Design and Implementation of Geothermal Systems for Heating and Air Conditioning

M. Fathizadeh, Daniel Seim

Abstract--Geothermal is the Earth's thermal energy. In recent years geothermal energy has been utilized for generation of electricity, heating and air conditioning (HVAC). Geothermal HVAC systems are cost effective, energy efficient, and environmentally friendly way of heating and cooling buildings. The Department of Energy (DOE) and the Environmental Protection Agency (EPA) have both endorsed geothermal HVAC systems. Their flexible design requirements make them a good choice for schools, high-rises, government's buildings, commercial and residential properties. Lower operating and maintenance costs, durability, and energy conservation make geothermal a great alternative to conventional HVAC systems.This paper gives the step-by-step for estimate, design, calculation, procurement, installation and commissioning of geothermal heating and air conditioning system for residential or small businesses. A comparison between the conventional HVAC and the geothermal counterpart is provided to demonstrate their advantages.

Index Terms — Geothermal, energy efficiency, green energy, heating and air conditioning.

I. INTRODUCTION

A geothermal heat pump (also known as a ground source heat pump) is a central heating and/or cooling system that pumps heat to or from the ground. To transfer energy to or from the ground, geothermal systems typically have a "loop" which consists of a long length of pipes. As a thermal fluid is pumped through the loop, conductive heat transfer occurs between the fluid, piping, and the ground. It uses the earth as a heat source (in the winter) or a heat sink (in the summer). This design takes advantage of the stable temperatures in the ground to boost efficiency and reduce the utility costs of heating and cooling systems. Like an air conditioner, these systems use a heat pump to transfer heat from the ground.

A heat pump is basically a loop of refrigerant pumped through a vapor-compression refrigeration cycle that moves heat [1]. The mean temperature of the earth 6 feet below the ground in Northwest Indiana is about 52°F [2]. Using the earth is very energy-efficient because underground temperatures are far more stable than air temperatures through the year. Especially during the hot and humid summer, an earth loop heat exchanger provides a greater temperature differential than conventional A.C. condensers or cooling towers.

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There is insignificant seasonal temperature variation below 30 ft. Much like a cave, the stable ground temperature is warmer than the air above during the winter and cooler than the air in the summer.

The initial costs are generally higher than conventional systems, but the difference is usually returned in energy savings in as little as 3 years. System life is estimated at 25 years for inside components and 50 years or more for the loop piping [3].

Ground source heat pumps are categorized as having closed or open loops, and those loops can be installed in three ways: horizontally, vertically, or in a lake/river. The type chosen depends on the available land areas, the soil and rock type at the installation site. These factors will help determine the most economical choice for installation of the ground loop. For closed loop systems, water or an antifreeze solution is circulated through plastic pipes buried beneath the earth's surface. During the winter, the fluid collects heat from the earth and carries it into the building. During the summer, the system reverses itself to cool the building by removing heat from the building and placing it in the ground.

Geothermal systems are very similar to conventional Boiler/Tower systems. Both Boiler/Tower and Geothermal systems use basically the same heat pump equipment and the Coefficient of Performance (COP) are similar when rated at the same conditions. Geothermal heat pumps can operate at a greater range in temperature allowing a larger temperature differential. The major difference in efficiency is in the external heat exchanger. Geothermal systems use the constant reliable temperature of the earth as a sink or a source for energy while boiler/tower systems use the seasonally affected ambient air [1-4].

One advantage of the closed loop system design is that it eliminates large ductwork runs. The concept allows energy that is not required in some areas of the building (cooling load) to be moved and used in areas that do require energy (heating load). Closed building loop design would be applicable to hotels where each room has its own independent control. When a portion of the rooms are heating and a portion is cooling, the building loop allows the zones to simply "trade" energy. Applications that could benefit would be facilities that have both heating and cooling process running simultaneously.

