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Design and Economic Analysis of a Geothermal Vertical Coupled Heat Pump System for the University of Tennessee, Knoxville Campus

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1. Introduction

The purpose of this report is to document a study-level design and economic analysis of a vertical ground coupled heat system (VGCHPS) for the University of Tennessee campus. Commercial geothermal heat pump systems are being developed to provide clean energy and reduce overall heating and cooling costs. VGCHP's are closed loop system's which use a reversible vapor compression cycle linked to an underground heat exchanger. Both the water to air and the water to water heat pumps utilize a circulating water-antifreeze solution. The solution circulates through an underground piping network and through a liquid-to-refrigerant coil. Fluid to be heated or cooled is circulated through a fluid-to-refrigerant coil and is transported to the point of utilization. VGCHPS's are normally constructed using two polyethylene tubes in the borehole. The polyethylene tubes are connected at bottom of the bore resulting in a closed U-tube shape. Vertical tube sizes are usually in the range from ¾ to 1.5 inches nominal diameter. Depending on drilling conditions and underground soil properties the vertical bore depths can range from 50 to 600 feet deep.

The design objectives of this project are (1) develop a flow sheet for the design process of the VGCHP system, (2) present relevant material and energy balances, (3) provide estimates of the initial capital cost and determine the payback period, and (4) compare the estimated economics of the VGCHPS with the current heating and cooling costs for the University of Tennessee.The heating requirements on campus are met by a central steam plant that uses three coal fired boilers capable of burning a total of 300,000 pounds of coal per hour and a natural gas fired turbine generator rated at 5 MW. The cooling requirements are met by a combination of 3,000 window air conditioners ranging from 5,000 to 32,000 BTU, 500 split and package systems ranging from 1 to 60 tons, and 92 chillers ranging from 20 to 995 tons. The total cooling capacity available from all the air conditioning equipment is approximately 30,000 tons. The University of Tennessee Facilities Services has requested the study level design of a geothermal HVAC system capable of replacing 3 chillers that provide 2400 tons cooling energy for the agriculture portion of campus. The 2400 tons of cooling was reduced to 600 tons due to limited space on the Agricultural Campus. This design is focused on delivering 600 tons of cooling.

This project is supported by Facility Services at the University of Tennessee (UT). This report documents a study-level design and economic analysis of the procurement and installation of a ground-source heat pump at UT and was prepared in Spring Semester, 2014 as fulfillment of course requirements of CBE 488 (Sustainable Design Internship) at the University of Tennessee. Advisors for this project are D. W. Bailey and T.E. Ledford of UT Facility Services and J.S. Watson and R. M. Counce of UT Chemical and Biomolecular Engineering Department.

2.0 Synthesis Information for Processes

2.1 Input Information

To determine the input information for this design we used several resources including the Engineering Group Design[1], Kavanaugh and Rafferty's Design Guide[2]. The requested amount of cooling to replace was 2400 tons but upon the completion of calculations, it was deemed impossible to replace 2400 tons with the green space available for the bore field. To determine the maximum cooling load that could be replaced, we utilized the largest open area and back calculated to determine the load that the area could withstand. The largest space on the Agricultural Campus was able to replace a total of 600 tons of cooling. Due to the size limits of the spreadsheet, the borehole field was divided into three equal parts each having a total cooling load of 200 tons and the hourly, monthly, and yearly ground loads were calculated using this number and the Design Guide[2].

In 2009, Engineering Services Group INC and Mid-State Construction completed an engineering study to determine the economic feasibility of using a VGSHP at the future University of Tennessee Sorority Village[1]. From this report we were able to get ground property information including thermal conductivity, thermal diffusivity, and local ground temperature. To verify that the information provided in the Engineering Services Group study we compared their values with values reported by the Tennessee Valley Authority from their geothermal test well data[3].

We were also able to obtain recommended values for design variables such as the equivalent diameter of the bore and the spacing between adjacent bores. Much of the physical property data and input information was determined using the Kavanaugh and Rafferty Geothermal Design Guide[2].

The remaining borehole specifications were calculated based on the properties of the one and a quarter inch high density polyethylene pipe. To determine the type of grout to use and the grout properties, GeoPro Inc., who specializes in geothermal grouts, was contacted and provided a recommended type of grout along with its properties.

Figure 2.1 shows the hierarchal structure of the spreadsheet that will be used to calculate the depth of each borehole. For a single borehole, the user must input the heating or cooling loads generated by the building, soil properties, heating or cooling fluid properties, heat pump outlet temperature, average fluid temperature in the borehole, and the characteristics of the borehole, such as the radius of the borehole. For a borefield, all of the information required for a single borehole is included as well as the distance between boreholes, number of boreholes, and the aspect ratio of the borefield.

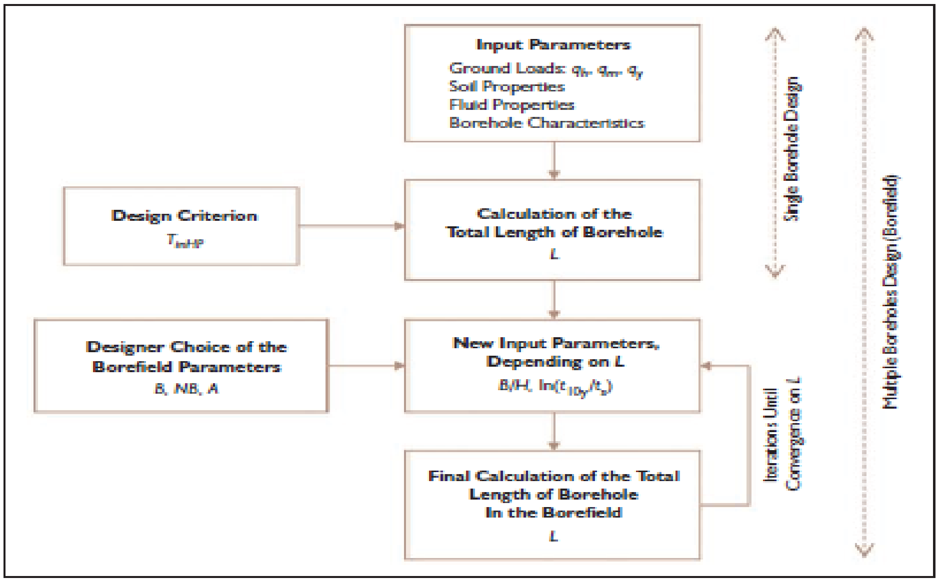


Figure 2.1: Flow for Design

Table 2.1: Ground Loads

peak hourly ground load	q_h	W	703370
monthly ground load	q_m	W	179316
yearly average ground load	q_y	W	3160

The inside of the borehole must have enough area for spacing of both pipes as well as the grout. The optimal spacing to reduce thermal effects is to have an equal distance between the wall and each pipe as well as between the pipes[4]. This leads to a center-to-center distance of 0.0541 m.

Table 2.2: Borehole Characteristics

borehole radius	r_{bore}	m	0.06
pipe inner radius	r_{pin}	m	0.0173
pipe outer radius	r_{pext}	m	0.0211
grout thermal conductivity	k_{grout}	$W.m^{-1}.K^{-1}$	2.076
pipe thermal conductivity	k_{pipe}	$W.m^{-1}.K^{-1}$	0.133
center-to-center distance between pipes	L_U	m	0.0541
internal convection coefficient	h_{conv}	$W.m^{-2}.K^{-1}$	1000

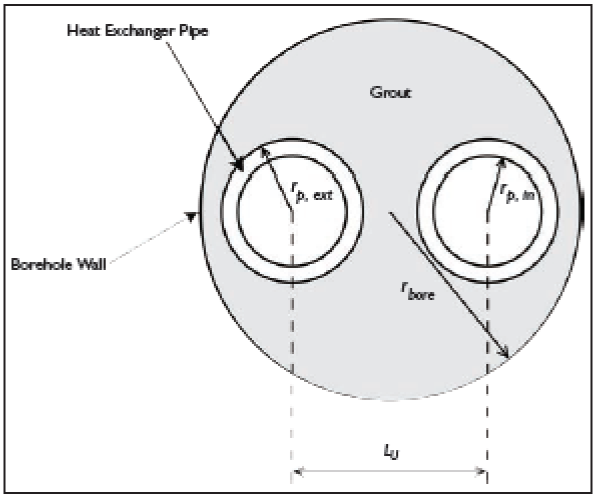


Figure 2.2: Borehole Characteristics

2.2 Physical Properties

Table 2.3: Ground Properties

thermal conductivity	k	$W.m^{-1}K^{-1}$	1.4358
thermal diffusivity		$m^2.day^{-1}$	0.151
Undisturbed ground temperature	T_g	°C	14.44

Coolant Fluids

Heating and cooling fluids used in geothermal applications differ from the typical heating and cooling fluids used in commercial settings. The main reason for the difference is the risk of ground water contamination. Taking into account the possibility for contamination, the fluids that are recommended to be used for vertical closed loop geothermal applications are as follows: food-grade propylene glycol-water solution, methanol-water solution of up to 20 percent methanol by volume, ethanol-water solution of up to 20 percent ethanol by volume[5]. The selection of the coolant fluid relies heavily on the amount of heat transfer necessary. We have chosen 50% propylene glycol as our cooling liquid because it best meets the requirements for the cooling.

Table 2.4: Fluid Properties

thermal heat capacity	Cp	$J.kg^{-1}.K^{-1}$	3558.78
total mass flow rate per kW of peak hourly ground load	m_{fls}	$kg.s^{-1}.kW^{-1}$	0.148
max/min heat pump inlet temperature	T_{inHP}	°C	4.44

2.3 Software Parameters

The calculations for the sizing of the borehole depth are carried out in a spreadsheet.The spreadsheet was compared against more advanced software tools and proved to be accurate with the other software tools' results[4]. These calculations require a specific set of inputs that must be within certain ranges for the spreadsheet to yield accurate results. These inputs and ranges are as follows:

$0.05\ m \le r_{bore} \le 0.1\ m$
$0.025 m^2/day \le \alpha \le 0.2 m^2/day$
$-2 \le \ln(t/t_s) \le 3$
$4 \le NB \le 144$
$1 \le A \le 9$

r_{bore} is the radius of the borehole
α is the ground thermal diffusivity
t is the ground load
t_s is the characteristic time
NB is the number of boreholes
A is the geometrical aspect ratio

3.0 Method of Approach

The first step in designing a VGCHP capable of heating or cooling a portion of the UT agricultural campus was to research similar commercial applications. Information on other similar scale geothermal applications was published in the literature by Ball State University and The University of North Dakota[6].

Software produced by ASHRAE has a high level of accuracy when compared with other design calculations. Vertical closed loop geothermal design software created by Michael Philippe et al will be used in our design calculations[4]. In using the software, we will fill in all of the input parameters and allow the software to calculate the borefield size and depth of bores.

The next step in our method of approach is to find a space on campus large enough to support the bore field size determined by the heating and cooling loads. Next, we will calculate the raw material costs, installation costs, and operating costs.

After computing all the cost information, we will compare our cost estimates with a spreadsheet compiled by Steve Kavanaugh[7] that contains all the cost information for approximately fifty commercial geothermal heating and cooling systems. Provided our numbers are similar when compared to other installed geothermal HVAC systems of similar size, we will make a recommendation between the current University heating and cooling methods or investing in a geothermal cooling system. We will also take into account the payback period of the project and factors including public perception of sustainable energy and impact on parking for the Agricultural Campus.

4.0 Results

Borefield Sizing

In order to determine if we could design a geothermal HVAC system capable of replacing 2400 tons of cooling capacity, it was necessary to determine the amount of land available on the agricultural campus where the borefield could be placed. Using Google Earth's satellite imagery we were able to examine all the open space on campus where the borefield could be installed. The only space that was able to provide adequate area for the borefield was a large staff parking lot located on the agricultural campus between the greenhouses and the College of Veterinary Medicine. The parking lot was measured as 240 meters long and 65 meters wide and this area provides sufficient space to install a borefield capable of meeting a portion of the requirements specified by Facilities Services (600 tons of cooling capacity).

Figure 4.1: Location of Borefield

4.1 First Set of Results

The first set of results calculated by the ASHRAE software can be seen in Tables 4.1, 4.2, and 4.3. These values include resistances of the boreholes, piping, as well as the effective ground thermal resistances over different time periods. The first set of results also includes an initial calculation of the heat pump outlet temperature, average fluid temperature in the borehole, and the total length of drilling for all of the bores. After the software calculates these values a new set of inputs must be entered for iteration to come up with an optimized solution. The new set of inputs can be seen in table 2.8 and include the distance between bores, number of boreholes, and the borefield aspect ratio. The borefield aspect ratio is the number of bores in the longest direction divided by the number of bores in the shortest direction. Given that we are working with a set distance between bores and a set area from the parking lot, there was only one optimal aspect ratio we could use to make sure the borefield fit in our given area.

