cooling systems are sustainable methods of temperature control utilizing renewable energy. These systems leverage the subsurface temperatures of the Earth by transferring heat between a fluid and its surroundings underground. This transfer of energy provides heating during colder months, and cooling during the hotter times of the year due to the consistency of the temperature below the Earth's surface year-round. Implementing a Geothermal heating and cooling system can save a significant amount of money annually in the form of decreased heating and cooling costs for both residential and industrial applications. Geothermal systems are versatile in the ways that they can be used, for not only residential buildings, but also large commercial buildings. The Massachusetts General Hospital (MGH), located in Boston, MA, is known as one of the top hospitals in the country and therefore utilize a significant amount of energy for heating and cooling. This provides an excellent opportunity for a Geothermal heat pump to be implemented at the MGH. This paper explains how installing a Geothermal vertical closed loop system at the Gray Building of the MGH can significantly reduce costs on heating and cooling. Currently, 37% of the total yearly energy consumption by the MGH is used for heating and cooling of the facility. By implementing the plan outlined in this paper, the MGH facility would see up to 60% savings in heating and cooling costs annually, resulting in a savings of $1,218,626 per year.

Keywords

Geothermal Energy, Heating and Coooling Systems, Renewable Energy, Vertical Closed Loop System

I. Introduction and Background

Geothermal Systems

A growing source of renewable energy is geothermal heating and cooling. Geothermal power is based from the heat energy stored underneath the ground, which means that it is 100% renewable energy. This procedure is considered clean because it works without the burning of any fossil fuels and only requires the extraction and conversion of heat energy from below the surface[1]. A geothermal system has two components: a heat pump and a ground loop. During hotter times of the year, the system uses the indoor heat pump to remove the hot air and releases it into the ground. The heat is removed using underground pipes called a ground loop. Once hot air is removed only cool air is left to be distributed through a building as air conditioning. During colder times the ground loop circulates water that absorbs heat from the ground and restores it into the heat pump inside the building. Once the water is indoors the heat pump extracts the heat from the water and distributes it into the air. After all the heat is removed from the liquid the water is pumped back through the loop underground to absorb heat again[2].

Ground temperatures are mostly consistent throughout the year which is a strong reason for this increase in system popularity[3]. These consistent temperatures hold true for ground temperatures but not for outside air temperatures. Geothermal heating and cooling systems are 400-600% efficient and can cut heating, cooling, and hot water costs by up to 80%.

There are four types of geothermal heat pump systems. Three are closed loop which consist of horizontal, vertical, and pond/lake. The fourth system is an open loop. All four systems can be used for residential and commercial buildings[4]. The facility or homeowner decide on which system is most efficient depending on the climate, soil conditions, and installation costs.

Geothermal heating and cooling is often confused with geothermal power plants, which generate electricity using heat from the ground[5]. This project focuses on simply using ground temperatures to heat or cool a home or building, which in turn will save energy. This process does not generate heat but rather transports heat. The energy savings and elimination of carbon dioxide emissions come from the elimination of using existing resources such as coal or natural gas to heat buildings[6].

Ecological Benefits of Geothermal Energy

A large ecological benefit to using geothermal energy is that it does not burn fossil fuels. A geothermal energy system may produce as little as one-sixth of the carbon dioxide emissions than that of a comparable relatively clean natural-gas system[7]. It is estimated by the U.S. Environmental Protection Agency (EPA) that 80% of the greenhouse gases emitted in the United States is made up of carbon dioxide (CO2). The emission of CO2 contributes to climate change by raising the global temperature. It does this by trapping the solar energy in the atmosphere, not allowing the escape of excess heat[8]. Climate change has proven to be detrimental to the Earth by harming crop production, rising sea levels, and bearing many other negative effects. With this in mind, reducing carbon emissions by 83% will provide immense ecological benefits.

Another ecological benefit of geothermal systems is the reduction of environmental exposure to on-site chemicals. The acidic compounds used to remove scaling in wells can be transported in a dry form. The dry compound is then mixed as needed and added to the system on-site[9] This greatly reduces the risk of accidental introduction of the acid into the environment during transportation to the site. It also ensures that only the amount of acidic solution that is needed to operate the well is created, eliminating disposal issues[9].