Water source heat pump systems (chilled water systems) generally require smaller mechanical rooms than other HVAC systems. Geothermal mechanical rooms are even smaller, requiring space for only the circulating pumps and the main header piping. This frees up valuable building space [5].

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II. CUMULATIVE ANNUAL ENERGY LOAD ON GROUND LOOP

Cumulative annual energy load is the change in the ground temperature over many years. If the building has a net heat gain or a net heat loss, the ground temperature will change. This is referred to as a thermal-flywheel effect. The more closely placed the boreholes or trenches, the larger the effect. Ground water moving through the borehole field can remove substantial energy and limit the long-term temperature changes. Most commercial buildings have a very high net cooling load; this can cause the earth temperature of the loop to rise. It is not uncommon for skyscrapers in Chicago to never turn on their boilers throughout the winter. Long term effects must be considered when designing a ground loop. Long term temperature rise is the most common problem in large-scale geothermal systems. Typically the loop return fluid temperature will rise in the first few years but it should settle to consistent annual variations [6].

The graph of Figure 1 shows the variation from ground temperature for various depths. Most horizontal systems usually stay within 5 ft. of the surface, which can swing as much as 20°F from summer to winter. Evaporation can also cool the surface soil and improve horizontal loop performance.

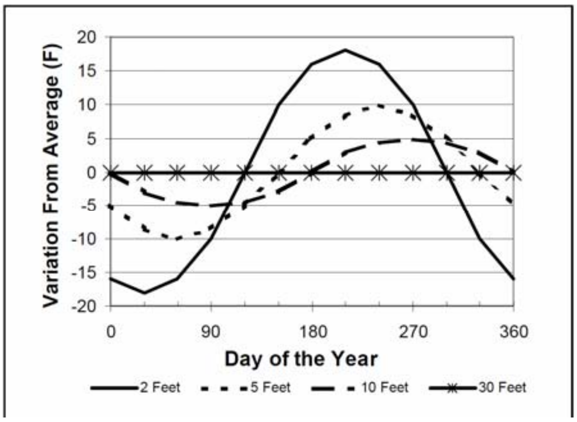

Fig. 1 – Seasonal ground temperature depth variation

A. Thermal Properties of Soil

Soil or rock composition greatly affects the thermal properties of a ground loop. A sieve test can be performed to determine the composition of sandy and clay soils. A soil map can usually be attained from the county surveyor's office or the Department of Natural Resources. A soil study may only be necessary for larger projects; most designers will already be aware of the composition of the soil commonly found on the project site [7-9].

B. Ground Water and Ground Temperature

Ground temperature is best obtained from local water well logs and geological surveys.

Ground water movement through the bore-hole field can have a large impact on its performance.

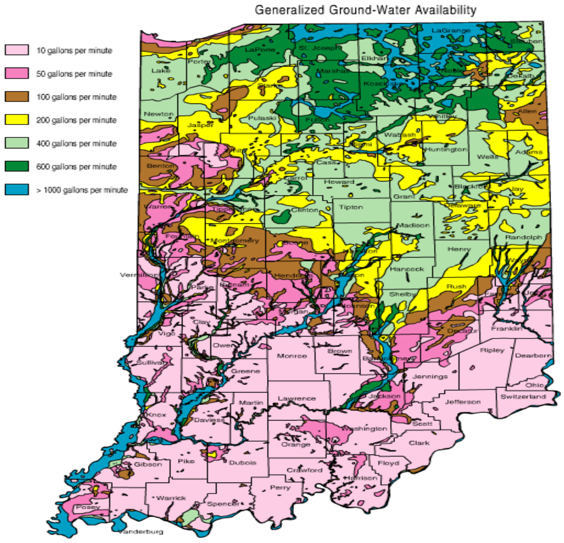

Fig. 2– Ground water conditions for the state of Indiana [4]

C. Pressurized Vs. Non- Pressurized Flow Centers

Geothermal pumping configurations (also referred to as flow-centers) consist of the "indoor" portion of the piping, the pumps, and the heat pumps. Flow-centers designated as either pressurized or non-pressurized.