Table 4.1: Effective Borehole Resistance

convective resistance	R_{conv}	$m.K.W^{-1}$	0.004
pipe resistance	R_p	$m.K.W^{-1}$	0.201
grout resistance	R_g	$m.K.W^{-1}$	0.020
effective borehole thermal resistance	R_b	$m.K.W^{-1}$	0.122

Table 4.2: Effective Ground Thermal Resistances

short term (6 hours pulse)	R_{6h}	$m.K.W^{-1}$	0.163
medium term (1 month pulse)	R_{1m}	$m.K.W^{-1}$	0.252
long term (10 years pulse)	R_{10y}	$m.K.W^{-1}$	0.266

Table 4.3: Total Length of Bore

heat pump outlet temperature	T_{outHP}	°C	2.5
average fluid temperature in the borehole	T_m	°C	3.5
total length	L	m	5626.4

Table 4.4: Borefield Characteristics (2nd Inputs)

distance between boreholes	B	m	6.1
number of boreholes	NB	-	117
borefield aspect ratio	A	-	1.44

4.2 Second Set of Results

After the second set of inputs is entered into the software and iterative procedure is performed to achieve a final set of results. The results include the total borefield length, the depth per bore, and a temperature penalty. The temperature penalty arises when heat transfer in the ground is inadequate and the borefield begins to change the temperature of the ground.

Table 4.5: Iterative Software Results

distance-depth ratio	B/H	-	0.044
logarithm of dimensionless time	$\ln(t_{10y}/t_s)$	-	-1.359
temperature penalty	T_p	°C	-0.204
total borefield length	L	m	16436.7
2nd iteration			
distance-depth ratio	B/H	-	0.043
logarithm of dimensionless time	$\ln(t_{10y}/t_s)$	-	-1.396
temperature penalty	T_p	°C	-.199
total borefield length	L	m	16430
3rd iteration			
distance-depth ratio	B/H	-	0.043
logarithm of dimensionless time	$\ln(t_{10y}/t_s)$	-	-1.395
temperature penalty	T_p	°C	-0.199
total borefield length	L	m	16430.2
4th iteration			
distance-depth ratio	B/H	-	0.043
logarithm of dimensionless time	$\ln(t_{10y}/t_s)$	-	-1.396
temperature penalty	T_p	°C	-0.199
total borefield length	L	m	16430.2
5th iteration			
distance-depth ratio	B/H	-	0.043
logarithm of dimensionless time	$\ln(t_{10y}/t_s)$	-	-1.396
temperature penalty	T_p	°C	-0.199
total borefield length	L	m	16430.2
Final results			
total borefield length	L	m	16430.2
borehole depth	H	m	140.4

4.3 Geothermal Ground Source Heat Pump

The heat pumps chosen for this design are manufactured by Daikin and the model is the WLVW1290 24 ton unit. For pricing and information on which heat pump would best suit our needs we contacted Daikin. Duke Hoffman, a representative from Daikin, was able to provide us with a cost estimate for the best model that would suit our application and the models exact specifications. The specifications and order for the cost estimate can be seen in Table 4.6 and the Appendices.

The WLVW 1290 is designed specifically for vertical geothermal applications and can be applied to all building types. The heat pump is constructed of G-60 galvanized steel and is insulated with dual density fiberglass. This heat pump also comes equipped with a thermal expansion valve for refrigerant metering. This allows the unit to operate at optimum efficiency with fluid temperatures ranging from 25 to 100 degrees Fahrenheit. A MicroTech III Unit Controller coupled with a BACnet communication module allows for multiple heat pumps to be controlled simultaneously using network communications[8]. The exact specifications for the heat pump operation can be seen in Table 4.6.

The most important factors regarding the performance of the heat pump are the coefficient of performance (COP) and the energy efficiency ratio (EER)[9]. The COP is the ratio of heating or cooling provided to the electrical energy consumed. The COP is dependent on the operating conditions, and a higher COP will lead to lower operating costs. The EER is a ratio of output cooling energy to the electrical input energy. The EER measures the efficiency of a cooling system operating at steady state over a specific duration of time. The EER and COP will be used as a tool to compare costs of a conventional HVAC system against the geothermal design.

Table 4.6: Heat Pump Performance and Specifications[7]

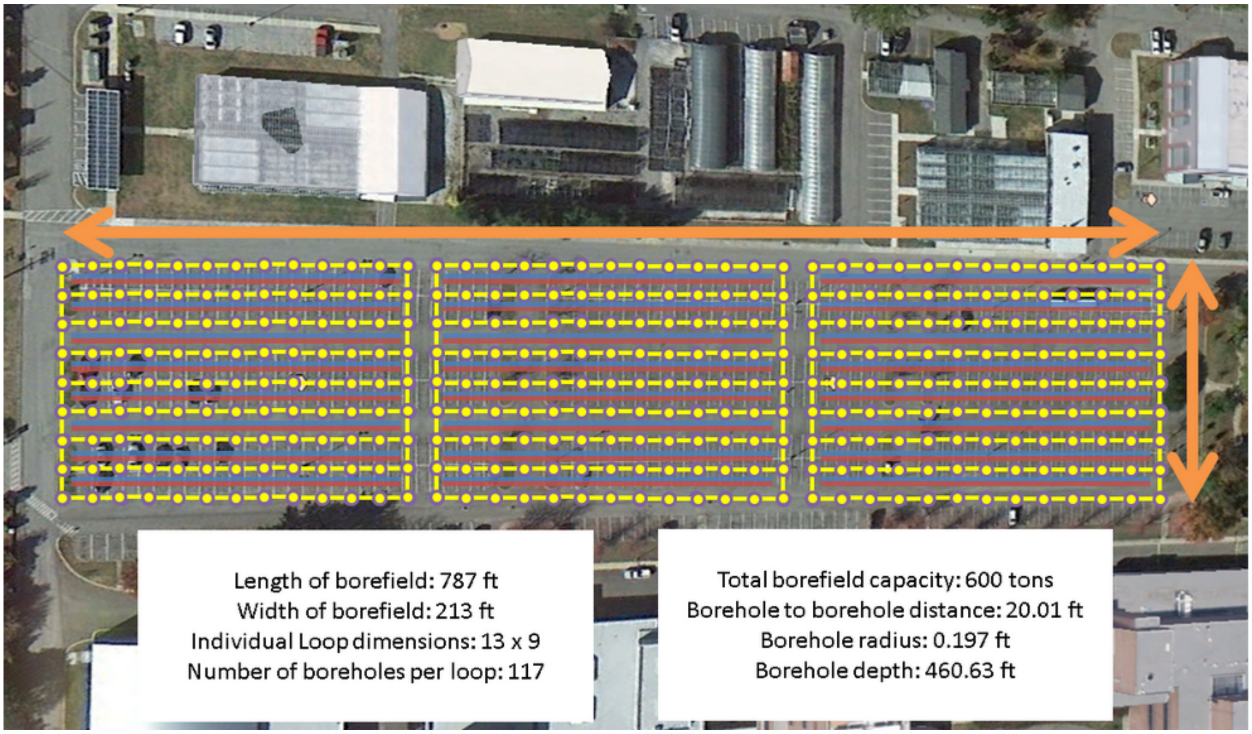
EWT	GPM	WPD	Cooling							Heating				
			EA (DB/WB)		TOT	SEN	kW	EER	THR	EA (DB)	TOT	kW	COP	THA
20	48.3	9.1	Operation Not Recommended							60	267730	16.89	3.0	210101
										70	262680	18.40	2.6	199881
										80	257720	20.08	2.3	189190
	72.5	18.6								60	270751	16.89	3.0	213109
										70	265200	18.40	2.6	202401
										80	258690	20.08	2.3	190160
	96.7	30.9								60	271870	16.89	3.0	214228
										70	265200	18.40	2.6	202401
										80	258690	20.08	2.3	190160
30	48.3	9.1	75	63	364460	244600	15.90	22.9	418730	60	268730	18.11	3.4	206914
			80	67	389830	250480	16.61	23.5	446506	70	263680	19.68	3.0	196499
			85	71	416570	255680	17.35	24.0	475789	80	258720	21.43	2.6	185573
	72.5	18.6	75	63	366390	245500	15.69	23.3	419947	60	272870	18.25	3.4	210593
			80	67	392060	251430	16.37	24.0	447931	70	266200	19.77	3.0	198715
			85	71	419110	256670	17.12	24.5	477523	80	259690	21.47	2.6	186416
	96.7	30.9	75	63	367340	245940	15.59	23.6	420549	60	272870	18.25	3.4	210593
			80	67	393140	251890	16.26	24.2	448639	70	266200	19.77	3.0	198715
			85	71	420360	257150	17.00	24.7	478384	80	259690	21.47	2.6	186416
40	48.3	9.1	75	63	351740	238770	17.41	20.2	411174	60	304470	19.81	3.6	236862
			80	67	376170	244720	18.10	20.8	437935	70	264620	20.71	2.8	193927
			85	71	401780	250000	18.86	21.3	466142	80	293040	24.50	2.6	209418
	72.5	18.6	75	63	353650	239640	17.17	20.6	412255	60	311000	20.03	3.6	242644
			80	67	378350	245640	17.85	21.2	439275	70	303940	22.21	3.1	228144
			85	71	404310	250970	18.58	21.8	467734	80	296110	24.63	2.6	212055
	96.7	30.9	75	63	354590	240070	17.05	20.8	412792	60	311690	20.05	3.6	243253
			80	67	379430	246090	17.73	21.4	439953	70	303940	22.21	3.1	228144
			85	71	405560	251450	18.45	22.0	468526	80	296110	24.63	2.6	212055
50	48.3	9.1	75	63	338940	232970	19.11	17.7	404145	60	346720	21.26	3.8	274149
			80	67	362200	238930	19.81	18.3	429798	70	339170	23.55	3.3	258784
			85	71	386720	244300	20.56	18.8	456895	80	331460	26.13	2.8	242282
	72.5	18.6	75	63	340860	233840	18.84	18.1	405147	60	354780	21.55	3.9	281226
			80	67	364410	239840	19.53	18.7	431056	70	346400	23.84	3.3	265044
			85	71	389300	245270	20.26	19.2	458434	80	337570	26.40	2.8	247484
	96.7	30.9	75	63	341790	234260	18.71	18.3	405644	60	358170	21.67	3.9	284200
			80	67	365490	240290	19.39	18.9	431661	70	347900	23.90	3.3	266340
			85	71	390550	245740	20.12	19.4	459202	80	337570	26.40	2.8	247484
60	48.3	9.1	75	63	325750	227080	21.03	15.5	397512	60	391870	22.92	4.1	313641
			80	67	347810	233040	21.75	16.0	422026	70	382120	25.29	3.5	295809
			85	71	371030	238460	22.50	16.5	447836	80	372170	27.95	2.9	276773
	72.5	18.6	75	63	327690	227950	20.74	15.8	398469	60	401620	23.29	4.1	322118
			80	67	350080	233960	21.42	16.3	423197	70	390820	25.66	3.5	303256
			85	71	373620	239420	22.18	16.8	449317	80	379860	28.31	3.0	283245
	96.7	30.9	75	63	328630	228370	20.60	16.0	398938	60	406930	23.50	4.1	326725
			80	67	351190	234420	21.27	16.5	423778	70	394800	25.83	3.5	306659
			85	71	374900	239890	22.02	17.0	450037	80	381580	28.39	3.0	284688
70	48.3	9.1	75	63	311880	220970	23.22	13.4	391137	60	439510	24.81	4.2	354851
			80	67	332730	226950	23.95	13.9	414454	70	427260	27.25	3.6	334256
			85	71	354550	232410	24.74	14.3	438988	80	414780	29.99	3.1	312428
	72.5	18.6	75	63	313900	221860	22.89	13.7	392034	60	451050	25.29	4.3	364752
			80	67	335090	227900	23.59	14.2	415592	70	437510	27.72	3.7	342912
			85	71	357260	233400	24.36	14.7	440390	80	423780	30.44	3.1	319892
	96.7	30.9	75	63	314900	222290	22.73	13.9	392481	60	457280	25.55	4.3	370085
			80	67	336220	228360	23.42	14.4	416163	70	443040	27.97	3.7	347572
			85	71	358590	233890	24.17	14.8	441086	80	427580	30.63	3.1	323036
80	48.3	9.1	75	63	297080	214480	25.71	11.6	384821	60	489020	26.93	4.4	397094
			80	67	316640	220500	26.45	12.0	406904	70	474040	29.45	3.8	373524
			85	71	337030	226030	27.26	12.4	430072	80	458740	32.26	3.2	348654
	72.5	18.6	75	63	299240	215420	25.34	11.8	385708	60	502310	27.54	4.4	408326
			80	67	319090	221470	26.07	12.2	408053	70	485810	30.03	3.8	383304
			85	71	339890	227070	26.84	12.7	431478	80	468980	32.81	3.2	357006
	96.7	30.9	75	63	300290	215880	25.15	11.9	386137	60	509470	27.87	4.4	414353
			80	67	320300	221960	25.87	12.4	408601	70	492140	30.35	3.8	388549
			85	71	341290	227580	26.63	12.8	432175	80	474440	33.11	3.2	361449
85	48.3	9.1	75	63	289250	211100	27.07	10.7	381633	60	514270	28.09	4.4	418389
			80	67	308170	217160	27.83	11.1	403164	70	497880	30.65	3.8	393289
			85	71	327840	222740	28.65	11.4	425609	80	480970	33.47	3.3	366747
	72.5	18.6	75	63	291490	212060	26.68	10.9	382532	60	528410	28.77	4.4	430232
			80	67	310680	218140	27.42	11.3	404258	70	510320	31.29	3.8	403527
			85	71	330770	223790	28.20	11.7	427013	80	491810	34.08	3.3	375512
	96.7	30.9	75	63	292590	212540	26.48	11.0	382980	60	536030	29.14	4.4	436592
			80	67	311920	218630	27.21	11.5	404798	70	517000	31.64	3.8	409006
			85	71	332180	224290	27.99	11.9	427720	80	497600	34.41	3.3	380176
90	48.3	9.1	75	63	281050	207580	28.51	9.9	378361	60	539760	29.32	4.4	439698
			80	67	299340	213710	29.30	10.2	399334	70	521790	31.90	3.8	412926
			85	71	318270	219340	30.12	10.6	421056	80	503340	34.74	3.3	384786
	72.5	18.6	75	63	283370	208580	28.10	10.1	379268	60	554660	30.06	4.5	452058
			80	67	301960	214730	28.86	10.5	400446	70	534950	32.61	3.9	423649
			85	71	321260	220400	29.66	10.8	422493	80	514640	35.40	3.3	393823
	96.7	30.9	75	63	284520	209070	27.90	10.2	379732	60	562670	30.47	4.5	458676
			80	67	303240	215230	28.64	10.6	400992	70	541990	33.00	3.9	429364
			85	71	322720	220920	29.44	11.0	423192	80	520660	35.76	3.3	398615