A third environmental benefit supporting the implementation of such a system is the relatively small physical footprint that geothermal systems have in the environment[9]. Geothermal systems by definition have relatively minimal equipment compared to other sources of energy generation.

Due to this fact, geothermal systems have less of a footprint both above and below the surface of the earth of other sources of energy.

Massachusetts General Hospital (MGH)

The Massachusetts General Hospital conducts the largest hospital-based research program in the world. It is currently ranked as the third best hospital in the United States by the U.S. News and World Report from 2016-2017[10]. With this, the hospital utilizes a significant amount of energy especially for heating and cooling. The project will focus on this hospital because of two significant reasons: its magnitude as a large and globally recognized hospital, as well as its online availability of energy data. Since MGH is split into a campus of buildings of different size and energy use, the project will focus specifically on the MGH Gray Building (332,664 sq-ft). The Gray Building is an inpatient care facility, and its space types include exam rooms, treatment rooms, procedure rooms, operating rooms, research laboratory space, patient rooms, and many other areas[11].

The rest of this paper is organized as follows. In Section II, the different types of geothermal systems are discussed as well as the type of system that should be used for the MGH, it's costs for maintenance and implementation, and its payoff. Finally, the conclusions are provided in Section III.

II. Study

MGH Energy Usage

The MGH energy data shows that the majority of energy usage in the hospital is used for heating and cooling. The two were coupled together as "Reheat and Heating" by the National Renewable Energy Laboratory (NREL) [12]. This category is valued as the heating and cooling. NREL considers them a couple because it is composed predominantly of heating energy in the winter/spring and primarily reheating or cooling in the summer/fall. The cooling of the facility encompasses another 10% of usage, bringing the total site usage of heating and cooling energy to 37% [12]. This data set is part of the motivation for the group's focus on heating and cooling, because using a pareto analysis, improving these areas will have the greatest effect on increasing the sustainability of the facility.

Types of Geothermal Systems

There are some differences between open and closed loop geothermal systems. A closed loop system uses a continuous loop of pipes as the heat exchanger. These form a sealed, underground loop where the fluid being used to transfer the heat is circulated. The fluid is constantly recirculated, eliminating any water waste[13]. There are also three different types of closed loop system that can be chosen from: horizontal, vertical, and pond/lake. A horizontal closed loop system is the most cost efficient for new construction and residential areas where there is a sufficient amount of land available. The horizontal loop requires trenches that are at least 4 feet deep and 2 feet wide in which pipes or coils lie side by side in the ground[4]. Vertical closed loop systems are often used for commercial buildings where there is less land available and are suitable for minimizing disturbances to the existing land. For the pond/lake system, a supply line pipe is run underground from the building to the water source that is nearby. There are coils that are placed in the water as long as they meet volume, depth, and quality requirements. Compared to a closed loop system, an open loop system requires an ample source of groundwater. It is connected directly to the source, usually a well or pond, and directly pumps water into a building's heat pump unit[14]. The cost of operation for closed and open loop systems are about the same, although there are higher capital investments to implement a closed loop system. For this project, the geothermal heating/cooling system that is suggested for the Massachusetts General Hospital is the vertical closed loop system.

The Massachusetts General Hospital is located in the West End of Boston, seen below in Figure 1. In 2016, the cost of living in Boston was 39.7% above the United States average[15]. Cost of living is highly correlated with property costs; for this reason, it was decided that a vertical closed loop system is the most suitable option for a city where cost of property to implement a horizontal system would be extremely high, and a lake or well system would be infeasible. Vertical closed loop systems are ideal in situations in which land is not cheap and not freely available.