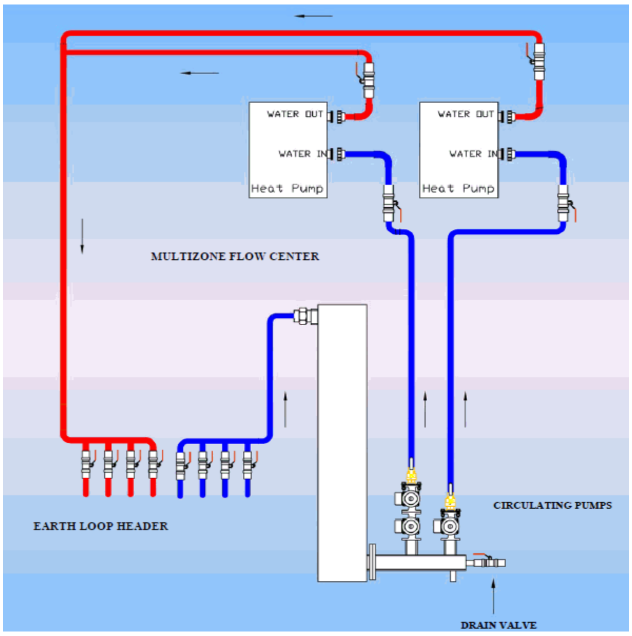

Figure 3– Non-pressurized flow center configuration.

Pressurized flow-centers typically require a contractor to pressurize the system to 40 psi with flushing pump. The loop should maintain the hydraulic pressure indefinitely. However, debris and dissolved air in the system often require the system to be flushed and recharged.

A non-pressurized configuration is vented to atmospheric pressure typically at the highest point on the system to help eliminate air. Advantages of non-pressurized flow-centers

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include ability to easily check the fluid chemistry and fluid level.

D. Net Positive Suction Head Required (NPSHR)

The major disadvantage of non-pressurized flow-centers is the lack of static pressure in the system required to operate the pumps at higher fluid temperatures. Pumps have a specified Net Positive Suction Head Required (NPSHR). This is the pressure required on the suction side of the pump so the pumps will not cavitate. This information is available from pump manufacturers. With a non-pressurized flow-center, the fluid does not have static pressure when vented to atmosphere. A tall vertical tank just before the pump is recommended to maintain a small hydrostatic pressure on the pump. Pump cavitation is a function of fluid temperature, fluid properties, hydrostatic pressure, and NPSHR of the pump.

E. NPSHA Calculation-(Cavitation Prevention)

To prevent pump cavitation, the Net Positive Suction Head Available (**NPSHA**) must be greater than the Net Positive Suction Head Required (NPSHR).

$$NPSHA > NPSHR \quad (1)$$

The objective is to determine adequate height for the water column on the flow center while checking the margin of safety for pump cavitation. NPSHR is given by the pump manufacturer. This is the pressure and temperature conditions at which the pump will “pull the water apart” causing cavitation. Cavitation will immediately destroy the pumps which in turn will cause system failure.

$$NPSHA=H_a + H_s + H_{vpa} + H_f \quad (2)$$

Where:

- H_a : the atmospheric pressure on surface of liquid entering the pump
- H_s : the Static elevation above pump
- H_{vpa} :the absolute vapor pressure at max liquid temperature
- H_f : the friction head losses on suction side of pump

F. Practical NPSHA Calculation

H_a (at 710 ft above sea level) = 32 ft of head
H_s is what we are solving for. This is the required height of the flow center water column.
H_{vpa} at max temp of 140ºF = 6.6 ft of head (140ºF is the maximum design temp for the system. This is a rule of thumb for open systems. This temperature restriction is also caused by the use of Schedule 40 PVC piping in the system.) Table 1 shows the minimum pressure for different water temperatures