EWT (°F) = Entering Water Temperature
GPM = Water flow rate in Gallons Per Minute
WPD (ft. of Water) = Water Pressure Drop
EAT (°F), Cooling = Entering Air Temperature, Dry Bulb-Wet Bulb
EAT (°F), Heating = Entering Air Temperature, Dry Bulb-Wet Bulb
Total (Btu/hr) = Total Cooling/Heating Capacity
Sensible (Btu/hr) = Sensible Cooling Capacity
Power Input (kW) = Total Power Input to unit
THR (Btu/hr) = Total Heat of Rejection
EER = Energy Efficiency Ratio
THA (Btu/hr) = Total Heat of Absorption
LAT (°F) = Leaving Air Temperature
COP = Coefficient of Performance

Figure 4.2: Heat Pump Performance

4.4 Borefield Layout

In Figure 4.3 you can see the design and layout of the geothermal borefield. The field is divided into 3-200 ton capacity sections and the circulating fluid can be routed to the heat pumps located in the surrounding buildings. When calculating the amount of piping needed, an extra length of 1000 feet per field was added to transport the heating/cooling fluid to the heat pumps. In between each field section there are two separate pipes to carry the hot and cold fluid which are represented by the red and blue lines.



Length of borefield: 787 ft
Width of borefield: 213 ft
Individual Loop dimensions: 13 x 9
Number of boreholes per loop: 117

Total borefield capacity: 600 tons
Borehole to borehole distance: 20.01 ft
Borehole radius: 0.197 ft
Borehole depth: 460.63 ft

Figure 4.3: Borefield Layout

5.0 Capital Cost Estimates

The raw material costs and installation costs cited in the study level design were obtained using sources on the web and the Geothermal Design guide. The ground loop installation cost per foot is recommended by Kavanaugh and Rafferty and can fall in the range of five dollars to eight dollars per foot. This price includes labor costs, U-tube insertion, backfilling, and header installation at 4 feet and assumes bentonite grout to forty feet of a 500 foot average bore depth, header to equipment room distance in 150 feet and the surface casing is less than 40 feet. It also states the cost can be near upper range or exceeded if the contractor has a high travel cost, the entire bore must be grouted, cuttings must be disposed off site, labor rates are higher than average, or nonstandard header arrangements are specified.

We also checked various website for pricing information on the HDPE piping and propylene glycol solution and all sources had approximately equal prices. The pricing for the connectors, tees, u bends, and elbows was obtained from HDPE Supply[10]. To determine the amount of bentonite grout and pricing information we contacted the GeoPro Inc. Company. The representative from their company recommended the best grout for our application and also gave us a price per bag. Their website has a tool that allows you to input your design parameters and calculates the amount of bentonite grout needed to backfill the bores. Using this tool we were able to calculate the number of bags of bentonite needed[11]. The propylene glycol solution was priced per gallon from ChemWorld's website[12].

Table 5.1: Material Costs for 200 tons

Material	Cost Per Unit	Total number of Units	Total Cost
1.25 in HDPE Pipe	$0.48 per foot	19,270 feet	$9,250
HDPE Connetors	$2.22 per 20ft	964	$2,140
U bend connectors	$11.50	117	$1345.50
Elbows	$5.93	234	$1387.62
Tee's	$7.19	117	$841.23
99.9% Propylene Glycol	$18.18 per gallon	180 gallons	$3272.4
TG Thermal Grout	$8.25 per bag	2,766 Bags	$22,819.5
Daikin WLVW1290 24 ton	$13,600	9 units	$122,400

Table 5.2: Labor and Construction Costs for 200 tons

Job	Cost Per Unit	Total Number of Units	Total Cost
Ground Loop Installation	$6.50	53,820	$353,080
Drilling Cost	$15 per foot	53,820 feet	$807,300

Table 5.3 Total Capital Cost Summary for 600 Tons Cooling

Material/Job	Total Units	Total Cost
Piping (HDPE, Connectors, elbows, tees)	1055 connectors, 351 U-bends, 702 elbows, 351 Tees	$204,944
Circulating fluid	540 gallons	$9,817
Grouting	8,298 bags	$68,458
Heat Pumps	25 heat pumps	$340,000
Loop Installation (labor, backfill, pipe fusion, trenching)	161,460 feet	$1,052,740
Drilling	161,460 feet	$2,421,900
Total Cost	-	$4,088,000

Table 5.4 Inflation and interest rates for different economic conditions

Economy	**Inflation (%)**	**Interest (%)**
Strong	2.5	4
Nominal	4	6
Poor	7	10

Table 5.5 Initial cost for conventional HVAC and geothermal systems

<table>
<tr><th colspan="2">Conventional HVAC System</th></tr>
<tr><td colspan="2">Initial Costs</td></tr>
<tr><td>Installation Cost</td><td>$25,000</td></tr>
<tr><td>Air Handler Cost</td><td>$330,000</td></tr>
<tr><td>Total Cost</td><td>$355,000</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">Geothermal System</td></tr>
<tr><td colspan="2">Initial Costs</td></tr>
<tr><td>Bore Field Cost(including Piping)</td><td>$3,748,000</td></tr>
<tr><td>Heat Pump Cost</td><td>$340,000</td></tr>
<tr><td>Total Cost</td><td>$4,088,000</td></tr>
</table>

Table 5.6 Energy load and efficiencies for conventional HVAC and geothermal

Conventional HVAC Heating Eff.	80%
Conventional HVAC Cooling EER	10
Heating Load(MMBtu/yr)	9952
Cooling Load (kWh/yr)	208486
Energy per year (kWh/yr)	3,125,720
Geothermal Heating COP	3.75
Geothermal Cooling EER	9.82
Energy per year (kWh/yr)	768,092

Table 5.7 Maintenance cost for conventional HVAC and geothermal

Conventional HVAC	
Annual Maintenance ($/yr)	$15,000
Later Maintenance ($/yr)	$22,500
Air Handler Replacement Cost ($)	$330,000
Geothermal	
Annual Maintenance ($/yr)	$9,000
Later Maintenance ($/yr)	$13,500
Heat Pump Replacement Cost($)	$340,000

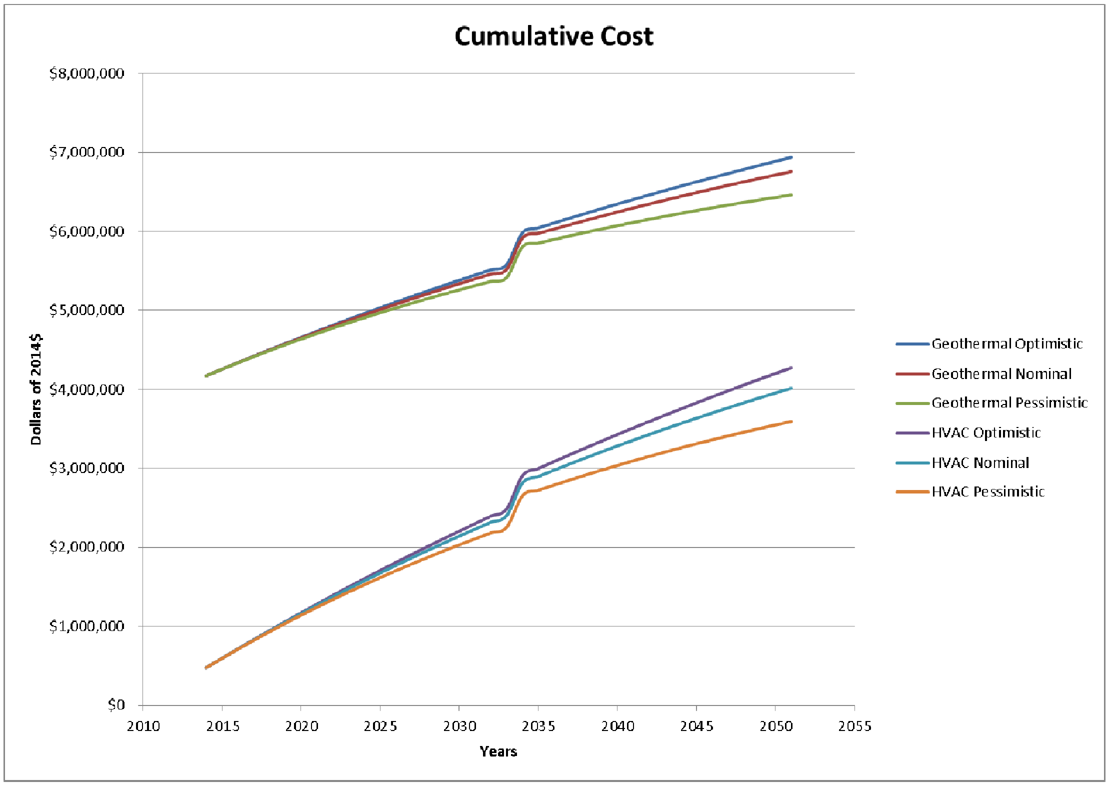


Figure 5.1 Cumulative costs for both the conventional HVAC and geothermal systems