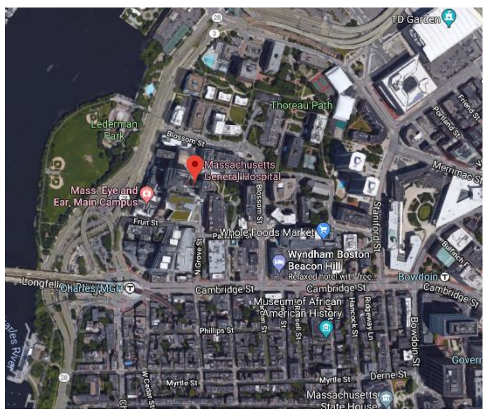

Figure 1: Massachusetts General Hospital Boston Location[16]

Vertical Closed Loop System

Large commercial buildings and schools often use vertical systems because the land area required is prohibitive. For a vertical system, 4 inch diameter holes are usually drilled about 20 feet apart, and 100-400 feet deep, with a typical depth of about 200 feet deep. Two pipes are placed in a u-bend in these holes to form a loop, connected with a horizontal pipe. This is placed in a trench that connects to the heat pump in the building[17]. The plastic pipes are filled with an antifreeze and water mixture and the system is considered 'closed' because it is the same mixture that gets re-circulated.

A company called Thein Wall Company installs Vertical Closed Loop Geothermal System to residential homes in the Minnesota area. The company explains that the system is installed by a series of borings that are drilled into the ground[18]. Two lines of plastic pipe are inserted into each boring and the pipes are fused into a u-bend at the bottom. The pipes are connected at the top and the configuration is brought into the house where it is connected to a furnace/air conditioner[18]. Another company called Gap Mountain Drilling LLC specializes in designing and installing geothermal heat pumps in New Hampshire, Rhode Island, Massachusetts, and Vermont regions.

This company installs geothermal systems to homes and buildings[19]. This company's specialties include consulting, site visits/permits, equipment sizing, formation thermal conductivity testing, drilling and loop installation, excavation services, and pressure testing[19]. Similarly, to Thein Wall Company, the Gap Mountain Drilling LLC uses a high-density polyethylene (HDPE) pipes and fills them with a water antifreeze solution. The fluid continuously flows between the geothermal system and the pipes while absorbing heat during the winter, and rejecting heat during the summer.

Comparison with Other Energy Sources

When making the case for the switch to geothermal heating, it is imperative that the comparison between geothermal and traditional heat sources be made. First and foremost, geothermal heat pumps provide an increase in comfort level throughout the year. The temperature of the Earth remains fairly constant throughout the year and is used to regulate a geothermal heat pump system. Therefore, the BTU exchange between the building itself and the Earth will change throughout the year to maintain a similar temperature. Since this exchange is constant, periods of hot blasts or cold blasts as experienced by traditional heating and cooling systems is virtually eliminated[20]. Rapid changes in outside temperature may cause larger inputs to a traditional system by the operators, making the building way too hot or way too cold. Then an opposing input must be made to bring the temperature back towards a more reasonable temperature. This dance back and forth is eliminated in a geothermal heating and cooling system. In addition to helping with the temperature regulation, the exchange with the Earth also aids greatly with controlling the humidity level in the building, further increasing the comfort advantage these systems have over traditional ones[20].

Geothermal and electric resistance are the only two sources that are considered to be environmentally friendly[20]. Geothermal is also one of only two systems (the other being Air-to-Air Heat Pump) that provide heating and cooling all in one system[20]. Furthermore, comparing the highest end of efficiency capabilities of these systems shows that geothermal is leaps and bounds ahead of traditional systems. These large benefits, coupled with the federal and potential state tax cuts for properties implementing geothermal systems, shows why one would choose geothermal over traditional heating systems.

A Table from Rabe Hardware's website provides some insight into the social benefits of a geothermal system over traditional heating sources[20]. First and foremost, there is little to no outdoor equipment in a geothermal heating pump. This means no unsightly pieces of equipment on the property, and less of an opportunity for vandalism and other risks. All of the traditional systems used in the comparison required outdoor equipment. Geothermal energy is also said to have minor impacts in regard to seismic activity, odor, pollution and noise[21]. These facts cannot be said for all traditional sources, and therefore put geothermal heating and cooling at a social advantage over traditional systems.