Table-1 MINIMUM INLET PRESSURE FOR DIFFERENT WATER TEMPERATURES

Water Temperature deg. F	Min Inlet Pressure in Ft of Head H_20
30	36
190	14
140	3

H_f is small enough to be negligible for the flow rate of our system. The water column is 6” diameter pipe with a short (<2’ long) section of horizontal 3” piping. Therefore,

$$H_f=0.$$
$$NPSHA= 32 + H_s + (-6.6) – 0$$
$$NPSHA=25.4 + H_s$$

For the family of pumps selected for our system, the minimum inlet pressure is given by the following: Grundfus UP-26 family of pumps (From Table 2). Therefore, at 140deg. F. max system temperature.

$$NPSHR = 3 \text{ ft. of } H_2O \text{ column}$$

To create the equation to determine our H_s, the previous values and set NPSHA equal to NPSHR.

$$NPSHA = 25.4 + H_s$$
$$NPSHR = 3$$
$$3 = 25.4 +H_s$$
$$H_s = (-22.4)$$

Therefore, with the UP family of pumps (Table-2), it should be not expected to have any cavitation. This leaves a safety margin of 22.4 ft. (9.7 PSI). The system will still have a water column to help balance volumetric thermal expansion and to provide a visual water level indicator. The water column also will act as a means of air bubble elimination.

If the system temperature was above 200ºF, or a lower quality pump was selected, the water column would have to be taller to accommodate the NPSHR. System

G. Configuration and Flow Calculations

The drawing shown in Figure 4 presents the calculation methods used to determine and plot the piping network’s performance curve. The performance curve is the system’s loss due to friction plotted against its flow rate. Since the recommended flow rates were specified by the heat pump manufacturer, design flow rates were simply divided by the number of pipes in parallel.

H. Performance Curve

The system’s friction head is calculated at each node in the piping network for three different corresponding flow rates. Please note that friction losses due to pipe fitting were simply added to the length using a corresponding length of pipe given in manufacturer’s datasheets.

Using the systems cumulative friction head the systems performance curve can be plotted. This plot is shown in Figure 4,

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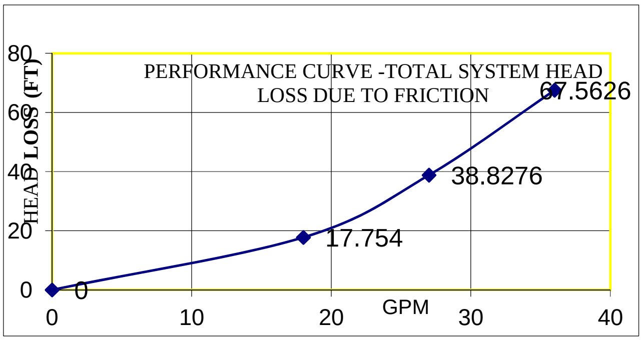

Figure 4 – System performance curve

I. Pump Selection

The next step is to select a pumping configuration that can achieve the proper flow to match the systems curve. Pump curves are available in datasheets from the pump manufacturer.

The selected pumps had to be specified with bronze casings to prevent corrosion.

The data from three similar pumps was plotted in excel to create pump curves and are shown in Figure 5.

Since two duplex pumps are running in parallel, the head must be doubled for duplex and doubled the flow for parallel. Figure 5 shows the pump curves against the system's performance values.