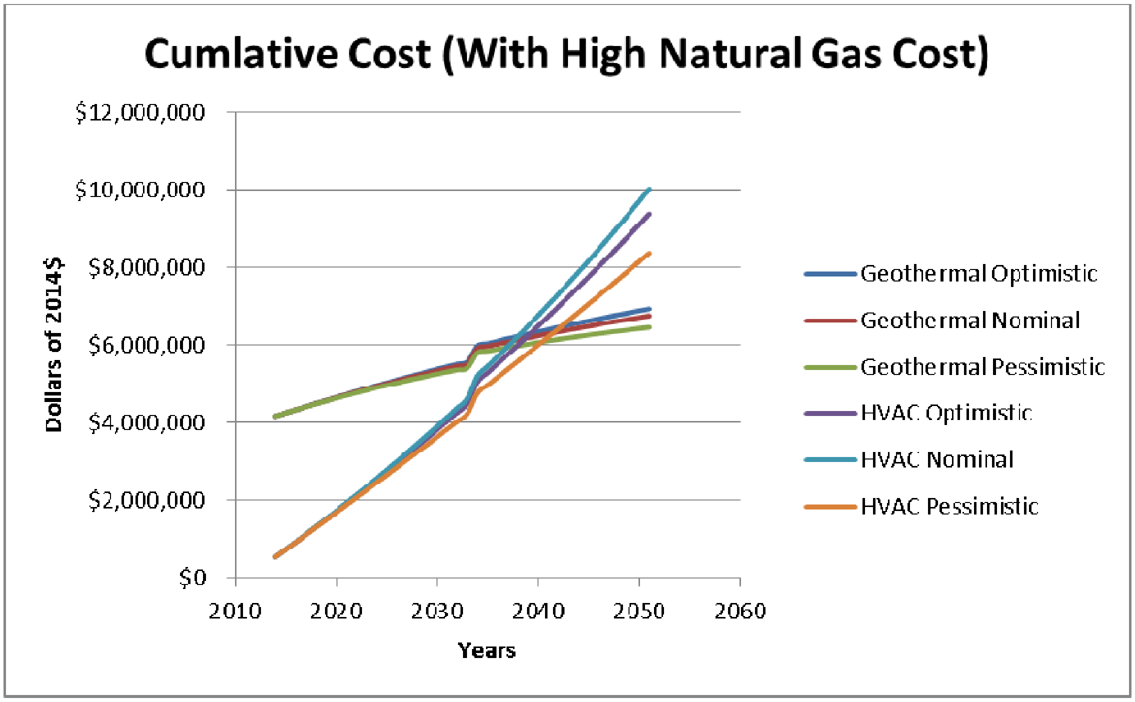


Figure 5.2 Cumulative costs with high natural gas prices

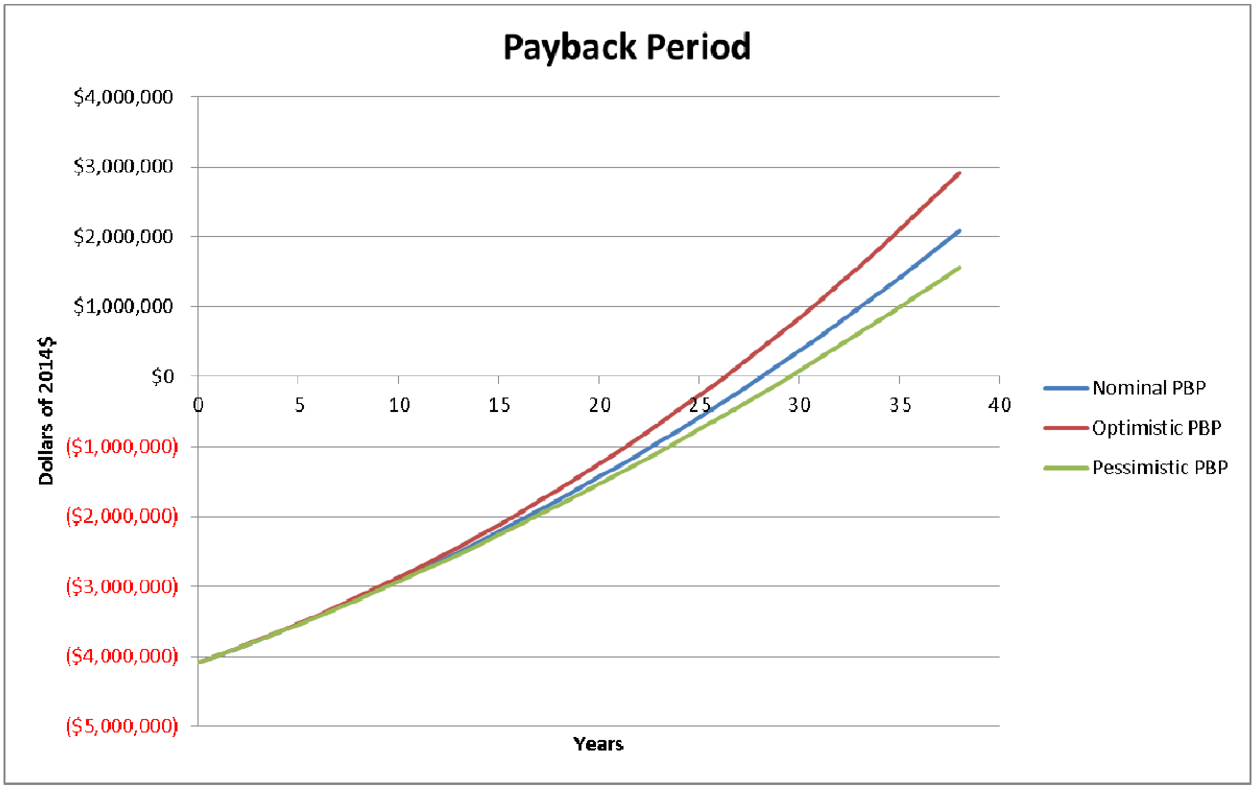


Figure 5.3 Payback Period

6.0 Discussion of Results and Economic Analysis

Due to the size restrictions of the available land, the overall cooling load that is attainable is 600 tons. This value is significantly less than that which is being utilized for the current cooling loads on the Agricultural Campus. A major benefit of this system is that it will not only be able to provide cooling energy in the warmer months, but it will also be able to generate approximately 780,000kwh/yr of energy for heating purposes. The combined ability to heat and cool, operate at a high efficiency, and produce clean sustainable energy are all very important benefits that would be attained by the installation of this system.

All the calculated parameters of the borefield are consistent with typical vertical closed loop geothermal systems. A brief design summary of the system can be seen in Table 7.1. The overall costs associated with the designed system are comparable to systems of similar size that are currently operating[7]. This means that the cost calculations were accurate and provide a good basis for long term analysis. The operating costs were estimated using several case studies of similar geothermal systems[7]. Vertical geothermal HVAC systems have very low operating and maintenance costs due to their simple design and few moving parts. The only significant operating costs occur from the electricity required to pump the circulating fluid and the labor to occasionally monitor the system and make sure everything is working properly. The main maintenance cost stems from leaks in the HDPE pipe resulting from age and normal wear. These leaks can be somewhat expensive to repair because of the labor involved in removing the pipe from the bore, repairing the leak, and freshly backfilling the bore.

For economic analysis and to give a comparison between the cumulative costs of a conventional HVAC system versus the geothermal system, three different cases were presented. These cases compared the two systems under strong, nominal, and poor economic conditions. The interest and inflation rates for each economic condition can be seen in Table 5.4. When making this comparison the main components of each system were given a 20 year lifetime. Regardless of the economic conditions, the geothermal system had a much higher cumulative cost compared the conventional HVAC system. We also made one more comparison of the two systems under the assumption of high natural gas prices. Natural gas is currently used as the main source of heating buildings so if the price of natural gas were to dramatically increase this would have a significant impact on the feasibility of a geothermal installation. After about 25 years under a high natural gas price scenario, the geothermal system becomes less expensive than the conventional system. The results of the comparison can be seen in Figure 5.2. More in depth tables with all of the values for the comparisons can be seen in the Appendices in tables 11.1 through 11.9. After determining a total capital cost of about 4 million dollars, the payback period was computed. This system gives a return of investment by reducing heating and cooling costs in the range of 40 to 60 percent. With approximate savings at 50% the payback period under a strong economy would come after about twenty five years and could be as long as thirty years in a poor economy. The results of the payback period calculation can be seen in figure 5.3 and the yearly data can be seen in Appendices tables 11.10 through 11.12.

Table 6.1 Design Summary Table

Total Length of Borefield	787 feet
Total Width of Borefield	213 feet
Total Number of Boreholes	351
Borehole to Borehole Distance	20.01 feet
Borehole Radius	0.197 feet
Borehole Depth	460.63 feet
Total Borefield Capacity	600 tons
Capital Cost	4.1 million

7.0 Conclusions

Currently, it is not economically feasible to install the designed geothermal system. The payback period of a feasible capital cost project of this magnitude is between ten to twenty years. The system that was designed has a payback period of between twenty-five to thirty years. Due to limited space, the already existing conventional HVAC infrastructure, and the high capital cost associated with the geothermal system it is a better economic decision to stick with conventional heating and cooling methods. It would be much more feasible to install a geothermal system if it was under new construction. If natural gas and electricity prices were to significantly increase, then it would justify retrofitting the existing heating and cooling system to include a geothermal system. With natural gas prices currently low the trend only slightly increasing in the future, natural gas appears to be the most economical source of energy for the foreseeable future. The projections for the price of natural gas can be seen in Figure 8.1. Although natural gas may be the best source of energy under current conditions, the fact still remains that natural gas is a non-renewable resource and is not sustainable. With the idea of climate change occurring due to our strong reliance on fossil fuels there may become many new incentives for sustainable energy production in the near future. With new incentives to reduce our carbon footprint and invest in sustainable technology the installation of this geothermal application may become much more feasible in the very near future.

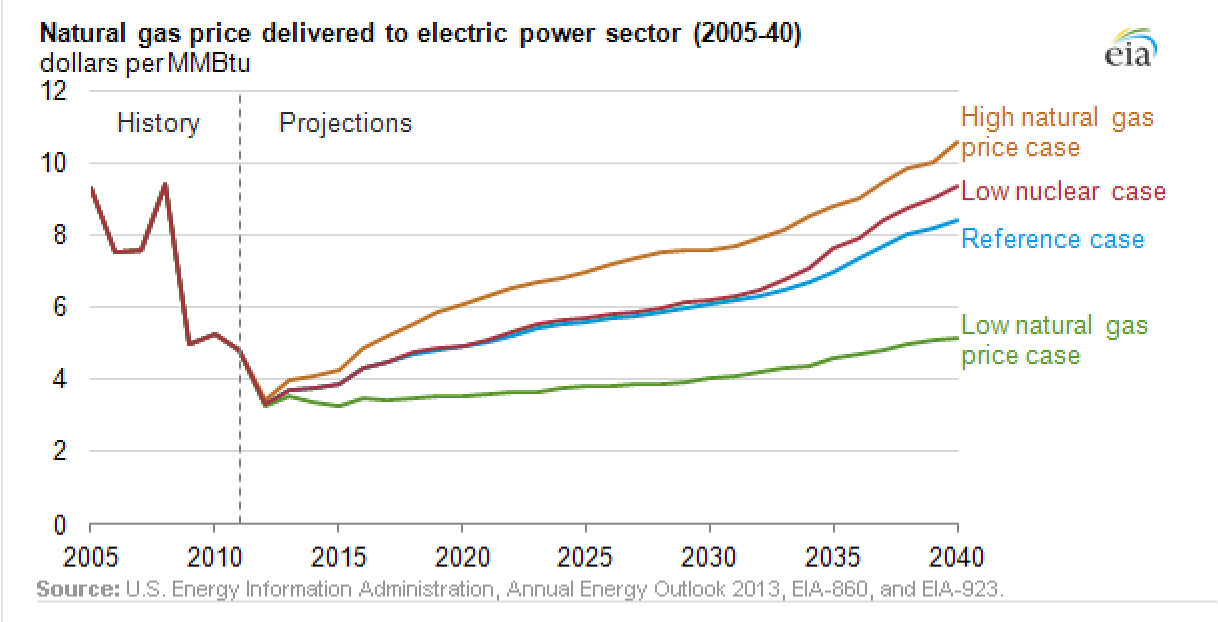


Figure 7.1 Natural Gas Projected Cost[16]

8.0 Recommendations

It is our recommendation based on the calculated capital costs and payback period that the system not be installed. If sustainability and public perception of sustainability of the University is of great importance, it would be our recommendation to install one of the three loops. Not only would this allow us to give the geothermal application a good “test,” but it would also decrease the overall capital cost of the project while giving notoriety to the University for increasing the presence of sustainable energy on campus. Due to the major scale of construction and limited parking on the Agricultural Campus, it would be our recommendation that only one loop at a time be installed. This would allow two-thirds of the parking lot to remain in use while construction of the boreholes and piping is being installed. This also allows for future loops to be completed with limited parking interference if gas and electricity prices rise and the University decided to increase its sustainable energy.

9.0 References

[1] Engineering Services Group design of a ground source heat pump system for the UT sorority village

[2] Kavanaugh, Stephen P., and Kevin D. Rafferty.*Ground-source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1997. Print. (Design Information)

[-3] http://www.tva.gov/commercial/TCStudy/ (Property Information)

[4] Phillippe, Mikael, Michel Bernier, and Dominique Marchio. Vertical Geothermal Bore fields: Sizing Calculation Spreadsheet. N.p.: ASHRAE Journal, 2010. Web. 11 Oct. 2012. (Software)

[5] http://www.michigan.gov/documents/deq/dnre-wb-dwehs-wcu-bestpracticesgeothermal_311868_7.pdf (coolant fluid types)

[6] Grandstrand, Tyrone, KirtipalBarse, and Jason Schaefer. "Preliminary Analysis of Large-Scale Geothermal Installation at The University of North Dakota." (2011): n. pag. Print.