Maintenance and Repairs

A geothermal system does not burn fuel, rather it transfers heat from one place to another. This means that the system is extremely cost-efficient to operate. The indoor components of the system last for about 25 years while the ground loop of the system can last to about 50 years. This compares to the typical furnace or conventional AC unit that lasts about 15 years[22]. Since this system is protected from outdoor elements and has fewer moving parts, it requires very minimal maintenance. The cost for repairs on a geothermal system varies depending on the extent of the problem, the type of the problem, and the geographical location. The national average cost is approximately $573 to repair a malfunctioning system. Malfunctions that happen within the pipes underground are the most common problems that occur in a geothermal system. Although the pipes are built to last for about 50 years, occasionally one can crack or break and create a leak. The cost of locating and repairing these leaks can cost between $75 and $100[23]. Issues that occur within heat pumps, such as debris build up, are solved by flushing out the system with acid and can cost anywhere between $150 to $200.

Savings, Implementation Cost, and Payoff

Implementation of a Vertical Closed Loop Geothermal System at MGH provides an excellent opportunity for cost savings in operation costs of heating/cooling per year. While the commercial rate of energy per kWh is currently $0.1384/kWh in the Boston, MA area[24], the amount of energy the hospital uses adds up due to the size of the facility.

At the MGH Gray Building 13,000,000 kBtu/yr are used for reheating and 23,000,000 kBtu/yr for heating, for a total of 36,000,000 kBtu/yr for reheat and heating[25]. For cooling, it is known that MGH uses on average 42.3 kBtu/ft^2 yr[26] and the facility is 332,664 ft^2[11], which demonstrates a use of 14,071,687 kBtu/yr for cooling. One kilowatt is equal to 29889 kBtu/yr, so the heating/reheating and cooling energy amounts convert to 10,550,996 kWh and 4,124,176 kWh per year respectively. From the previously stated price of energy ($0.1384/kWh in the Boston, MA), it is estimated the heating and cooling costs at MGH are currently a total of $2,031,044.

Geothermal heating/cooling systems are found to save 40-60% of costs per year on utility bills[27]. In Tables 1,2, and 3, the calculations can be seen using 40-60% savings on operational costs. For example, in Table 3 the data shows that the hospital's heating/cooling costs per year would be reduced to $812,418 for a total savings of $1,218,626/yr. Table 4 below, shows an overview of each percentage of cost savings and their total effect on savings per year.

Table 1: MGH Average Annual Energy Cost assuming 40% Savings on Operational Costs

Massachusetts General Hospital Gray Building							
Current System	**MMBtu/yr**	**kBtu/(ft^2*yr)**	**kBtu/yr**	**kW**	**kWh**	**MGH Size (sq ft)**	**Yearly Cost**
Heating	36000	108.4	36000000	1204	10550996	332664	$1,460,257.91
Cooling	14072	42.3	14071687	471	4124176	332664	$570,785.91
Total	Total	150.7	50071687			**Total**	$2,031,043.82
						Reduction Rate	40%
						Reduced Cost	$1,218,626.29
						Savings Per Year	$812,417.53

kW	kBtu/hr	kBtu/yr
1	3.412	29889

Commercial Price of Electricity ($/kWh)
0.1384

Table 2: MGH Average Annual Energy Cost assuming 50% Savings on Operational Costs

Massachusetts General Hospital Gray Building								
Current System	MMBtu/yr	kBtu/(ft^2*yr)	kBtu/yr	kW	kWh	MGH Size (sq ft)	Yearly Cost
Heating	36000	108.4	36000000	1204	10550996	332664	$1,460,257.91
Cooling	14072	42.3	14071687	471	4124176	332664	$570,785.91
Total	Total	150.7	50071687			**Total**	$2,031,043.82
						Reduction Rate	50%
						Reduced Cost	$1,015,521.91
						Savings Per Year	$1,015,521.91

kW	kBtu/hr	kBtu/yr
1	3.412	29889

Commercial Price of Electricity ($/kWh)
0.1384

Table 3: MGH Average Annual Energy Cost assuming 60% Savings on Operational Costs