Table-2 PUMP SLECTION FOR DIFFERENT FLOW RATE

UPS 26-99F-LS			
GPM	HD	GPM X 2	HD X 2
0	24.25	0	48.5
2	20.75	4	41.5
4	17.25	8	34.5
6	14	12	28
8	11	16	22
10	8.5	20	17
12	6.25	24	12.5
14	4.25	28	8.5
16	2.5	32	5
18	1	36	2
20	0	40	0
22		44	
24		48	
26		52	
28		56	
30		60	
32		64	
34		68	
36		72	
38		76	
40		80	
42		84	
44		88	

UPS 26-99F-MS			
GPM	HD	GPM X 2	HD X 2
0	28	0	56
2	26.25	4	52.5
4	24.25	8	48.5
6	22.5	12	45
8	20.5	16	41
10	18.5	20	37
12	16.5	24	33
14	14.5	28	29
16	12.25	32	24.5
18	10.25	36	20.5
20	8	40	16
22	6	44	12
24	3.75	48	7.5
26	1.5	52	3
28	0	56	0
30		60	
32		64	
34		68	
36		72	
38		76	
40		80	
42		84	
44		88	

UPS 26-99F-HS			
GPM	HD	GPM X 2	HD X 2
0	29.25	0	58.5
2	28	4	56
4	26.75	8	53.5
6	25.5	12	51
8	24.25	16	48.5
10	22.75	20	45.5
12	21.25	24	42.5
14	19.5	28	39
16	18	32	36
18	16.25	36	32.5
20	14.25	40	28.5
22	12.25	44	24.5
24	10	48	20
26	7.5	52	15
28	5	56	10
30	2.25	60	4.5
32	0	64	0
34		68	
36		72	
38		76	
40		80	
42		84	
44		88	

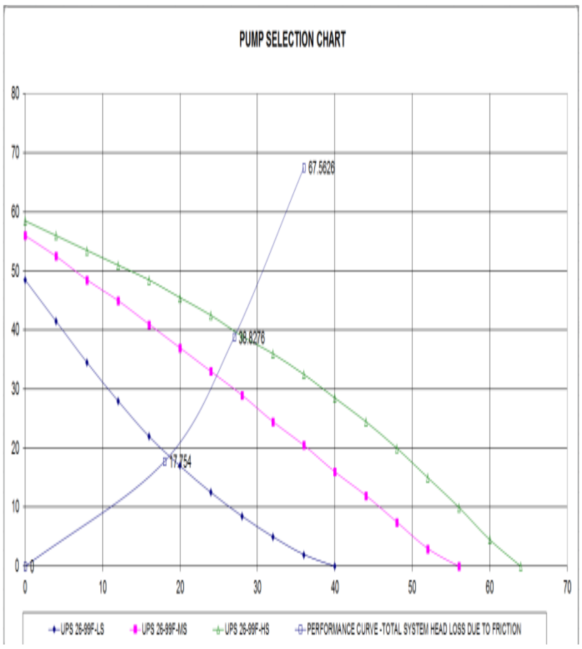

Fig. 5 Pump curves plotted against the system's performance values

Using the chart a pump selection can be made. The total system flow rate is based on the cumulative nominal flow recommended by the heat pump manufacturer. For this case is 38.8 gallons per minute. The pump was specified for the system is the Grundfos UPS 26-99F-HS in parallel duplex configuration. This was the correct choice of pump and was later verified by measuring the differential pressure across the units and referencing it with their given head loss.

The Primaries were extended to the rear of the building to feed the secondary loop field. Notice the tubing stubbed into the future pumping room.

III. PROJECT COST AND COMPARISON TO APPLICABLE HIGH EFFICIENCY ALTERNATIVES

Figure 6 shows the spread sheet for the project budget. The project budget is given in the light blue column below. The other columns are alternative systems that were quoted for the project.

A. Natural Gas Fired Boiler and Hydronic Heat System

An 110,000 BTU natural gas boiler was installed to provide hydronic heating to the plant.

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The heated water is pumped through 10,000 ft. of ½" PEX tubing suspended in the concrete floor. The boiler is an HTP Elite-110 modulating and condensing boiler that currently the most efficient boiler on the market. The 32' tall PVC flue stack allows a larger condensing area to reclaim heat that would normally be lost with the exhaust gas. With the longer flue, the boiler may very well be more efficient than the advertised 98.1% AFUE.