[7] *www.geokiss.com/software/GHP$-PerfSum9-21-11.xlsx* (Price Comparison)

[8] Daikin Efinity Large Vertical Source Heat Pumps Catalog 1109-5 (Heat Pump Cost)

[9] http://www.powerknot.com/how-efficient-is-your-air-conditioning-system.html (EER and COP)

[10] http://www.hdpesupply.com/ (Connectors, etc)

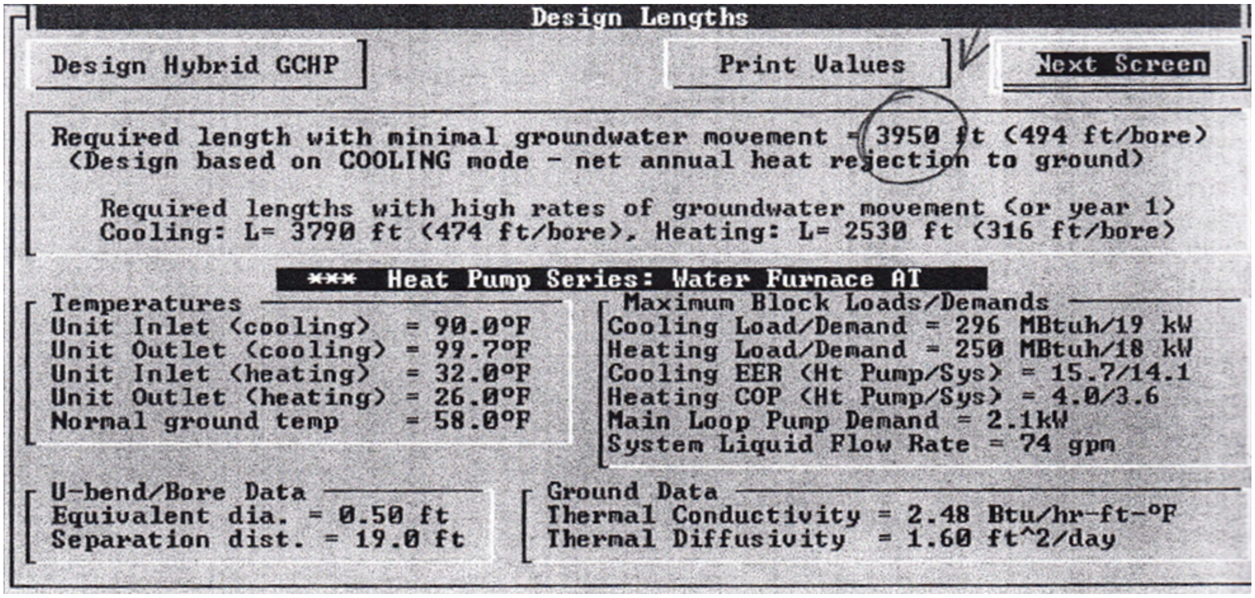
[11] http://www.geoproinc.com/ (Bentonite grout cost)

[12] http://www.chemworld.com/ (Circulating fluid price)

[15] http://www.npr.org/blogs/money/2011/10/27/141766341/the-price-of-electricity-in-your-state (electricity price)

[16] http://www.eia.gov/todayinenergy/detail.cfm?id=10991 (natural gas projection)