Massachusetts General Hospital Gray Building							
Current System	MMBtu/yr	kBtu/(ft^2*yr)	kBtu/yr	kW	kWh	MGH Size (sq ft)	Yearly Cost
Heating	36000	108.4	36000000	1204	10550996	332664	$1,460,257.91
Cooling	14072	42.3	14071687	471	4124176	332664	$570,785.91
Total	Total	150.7	50071687			**Total**	$2,031,043.82
						Reduction Rate	60%
						Reduced Cost	$812,417.53
						Savings Per Year	$1,218,626.29

kW	kBtu/hr	kBtu/yr
1	3.412	29889

Commercial Price of Electricity ($/kWh)
0.1384

Table 4: Overview of Savings per Year

Reduction Rate	60%	50%	40%
Reduced Cost	$812,417.53	$1,015,521.91	$1,218,626.29
Savings Per Year	$1,218,626.29	$1,015,521.91	$812,417.53

With the amount of savings that geothermal heating/cooling systems provide, the payback period is not long. A similar project of a geothermal system of a 344,000 sq-ft corporate center for a large food service company is being constructed in Michigan[28]. It is a vertical closed loop and expected to cost $1,150,000 for implementation. Since the building that the system for MGH would be implemented is similar size (332,664 sq-ft) it is fair to assume it would cost a similar price. From the fact that the system in this case would be built in the city of Boston (where land/permits are more expensive), the estimated figure for implementation cost will be set to $1,800,000.

Annual savings are estimated to be $1,218,626. Since the construction and setup costs are $1,800,000, it is calculated that the cost of implementing the system will be paid back by cost savings in about one year and six months (1.48 years) as seen in Table 5. This estimate assumes that the cost will be paid for upfront and does not take interest into account. The quick payoff time and continuous cost savings under the lifetime of the geothermal heating/cooling system proves that this method is a financially reasonable and wise move for Massachusetts General Hospital.

Table 5: Payback Period Calculation for MGH Geothermal Heating/Cooling System with 60% Savings in Operational Costs

Cost	Size (sq ft)	
$1,800,000.00	332664	
Yearly Cost Savings		**Payback Period**
$1,218,626.29		1.477073008

III. Conclusion

The goal of the project was to research geothermal energy sourcing, as well as the implementation of a sustainable energy plan at Massachusetts General Hospital. As one of the best and largest hospitals in America, MGH provides a great opportunity for improvement with the methods they use for heating and cooling. Geothermal energy is an environmentally friendly, socially advocated, and financially sound method of heating and cooling. Using a geothermal system, a large impact can be made in each of these areas.

Geothermal systems have many ecological benefits, they boast a relatively small physical and ecological footprint in the environment. Geothermal energy does not burn nonrenewable fossil fuels, the heat pump uses the temperature of the earth to heat or cool the building. With this, it is a clean method of heat production, and is able to reduce carbon emissions for the hospital. Implementing a geothermal system reduces the environmental exposure to on-site chemicals. Geothermal systems have a relatively small physical and ecological footprint in the environment[9].

In terms of finances, a closed loop vertical geothermal system would cost about $1,800,000 to implement, and with the savings from their current energy system would have a payback period of 1.5 years. A closed loop vertical system is one of the more expensive geothermal systems, however, the cost savings from the smaller amount of land necessary for this system will outweigh the higher price of the vertical system. Geothermal heat pump systems have an average 20+ year life expectancy for the heat pump itself and 25 to 50 years for the underground infrastructure [29]. This lifetime is well above the average lifetime of a standard HVAC system, which is 20 years[30]. From the average lifetime of a geothermal system and the infrastructure it is seen that the period of payback from investment of 1.5 years is well worth it. Furthermore, the costs of maintaining and repairing this system are very low. The average cost of repairing malfunctions is $573. Overall, implementing a vertical closed loop geothermal heating/cooling system is the most financial and ecological decision for the Massachusetts General Hospital.

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