The boiler is the primary heat source. The large thermal mass of the concrete floor will also allow temperature to be easier to control. Once the entire system is tuned properly, the boiler should only fire one time each day per zone. (See thermostat profiles shown in Figure 7)

Using the concrete floor to radiate heat will also allow the plant to operate at a lower temperature. This is due to the fact that the human comfort temperature level is lower when the floor is warm.

The insulating foam on the tubing is installed. This is to prevent the boiler room from overheating. The tubing is temporarily terminated in series for pressure testing. The system was held at 150 PSI prior to and during the concrete pour so any punctures caused by the concrete contractors would be immediately apparent.

B. Natural Gas Fired Boiler and Hydronic Heat System

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Cost Comparison of Applicable High Efficiency Alternatives			
MFG	Daikin Mcquay	Daikin Mcquay	Trane
TYPE	GSHP (Geothermal Temp Range)	Air Cooled Curb/Rooftop Scroll Compressor Heatpump	Water Cooled Rooftop Electric Packaged Unitary
Heat Pump Units (2)	$ 8,296.00	$ 11,613.00	$ 11,628.00
Installed Ductwork (subcontracted)	$ 14,550.00	$ 16,550.00	$ 14,550.00
Underground PE Tubing	$ 3,743.00	$ -	$ -
Building Piping	$ 1,200.00	$ 300.00	$ 1,000.00
Circulation Pumps	$ 1,430.00	$ -	$ 1,110.00
Special Tools and Equipment Rental	$ 4,500.00	$ 1,900.00	$ 1,900.00
Control System	$ 1,250.00	$ 1,250.00	$ 1,250.00
Total Labor (300 x $50)	$ 15,000.00	$ 10,000.00	$ 11,000.00
Total Installed Cost	**$ 49,969.00**	**$ 41,613.00**	**$ 42,438.00**
Subtract Federal Investment Tax Credit 10%	**$ 44,972.10**		
Subtract State Property Tax Deduction 1%	**$ 44,522.38**		
Initial Differential Cost	**$ 2,496.88**		
Unit EER (5 ton used for comparison)	19.2	13.9	13.1
Total System EER	19	13.9	12.9
System Capacity (Btu)	108000	108000	108000
Multiply by Annual Runtime (hrs)	1500	1500	1500
Btu-hours produced per year	162000000	162000000	162000000
Divide by system EER	19	13.9	12.9
Watt-hours consumed per year	8526315.789	11654676.26	12558139.53
Multiply by W to KW Conversion	0.001	0.001	0.001
Annual KWh Consumed	8526.315789	11654.67626	12558.13953
Multiply by Cost of Electricity	$ 0.12	$ 0.12	$ 0.12
Annual Cost of Electricity for Cooling	**$ 1,023.16**	**$ 1,398.56**	**$ 1,506.98**
Annual Electricty Savings	$ 429.61		
Energy Reduction Utility Rebate $.045/KW	$ (140.78)		
Total Annual Electrical Savings	$ 570.39		
Divide by Initial Differential Cost			
Payback Period (Yrs)	4.4		

Fig. 6– Spreadsheet showing cost breakdown and payback period of applicable project alternatives

C. *Thermostat Profiles*

The heating and cooling system zones were controlled by seven programmable thermostats. We wanted the boiler to preheat the building every morning to minimize the load on the heat pumps throughout the day because they are not as efficient for heating as the boiler. The boiler is programmed to overshoot the desired temperature for one hour prior to occupancy because the hydronic system's large thermal mass would keep the heat for most of the pre-noon hours of occupancy. The warehouse portion of the building needed only to be heated to 65 degrees and care was taken to make sure the warehouse and office zones did not fire at the same time. Please see thermostat profiles below.