10. Appendices



```
Required length with minimal groundwater movement = 3950 ft (494 ft/bore)
 (Design based on COOLING mode - net annual heat rejection to ground)

   Required lengths with high rates of groundwater movement (or year 1)
   Cooling: L= 3790 ft (474 ft/bore), Heating: L= 2530 ft (316 ft/bore)

               *** Heat Pump Series: Water Furnace AT

Temperatures                          Maximum Block Loads/Demands
Unit Inlet (cooling)  = 90.0°F        Cooling Load/Demand = 296 MBtuh/19 kW
Unit Outlet (cooling) = 99.7°F        Heating Load/Demand = 250 MBtuh/18 kW
Unit Inlet (heating)  = 32.0°F        Cooling EER (Ht Pump/Sys) = 15.7/14.1
Unit Outlet (heating) = 26.0°F        Heating COP (Ht Pump/Sys) = 4.0/3.6
Normal ground temp    = 58.0°F        Main Loop Pump Demand = 2.1kW
                                      System Liquid Flow Rate = 74 gpm

U-bend/Bore Data                   Ground Data
Equivalent dia. = 0.50 ft          Thermal Conductivity = 2.48 Btu/hr-ft-°F
Separation dist. = 19.0 ft         Thermal Diffusivity  = 1.60 ft^2/day
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Figure 11.0 Engineering Services Group Design for UT Sorority Village[1]

Table 10.1 U-Tube Thermal Resistance Information[2]

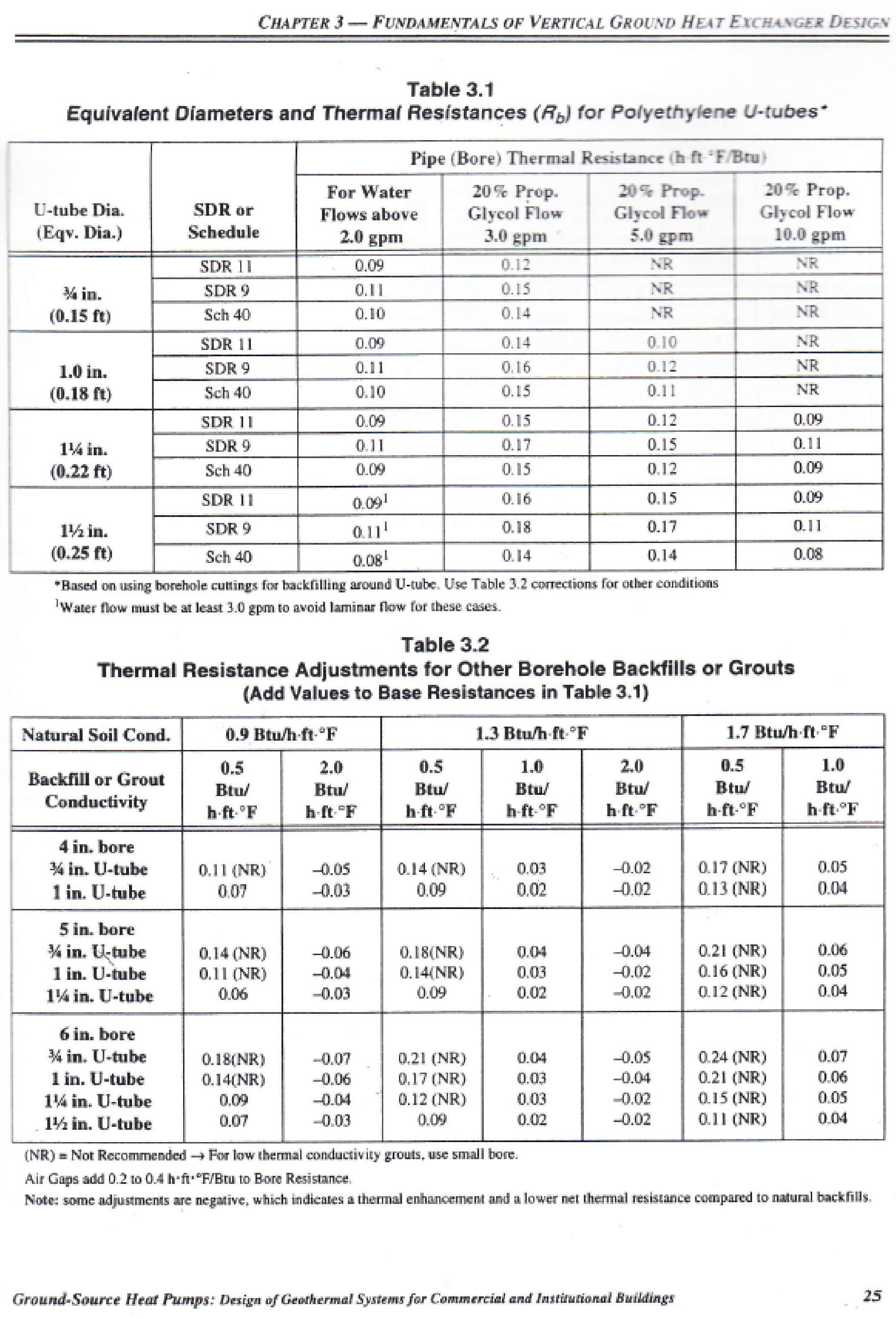


Table 3.1
Equivalent Diameters and Thermal Resistances (R_b) for Polyethylene U-tubes*

U-tube Dia. (Eqv. Dia.)	SDR or Schedule	Pipe (Bore) Thermal Resistance (h·ft·°F/Btu)			
		For Water Flows above 2.0 gpm	20% Prop. Glycol Flow 3.0 gpm	20% Prop. Glycol Flow 5.0 gpm	20% Prop. Glycol Flow 10.0 gpm
¾ in. (0.15 ft)	SDR 11	0.09	0.12	NR	NR
	SDR 9	0.11	0.15	NR	NR
	Sch 40	0.10	0.14	NR	NR
1.0 in. (0.18 ft)	SDR 11	0.09	0.14	0.10	NR
	SDR 9	0.11	0.16	0.12	NR
	Sch 40	0.10	0.15	0.11	NR
1¼ in. (0.22 ft)	SDR 11	0.09	0.15	0.12	0.09
	SDR 9	0.11	0.17	0.15	0.11
	Sch 40	0.09	0.15	0.12	0.09
1½ in. (0.25 ft)	SDR 11	0.09[1]	0.16	0.15	0.09
	SDR 9	0.11[1]	0.18	0.17	0.11
	Sch 40	0.08[1]	0.14	0.14	0.08

*Based on using borehole cuttings for backfilling around U-tube. Use Table 3.2 corrections for other conditions

[1] Water flow must be at least 3.0 gpm to avoid laminar flow for these cases.

Table 3.2
Thermal Resistance Adjustments for Other Borehole Backfills or Grouts
(Add Values to Base Resistances in Table 3.1)

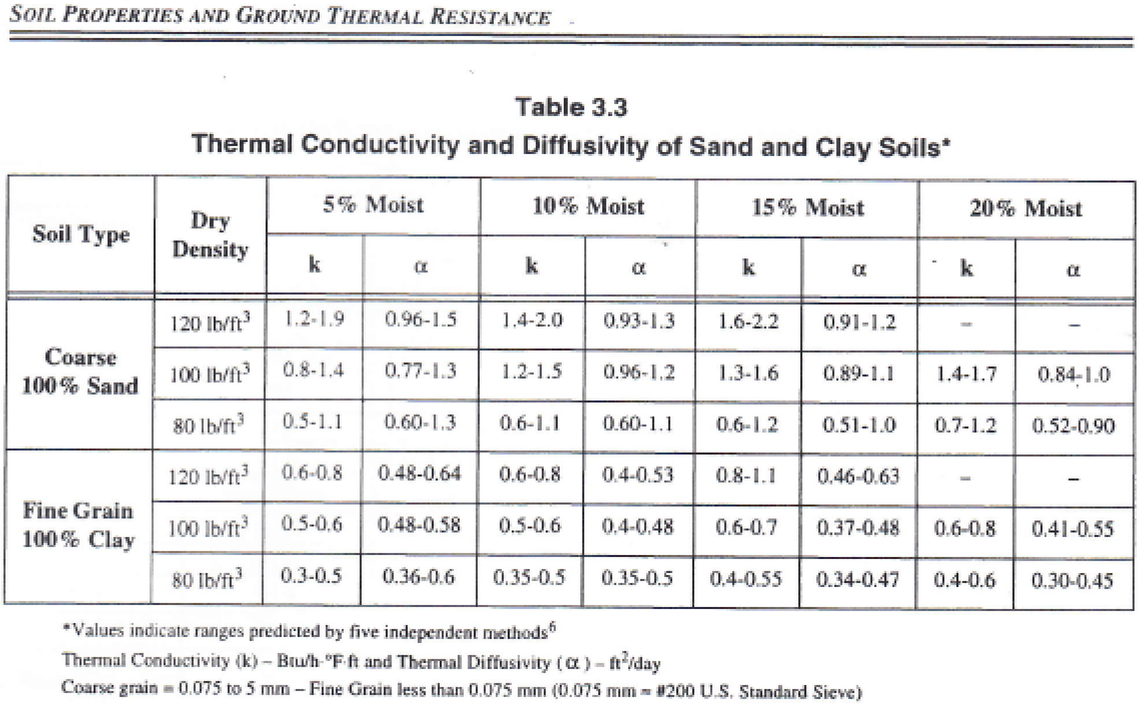
Natural Soil Cond.	0.9 Btu/h·ft·°F		1.3 Btu/h·ft·°F			1.7 Btu/h·ft·°F	
Backfill or Grout Conductivity	**0.5 Btu/ h·ft·°F**	**2.0 Btu/ h·ft·°F**	**0.5 Btu/ h·ft·°F**	**1.0 Btu/ h·ft·°F**	**2.0 Btu/ h·ft·°F**	**0.5 Btu/ h·ft·°F**	**1.0 Btu/ h·ft·°F**
4 in. bore							
¾ in. U-tube	0.11 (NR)	–0.05	0.14 (NR)	0.03	–0.02	0.17 (NR)	0.05
1 in. U-tube	0.07	–0.03	0.09	0.02	–0.02	0.13 (NR)	0.04
5 in. bore							
¾ in. U-tube	0.14 (NR)	–0.06	0.18(NR)	0.04	–0.04	0.21 (NR)	0.06
1 in. U-tube	0.11 (NR)	–0.04	0.14(NR)	0.03	–0.02	0.16 (NR)	0.05
1¼ in. U-tube	0.06	–0.03	0.09	0.02	–0.02	0.12 (NR)	0.04
6 in. bore							
¾ in. U-tube	0.18(NR)	–0.07	0.21 (NR)	0.04	–0.05	0.24 (NR)	0.07
1 in. U-tube	0.14(NR)	–0.06	0.17 (NR)	0.03	–0.04	0.21 (NR)	0.06
1¼ in. U-tube	0.09	–0.04	0.12 (NR)	0.03	–0.02	0.15 (NR)	0.05
1½ in. U-tube	0.07	–0.03	0.09	0.02	–0.02	0.11 (NR)	0.04

(NR) = Not Recommended → For low thermal conductivity grouts, use small bore.

Air Gaps add 0.2 to 0.4 h·ft·°F/Btu to Bore Resistance.

Note: some adjustments are negative, which indicates a thermal enhancement and a lower net thermal resistance compared to natural backfills.

Table 10.2 Soil Conductivity[2]



SOIL PROPERTIES AND GROUND THERMAL RESISTANCE

Table 3.3
Thermal Conductivity and Diffusivity of Sand and Clay Soils*

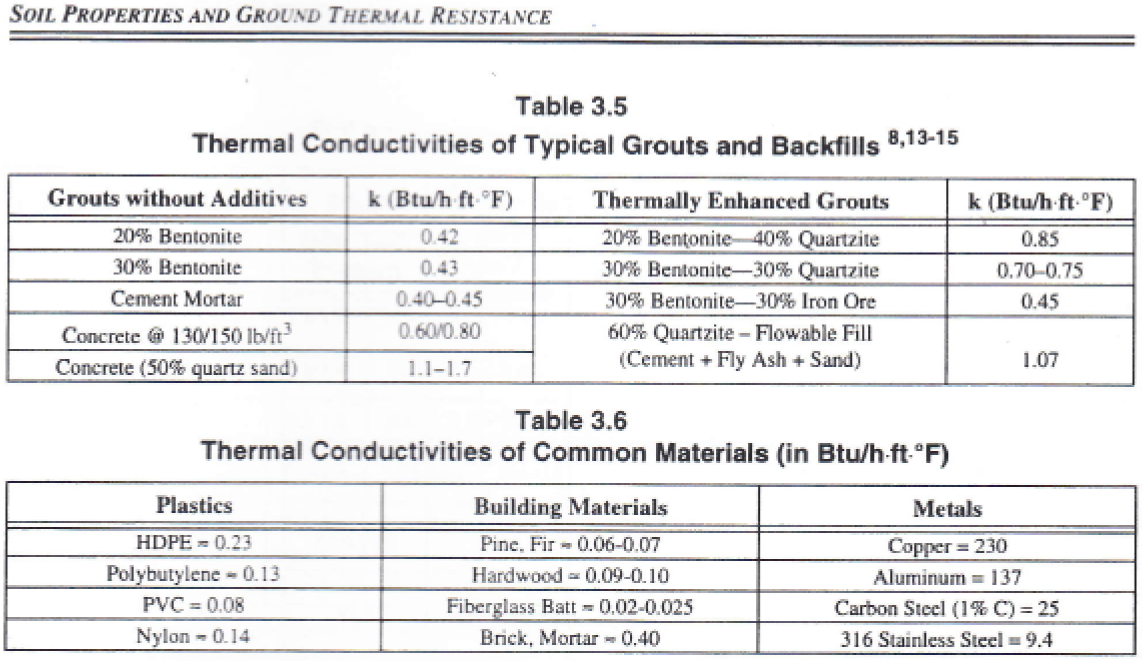
Soil Type	Dry Density	5% Moist		10% Moist		15% Moist		20% Moist	
		k	α	k	α	k	α	k	α
Coarse 100% Sand	120 lb/ft³	1.2-1.9	0.96-1.5	1.4-2.0	0.93-1.3	1.6-2.2	0.91-1.2	–	–
	100 lb/ft³	0.8-1.4	0.77-1.3	1.2-1.5	0.96-1.2	1.3-1.6	0.89-1.1	1.4-1.7	0.84-1.0
	80 lb/ft³	0.5-1.1	0.60-1.3	0.6-1.1	0.60-1.1	0.6-1.2	0.51-1.0	0.7-1.2	0.52-0.90
Fine Grain 100% Clay	120 lb/ft³	0.6-0.8	0.48-0.64	0.6-0.8	0.4-0.53	0.8-1.1	0.46-0.63	–	–
	100 lb/ft³	0.5-0.6	0.48-0.58	0.5-0.6	0.4-0.48	0.6-0.7	0.37-0.48	0.6-0.8	0.41-0.55
	80 lb/ft³	0.3-0.5	0.36-0.6	0.35-0.5	0.35-0.5	0.4-0.55	0.34-0.47	0.4-0.6	0.30-0.45

*Values indicate ranges predicted by five independent methods[6]

Thermal Conductivity (k) – Btu/h·°F·ft and Thermal Diffusivity (α) – ft²/day

Coarse grain = 0.075 to 5 mm – Fine Grain less than 0.075 mm (0.075 mm = #200 U.S. Standard Sieve)

Table 10.3 Thermal Conductivity of Grouts[2]



SOIL PROPERTIES AND GROUND THERMAL RESISTANCE

Table 3.5
Thermal Conductivities of Typical Grouts and Backfills [8,13-15]

Grouts without Additives	k (Btu/h·ft·°F)	Thermally Enhanced Grouts	k (Btu/h·ft·°F)
20% Bentonite	0.42	20% Bentonite—40% Quartzite	0.85
30% Bentonite	0.43	30% Bentonite—30% Quartzite	0.70–0.75
Cement Mortar	0.40–0.45	30% Bentonite—30% Iron Ore	0.45
Concrete @ 130/150 lb/ft³	0.60/0.80	60% Quartzite – Flowable Fill (Cement + Fly Ash + Sand)	1.07
Concrete (50% quartz sand)	1.1–1.7		

Table 3.6
Thermal Conductivities of Common Materials (in Btu/h·ft·°F)

Plastics	Building Materials	Metals
HDPE = 0.23	Pine, Fir = 0.06-0.07	Copper = 230
Polybutylene = 0.13	Hardwood = 0.09-0.10	Aluminum = 137
PVC = 0.08	Fiberglass Batt = 0.02-0.025	Carbon Steel (1% C) = 25
Nylon = 0.14	Brick, Mortar = 0.40	316 Stainless Steel = 9.4

Table 10.1 Geothermal Operational and Maintenance Costs- Optimistic Case

Year	Electricity	Maintenance	Annual	Cumulative
2014	$75,273	$10,000	$85,273	$4,173,273
2015	$74,190	$9,856	$84,046	$4,257,319
2016	$73,122	$9,714	$82,837	$4,340,155
2017	$72,070	$9,574	$81,645	$4,421,800
2018	$71,033	$9,437	$80,470	$4,502,270
2019	$70,011	$9,301	$79,312	$4,581,581
2020	$69,003	$9,167	$78,170	$4,659,752
2021	$68,010	$9,035	$77,046	$4,736,797
2022	$67,032	$8,905	$75,937	$4,812,734
2023	$66,067	$8,777	$74,844	$4,887,578
2024	$65,116	$8,651	$73,767	$4,961,345
2025	$64,179	$8,526	$72,706	$5,034,051
2026	$63,256	$8,404	$71,659	$5,105,710
2027	$62,346	$8,283	$70,628	$5,176,339
2028	$61,448	$8,163	$69,612	$5,245,951
2029	$60,564	$8,046	$68,610	$5,314,561
2030	$59,693	$7,930	$67,623	$5,382,184
2031	$58,834	$7,816	$66,650	$5,448,834
2032	$57,987	$7,704	$65,691	$5,514,524
2033	$57,153	$7,593	$64,745	$5,579,270
2034	$56,330	$7,483	$403,814	$5,983,083
2035	$55,520	$7,376	$62,895	$6,045,979
2036	$54,721	$7,270	$61,990	$6,107,969
2037	$53,933	$7,165	$61,098	$6,169,068
2038	$53,157	$7,062	$60,219	$6,229,287
2039	$52,392	$6,960	$59,353	$6,288,640
2040	$51,638	$6,860	$58,499	$6,347,138
2041	$50,895	$6,761	$57,657	$6,404,795
2042	$50,163	$6,664	$56,827	$6,461,622
2043	$49,441	$6,568	$56,009	$6,517,631
2044	$48,730	$6,474	$55,203	$6,572,835
2045	$48,028	$6,381	$54,409	$6,627,244
2046	$47,337	$6,289	$53,626	$6,680,870
2047	$46,656	$6,198	$52,854	$6,733,724
2048	$45,985	$6,109	$52,094	$6,785,818
2049	$45,323	$6,021	$51,344	$6,837,162
2050	$44,671	$5,935	$50,605	$6,887,768
2051	$44,028	$5,849	$49,877	$6,937,645

Table 10.2 Geothermal Operational and Maintenance Costs- Nominal Case

Year	Electricity	Maintenance	Annual	Cumulative
2014	$75,273	$10,000	$85,273	$4,173,273
2015	$73,855	$9,812	$83,667	$4,256,940
2016	$72,464	$9,627	$82,090	$4,339,030
2017	$71,099	$9,445	$80,544	$4,419,574
2018	$69,759	$9,267	$79,027	$4,498,601
2019	$68,445	$9,093	$77,538	$4,576,139
2020	$67,156	$8,922	$76,077	$4,652,216
2021	$65,891	$8,754	$74,644	$4,726,860
2022	$64,649	$8,589	$73,238	$4,800,098
2023	$63,431	$8,427	$71,858	$4,871,956
2024	$62,236	$8,268	$70,505	$4,942,461
2025	$61,064	$8,112	$69,176	$5,011,637
2026	$59,914	$7,960	$67,873	$5,079,511
2027	$58,785	$7,810	$66,595	$5,146,105
2028	$57,678	$7,662	$65,340	$5,211,445
2029	$56,591	$7,518	$64,109	$5,275,555
2030	$55,525	$7,376	$62,901	$5,338,456
2031	$54,479	$7,238	$61,717	$5,400,173
2032	$53,453	$7,101	$60,554	$5,460,726
2033	$52,446	$6,967	$59,413	$5,520,140
2034	$51,458	$6,836	$398,294	$5,918,434
2035	$50,488	$6,707	$57,196	$5,975,629
2036	$49,537	$6,581	$56,118	$6,031,748
2037	$48,604	$6,457	$55,061	$6,086,809
2038	$47,688	$6,335	$54,024	$6,140,833
2039	$46,790	$6,216	$53,006	$6,193,839
2040	$45,909	$6,099	$52,008	$6,245,846
2041	$45,044	$5,984	$51,028	$6,296,874
2042	$44,195	$5,871	$50,067	$6,346,941
2043	$43,363	$5,761	$49,123	$6,396,064
2044	$42,546	$5,652	$48,198	$6,444,262
2045	$41,744	$5,546	$47,290	$6,491,552
2046	$40,958	$5,441	$46,399	$6,537,951
2047	$40,186	$5,339	$45,525	$6,583,476
2048	$39,429	$5,238	$44,667	$6,628,144
2049	$38,687	$5,139	$43,826	$6,671,970
2050	$37,958	$5,043	$43,000	$6,714,970
2051	$37,243	$4,948	$42,190	$6,757,161

Table 10.3 Geothermal Operational and Maintenance Costs-Pessimistic Case

Year	Electricity	Maintenance	Annual	Cumulative
2014	$75,273	$10,000	$85,273	$4,173,273
2015	$73,223	$9,728	$82,950	$4,256,223
2016	$71,228	$9,463	$80,691	$4,336,914
2017	$69,288	$9,205	$78,493	$4,415,408
2018	$67,401	$8,954	$76,355	$4,491,763
2019	$65,565	$8,710	$74,276	$4,566,039
2020	$63,779	$8,473	$72,252	$4,638,291
2021	$62,042	$8,242	$70,285	$4,708,576
2022	$60,352	$8,018	$68,370	$4,776,946
2023	$58,709	$7,799	$66,508	$4,843,454
2024	$57,109	$7,587	$64,696	$4,908,150
2025	$55,554	$7,380	$62,934	$4,971,084
2026	$54,041	$7,179	$61,220	$5,032,304
2027	$52,569	$6,984	$59,553	$5,091,857
2028	$51,137	$6,794	$57,931	$5,149,788
2029	$49,744	$6,609	$56,353	$5,206,140
2030	$48,389	$6,429	$54,818	$5,260,958
2031	$47,071	$6,253	$53,325	$5,314,283
2032	$45,789	$6,083	$51,872	$5,366,155
2033	$44,542	$5,917	$50,459	$5,416,615
2034	$43,329	$5,756	$389,085	$5,805,700
2035	$42,149	$5,599	$47,748	$5,853,448
2036	$41,001	$5,447	$46,448	$5,899,895
2037	$39,884	$5,299	$45,182	$5,945,078
2038	$38,798	$5,154	$43,952	$5,989,030
2039	$37,741	$5,014	$42,755	$6,031,784
2040	$36,713	$4,877	$41,590	$6,073,375
2041	$35,713	$4,744	$40,457	$6,113,832
2042	$34,740	$4,615	$39,355	$6,153,187
2043	$33,794	$4,490	$38,283	$6,191,471
2044	$32,873	$4,367	$37,241	$6,228,711
2045	$31,978	$4,248	$36,226	$6,264,938
2046	$31,107	$4,133	$35,240	$6,300,178
2047	$30,260	$4,020	$34,280	$6,334,457
2048	$29,436	$3,911	$33,346	$6,367,804
2049	$28,634	$3,804	$32,438	$6,400,241
2050	$27,854	$3,700	$31,554	$6,431,796
2051	$27,095	$3,600	$30,695	$6,462,491

Table 10.4 Conventional HVAC Costs-Optimistic Case

Year	Gas	Electricity	Maintenance	Annual	Cumulative
2014	$81,507	$20,432	$20,000	$121,939	$476,939
2015	$80,334	$20,138	$19,712	$120,184	$597,122
2016	$79,178	$19,848	$19,429	$118,454	$715,577
2017	$78,039	$19,562	$19,149	$116,750	$832,327
2018	$76,916	$19,281	$18,873	$115,070	$947,396
2019	$75,809	$19,003	$18,602	$113,414	$1,060,810
2020	$74,718	$18,730	$18,334	$111,782	$1,172,592
2021	$73,643	$18,460	$18,070	$110,173	$1,282,766
2022	$72,583	$18,195	$17,810	$108,588	$1,391,354
2023	$71,539	$17,933	$17,554	$107,025	$1,498,379
2024	$70,509	$17,675	$17,301	$105,485	$1,603,865
2025	$69,495	$17,420	$17,052	$103,967	$1,707,832
2026	$68,495	$17,170	$16,807	$102,471	$1,810,304
2027	$67,509	$16,923	$16,565	$100,997	$1,911,301
2028	$66,537	$16,679	$16,327	$99,544	$2,010,844
2029	$65,580	$16,439	$16,092	$98,111	$2,108,955
2030	$64,636	$16,203	$15,860	$96,699	$2,205,654
2031	$63,706	$15,969	$15,632	$95,308	$2,300,962
2032	$62,789	$15,740	$15,407	$93,936	$2,394,898
2033	$61,886	$15,513	$15,185	$92,585	$2,487,483
2034	$60,995	$15,290	$14,967	$421,252	$2,908,735
2035	$60,118	$15,070	$14,752	$89,939	$2,998,674
2036	$59,253	$14,853	$14,539	$88,645	$3,087,319
2037	$58,400	$14,639	$14,330	$87,369	$3,174,689
2038	$57,560	$14,429	$14,124	$86,112	$3,260,801
2039	$56,731	$14,221	$13,921	$84,873	$3,345,674
2040	$55,915	$14,016	$13,720	$83,652	$3,429,326
2041	$55,110	$13,815	$13,523	$82,448	$3,511,774
2042	$54,317	$13,616	$13,328	$81,262	$3,593,035
2043	$53,536	$13,420	$13,136	$80,092	$3,673,127
2044	$52,765	$13,227	$12,947	$78,940	$3,752,067
2045	$52,006	$13,037	$12,761	$77,804	$3,829,871
2046	$51,258	$12,849	$12,578	$76,684	$3,906,555
2047	$50,520	$12,664	$12,397	$75,581	$3,982,135
2048	$49,793	$12,482	$12,218	$74,493	$4,056,628
2049	$49,077	$12,302	$12,042	$73,421	$4,130,050
2050	$48,370	$12,125	$11,869	$72,365	$4,202,414
2051	$47,674	$11,951	$11,698	$71,323	$4,273,737

Table 10.5 Conventional HVAC Costs-Nominal Case

Year	Gas	Electricity	Maintenance	Annual	Cumulative
2014	$81,507	$20,432	$20,000	$121,939	$476,939
2015	$79,971	$20,047	$19,623	$119,641	$596,580
2016	$78,465	$19,669	$19,254	$117,388	$713,967
2017	$76,987	$19,299	$18,891	$115,176	$829,144
2018	$75,536	$18,935	$18,535	$113,006	$942,150
2019	$74,113	$18,578	$18,186	$110,878	$1,053,028
2020	$72,717	$18,228	$17,843	$108,789	$1,161,817
2021	$71,347	$17,885	$17,507	$106,739	$1,268,556
2022	$70,003	$17,548	$17,177	$104,729	$1,373,285
2023	$68,685	$17,217	$16,854	$102,756	$1,476,041
2024	$67,391	$16,893	$16,536	$100,820	$1,576,861
2025	$66,121	$16,575	$16,225	$98,921	$1,675,781
2026	$64,876	$16,263	$15,919	$97,057	$1,772,839
2027	$63,653	$15,956	$15,619	$95,229	$1,868,067
2028	$62,454	$15,656	$15,325	$93,435	$1,961,502
2029	$61,278	$15,361	$15,036	$91,675	$2,053,177
2030	$60,123	$15,071	$14,753	$89,948	$2,143,125
2031	$58,991	$14,787	$14,475	$88,253	$2,231,378
2032	$57,880	$14,509	$14,202	$86,591	$2,317,969
2033	$56,789	$14,236	$13,935	$84,960	$2,402,928
2034	$55,719	$13,967	$13,672	$413,359	$2,816,287
2035	$54,670	$13,704	$13,415	$81,789	$2,898,076
2036	$53,640	$13,446	$13,162	$80,248	$2,978,324
2037	$52,629	$13,193	$12,914	$78,736	$3,057,060
2038	$51,638	$12,944	$12,671	$77,253	$3,134,313
2039	$50,665	$12,700	$12,432	$75,798	$3,210,111
2040	$49,711	$12,461	$12,198	$74,370	$3,284,480
2041	$48,774	$12,226	$11,968	$72,969	$3,357,449
2042	$47,855	$11,996	$11,743	$71,594	$3,429,043
2043	$46,954	$11,770	$11,521	$70,245	$3,499,289
2044	$46,069	$11,548	$11,304	$68,922	$3,568,211
2045	$45,201	$11,331	$11,091	$67,624	$3,635,834
2046	$44,350	$11,117	$10,883	$66,350	$3,702,184
2047	$43,514	$10,908	$10,677	$65,100	$3,767,284
2048	$42,695	$10,702	$10,476	$63,874	$3,831,158
2049	$41,890	$10,501	$10,279	$62,670	$3,893,828
2050	$41,101	$10,303	$10,085	$61,490	$3,955,318
2051	$40,327	$10,109	$9,895	$60,331	$4,015,649

Table 10.6 Conventional HVAC Costs- Pessimistic Case

Year	Gas	Electricity	Maintenance	Annual	Cumulative
2014	$81,507	$20,432	$20,000	$121,939	$476,939
2015	$79,287	$19,875	$19,455	$118,617	$595,556
2016	$77,127	$19,334	$18,925	$115,386	$710,942
2017	$75,027	$18,807	$18,410	$112,244	$823,186
2018	$72,983	$18,295	$17,908	$109,186	$932,372
2019	$70,995	$17,797	$17,421	$106,212	$1,038,585
2020	$69,061	$17,312	$16,946	$103,319	$1,141,904
2021	$67,180	$16,840	$16,485	$100,505	$1,242,409
2022	$65,351	$16,382	$16,036	$97,768	$1,340,177
2023	$63,571	$15,935	$15,599	$95,105	$1,435,282
2024	$61,839	$15,501	$15,174	$92,514	$1,527,797
2025	$60,155	$15,079	$14,761	$89,995	$1,617,791
2026	$58,516	$14,669	$14,359	$87,543	$1,705,335
2027	$56,922	$14,269	$13,968	$85,159	$1,790,494
2028	$55,372	$13,880	$13,587	$82,839	$1,873,333
2029	$53,864	$13,502	$13,217	$80,583	$1,953,916
2030	$52,397	$13,134	$12,857	$78,388	$2,032,305
2031	$50,970	$12,777	$12,507	$76,253	$2,108,558
2032	$49,581	$12,429	$12,166	$74,176	$2,182,734
2033	$48,231	$12,090	$11,835	$72,156	$2,254,890
2034	$46,917	$11,761	$11,512	$400,191	$2,655,080
2035	$45,639	$11,441	$11,199	$68,279	$2,723,359
2036	$44,396	$11,129	$10,894	$66,419	$2,789,778
2037	$43,187	$10,826	$10,597	$64,610	$2,854,388
2038	$42,011	$10,531	$10,308	$62,850	$2,917,238
2039	$40,866	$10,244	$10,028	$61,138	$2,978,377
2040	$39,753	$9,965	$9,755	$59,473	$3,037,850
2041	$38,671	$9,694	$9,489	$57,853	$3,095,703
2042	$37,617	$9,430	$9,230	$56,277	$3,151,980
2043	$36,593	$9,173	$8,979	$54,745	$3,206,725
2044	$35,596	$8,923	$8,734	$53,253	$3,259,978
2045	$34,626	$8,680	$8,497	$51,803	$3,311,781
2046	$33,683	$8,444	$8,265	$50,392	$3,362,173
2047	$32,766	$8,214	$8,040	$49,019	$3,411,192