Time (Hour of Day)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Occupancy (Target Temp)	64	65	66	67	68	69	70	71	71	71	71	71	71	71	71	71	71	70	69	68	67	66	65	64
HP48_Zone 1 Office North 1st Flr	60	60	60	60	60	69	69	71	71	71	71	71	71	71	71	71	69	60	60	60	60	60	60	60
HP48_Zone 2 Office South 1st Flr	60	60	60	60	60	69	69	71	71	71	71	71	71	71	71	71	69	60	60	60	60	60	60	60
HP48_Zone 3 Office 2nd Flr	60	60	60	60	60	69	69	71	71	71	71	71	71	71	71	71	69	60	60	60	60	60	60	60
HP60_Zone 1 Warehouse																								
BLR_Zone_1 Warehouse	62	62	62	62	62	62	62	65	65	65	65	65	65	65	65	65	62	62	62	62	62	62	62	62
BLR_Zone_2 Office 1st Flr	62	62	70	70	70	70	72	69	69	69	69	69	69	69	69	69	69	62	62	62	62	62	62	62
BLR_Zone_3 Office 2nd Flr	62	62	62	70	70	70	72	69	69	69	69	69	69	69	69	69	69	61	61	61	61	61	61	61

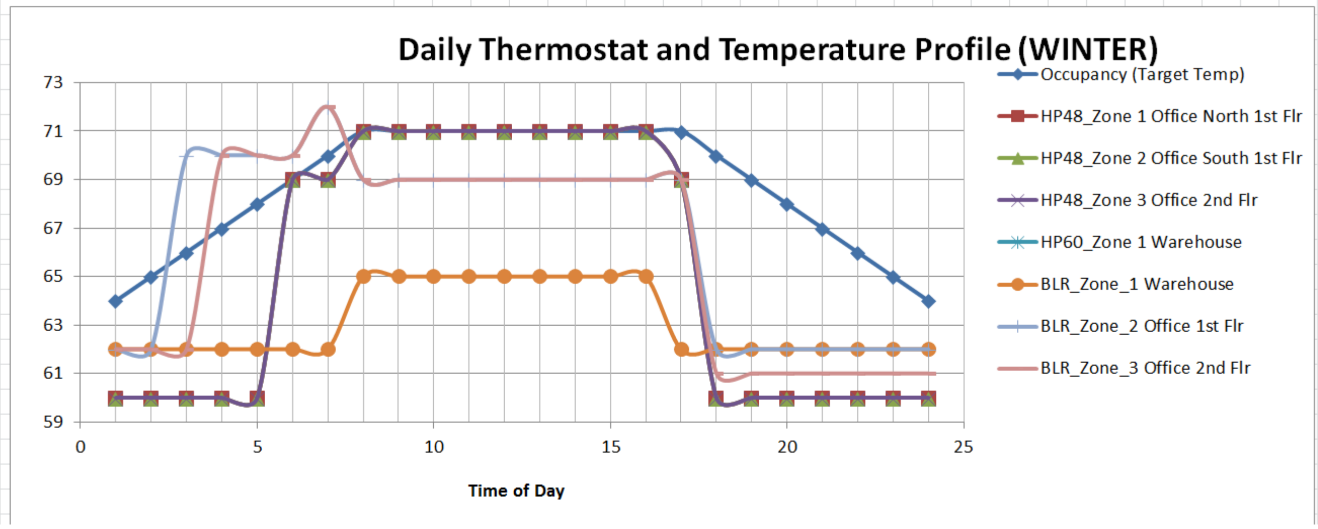

Figure 7– Programmable thermostat profiles for different applications

IV. CONCLUSION

A practical step by step design procedure for the design and installation of a Geothermal HAVC system was given. Calculation and specific consideration for the design was mentioned. The cost evaluation and performance criteria were determined and a comparison between the conventional HVAC system and the new geothermal one is shown. The advantages of geothermal system are more pronounced in larger installations and institutions.

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