2048	$31,873	$7,990	$7,821	$47,684	$3,458,877
2049	$31,005	$7,772	$7,608	$46,385	$3,505,262
2050	$30,161	$7,561	$7,401	$45,122	$3,550,384
2051	$29,339	$7,355	$7,199	$43,893	$3,594,277

Table 10.7 Conventional HVAC Costs with High Natural Gas Price-Optimistic Case

Year	Gas	Electricity	Maintenance	Annual	Cumulative
2014	$149,280	$20,432	$20,000	$189,712	$544,712
2015	$151,459	$20,138	$19,712	$191,309	$736,021
2016	$153,671	$19,848	$19,429	$192,947	$928,968
2017	$155,914	$19,562	$19,149	$194,626	$1,123,594
2018	$158,191	$19,281	$18,873	$196,345	$1,319,939
2019	$160,500	$19,003	$18,602	$198,105	$1,518,044
2020	$162,844	$18,730	$18,334	$199,908	$1,717,952
2021	$165,221	$18,460	$18,070	$201,752	$1,919,704
2022	$167,633	$18,195	$17,810	$203,638	$2,123,342
2023	$170,081	$17,933	$17,554	$205,568	$2,328,910
2024	$172,564	$17,675	$17,301	$207,540	$2,536,450
2025	$175,083	$17,420	$17,052	$209,556	$2,746,006
2026	$177,640	$17,170	$16,807	$211,617	$2,957,623
2027	$180,233	$16,923	$16,565	$213,721	$3,171,344
2028	$182,865	$16,679	$16,327	$215,871	$3,387,214
2029	$185,534	$16,439	$16,092	$218,066	$3,605,280
2030	$188,243	$16,203	$15,860	$220,306	$3,825,586
2031	$190,992	$15,969	$15,632	$222,593	$4,048,179
2032	$193,780	$15,740	$15,407	$224,927	$4,273,106
2033	$196,609	$15,513	$15,185	$227,308	$4,500,414
2034	$199,480	$15,290	$14,967	$559,737	$5,060,151
2035	$202,392	$15,070	$14,752	$232,214	$5,292,364
2036	$205,347	$14,853	$14,539	$234,739	$5,527,104
2037	$208,345	$14,639	$14,330	$237,315	$5,764,418
2038	$211,387	$14,429	$14,124	$239,940	$6,004,358
2039	$214,473	$14,221	$13,921	$242,615	$6,246,973
2040	$217,605	$14,016	$13,720	$245,341	$6,492,314
2041	$220,782	$13,815	$13,523	$248,119	$6,740,433
2042	$224,005	$13,616	$13,328	$250,949	$6,991,382
2043	$227,275	$13,420	$13,136	$253,832	$7,245,214
2044	$230,594	$13,227	$12,947	$256,768	$7,501,982
2045	$233,960	$13,037	$12,761	$259,758	$7,761,740
2046	$237,376	$12,849	$12,578	$262,803	$8,024,543
2047	$240,842	$12,664	$12,397	$265,902	$8,290,445
2048	$244,358	$12,482	$12,218	$269,058	$8,559,503
2049	$247,926	$12,302	$12,042	$272,270	$8,831,774
2050	$251,545	$12,125	$11,869	$275,540	$9,107,313
2051	$255,218	$11,951	$11,698	$278,867	$9,386,180

Table 10.8 Conventional HVAC Costs with High Natural Gas Prices- Nominal Case

Year	Gas	Electricity	Maintenance	Annual	Cumulative
2014	$149,280	$20,432	$20,000	$189,712	$544,712
2015	$152,146	$20,047	$19,623	$191,816	$736,528
2016	$155,067	$19,669	$19,254	$193,990	$930,518
2017	$158,045	$19,299	$18,891	$196,234	$1,126,752
2018	$161,079	$18,935	$18,535	$198,549	$1,325,301
2019	$164,172	$18,578	$18,186	$200,936	$1,526,237
2020	$167,324	$18,228	$17,843	$203,396	$1,729,633
2021	$170,537	$17,885	$17,507	$205,929	$1,935,561
2022	$173,811	$17,548	$17,177	$208,536	$2,144,097
2023	$177,148	$17,217	$16,854	$211,219	$2,355,317
2024	$180,549	$16,893	$16,536	$213,979	$2,569,295
2025	$184,016	$16,575	$16,225	$216,815	$2,786,111
2026	$187,549	$16,263	$15,919	$219,731	$3,005,841
2027	$191,150	$15,956	$15,619	$222,725	$3,228,566
2028	$194,820	$15,656	$15,325	$225,801	$3,454,367
2029	$198,560	$15,361	$15,036	$228,957	$3,683,324
2030	$202,373	$15,071	$14,753	$232,197	$3,915,522
2031	$206,258	$14,787	$14,475	$235,521	$4,151,042
2032	$210,219	$14,509	$14,202	$238,930	$4,389,972
2033	$214,255	$14,236	$13,935	$242,425	$4,632,397
2034	$218,368	$13,967	$13,672	$576,008	$5,208,406
2035	$222,561	$13,704	$13,415	$249,680	$5,458,086
2036	$226,834	$13,446	$13,162	$253,442	$5,711,528
2037	$231,190	$13,193	$12,914	$257,296	$5,968,825
2038	$235,628	$12,944	$12,671	$261,243	$6,230,068
2039	$240,152	$12,700	$12,432	$265,285	$6,495,353
2040	$244,763	$12,461	$12,198	$269,422	$6,764,775
2041	$249,463	$12,226	$11,968	$273,657	$7,038,433
2042	$254,253	$11,996	$11,743	$277,991	$7,316,424
2043	$259,134	$11,770	$11,521	$282,426	$7,598,850
2044	$264,110	$11,548	$11,304	$286,962	$7,885,812
2045	$269,180	$11,331	$11,091	$291,603	$8,177,415
2046	$274,349	$11,117	$10,883	$296,349	$8,473,763
2047	$279,616	$10,908	$10,677	$301,202	$8,774,965
2048	$284,985	$10,702	$10,476	$306,164	$9,081,129
2049	$290,457	$10,501	$10,279	$311,236	$9,392,365
2050	$296,033	$10,303	$10,085	$316,422	$9,708,787
2051	$301,717	$10,109	$9,895	$321,721	$10,030,508

Table 10.9 Conventional HVAC Costs with High Natural Gas Prices- Pessimistic Case

Year	Gas	Electricity	Maintenance	Annual	Cumulative
2014	$149,280	$20,432	$20,000	$189,712	$544,712
2015	$150,624	$19,875	$19,455	$189,954	$734,666
2016	$151,979	$19,334	$18,925	$190,238	$924,904
2017	$153,347	$18,807	$18,410	$190,564	$1,115,468
2018	$154,727	$18,295	$17,908	$190,930	$1,306,398
2019	$156,120	$17,797	$17,421	$191,337	$1,497,735
2020	$157,525	$17,312	$16,946	$191,783	$1,689,518
2021	$158,942	$16,840	$16,485	$192,267	$1,881,785
2022	$160,373	$16,382	$16,036	$192,790	$2,074,575
2023	$161,816	$15,935	$15,599	$193,351	$2,267,926
2024	$163,273	$15,501	$15,174	$193,948	$2,461,874
2025	$164,742	$15,079	$14,761	$194,582	$2,656,456
2026	$166,225	$14,669	$14,359	$195,252	$2,851,708
2027	$167,721	$14,269	$13,968	$195,957	$3,047,665
2028	$169,230	$13,880	$13,587	$196,698	$3,244,363
2029	$170,753	$13,502	$13,217	$197,473	$3,441,835
2030	$172,290	$13,134	$12,857	$198,282	$3,640,117
2031	$173,841	$12,777	$12,507	$199,124	$3,839,241
2032	$175,405	$12,429	$12,166	$200,000	$4,039,241
2033	$176,984	$12,090	$11,835	$200,909	$4,240,150
2034	$178,577	$11,761	$11,512	$531,850	$4,772,000
2035	$180,184	$11,441	$11,199	$202,823	$4,974,824
2036	$181,806	$11,129	$10,894	$203,828	$5,178,652
2037	$183,442	$10,826	$10,597	$204,865	$5,383,517
2038	$185,093	$10,531	$10,308	$205,932	$5,589,449
2039	$186,759	$10,244	$10,028	$207,031	$5,796,480
2040	$188,440	$9,965	$9,755	$208,159	$6,004,639
2041	$190,135	$9,694	$9,489	$209,318	$6,213,957
2042	$191,847	$9,430	$9,230	$210,507	$6,424,464
2043	$193,573	$9,173	$8,979	$211,725	$6,636,189
2044	$195,315	$8,923	$8,734	$212,973	$6,849,162
2045	$197,073	$8,680	$8,497	$214,250	$7,063,412
2046	$198,847	$8,444	$8,265	$215,556	$7,278,967
2047	$200,637	$8,214	$8,040	$216,890	$7,495,857
2048	$202,442	$7,990	$7,821	$218,253	$7,714,111
2049	$204,264	$7,772	$7,608	$219,645	$7,933,755
2050	$206,103	$7,561	$7,401	$221,064	$8,154,819
2051	$207,958	$7,355	$7,199	$222,511	$8,377,331

Table 10.10 Payback Period-Nominal

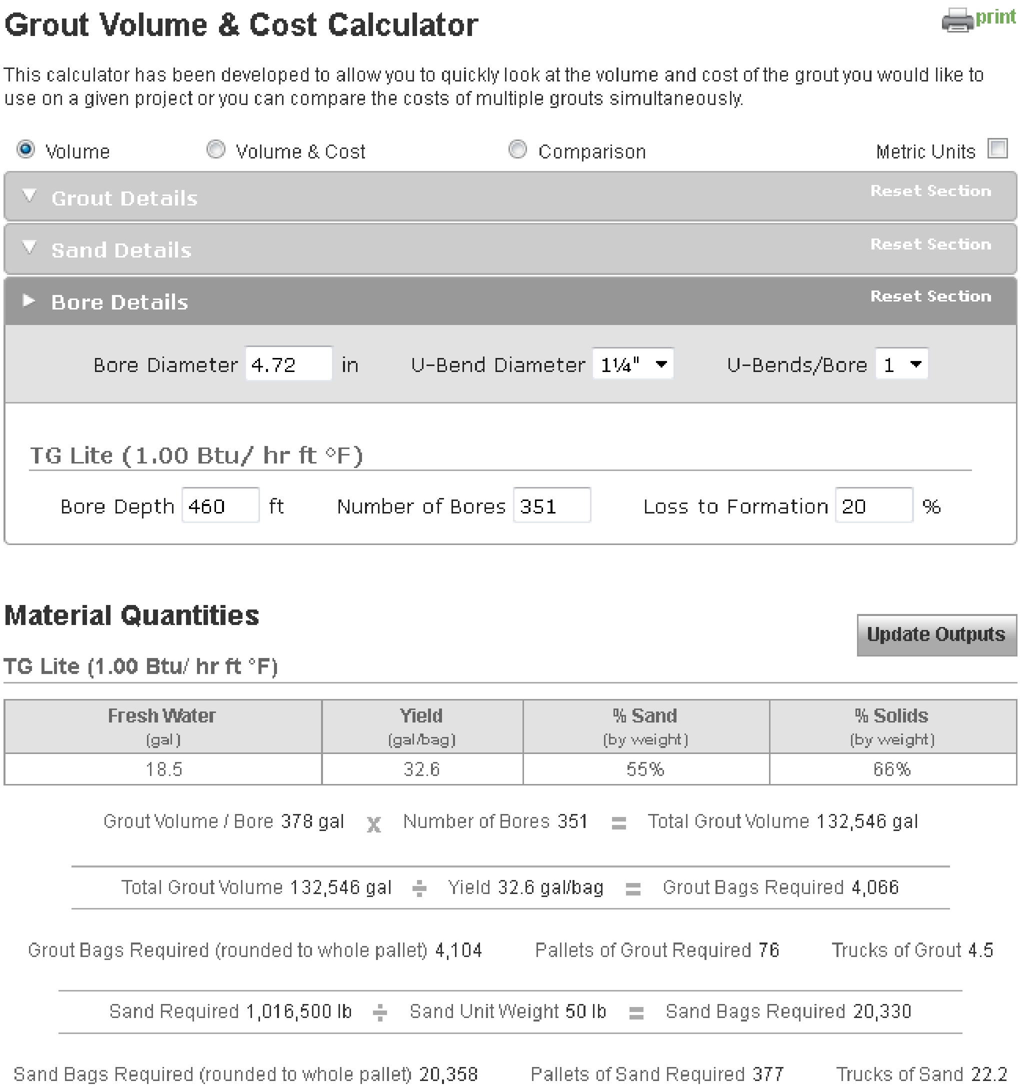
Nominal Payback Period			
Year	Savings	Cost	Total
0		($4,088,000)	($4,088,000)
1	$104,439		($3,983,561)
2	$107,263		($3,876,298)
3	$110,111		($3,766,187)
4	$112,981		($3,653,206)
5	$115,875		($3,537,331)
6	$118,794		($3,418,537)
7	$121,737		($3,296,800)
8	$124,706		($3,172,094)
9	$127,701		($3,044,392)
10	$130,724		($2,913,669)
11	$133,773		($2,779,896)
12	$136,851		($2,643,045)
13	$139,957		($2,503,088)
14	$143,093		($2,359,995)
15	$146,259		($2,213,736)
16	$149,455		($2,064,281)
17	$152,683		($1,911,598)
18	$155,943		($1,755,654)
19	$159,236		($1,596,418)
20	$162,562		($1,433,856)
21	$155,923		($1,277,933)
22	$169,318		($1,108,615)
23	$172,749		($935,866)
24	$176,216		($759,650)
25	$179,720		($579,929)
26	$183,262		($396,667)
27	$186,843		($209,824)
28	$190,462		($19,362)
29	$194,122		$174,760
30	$197,823		$372,583
31	$201,565		$574,147
32	$205,349		$779,496
33	$209,177		$988,673
34	$213,048		$1,201,721
35	$216,964		$1,418,685
36	$220,926		$1,639,611
37	$224,934		$1,864,545
38	$228,990		$2,093,535

Table 10.11 Payback Period- Optimistic

Optimistic Payback Period			
Year	Saving	Cost	Total
0		($4,088,000)	($4,088,000)
1	$104,439		($3,983,561)
2	$108,150		($3,875,412)
3	$111,900		($3,763,512)
4	$115,690		($3,647,822)
5	$119,522		($3,528,300)
6	$123,398		($3,404,902)
7	$127,318		($3,277,583)
8	$131,284		($3,146,299)
9	$135,298		($3,011,001)
10	$139,361		($2,871,640)
11	$143,474		($2,728,166)
12	$147,639		($2,580,527)
13	$151,857		($2,428,670)
14	$156,131		($2,272,539)
15	$160,460		($2,112,078)
16	$164,848		($1,947,230)
17	$169,296		($1,777,934)
18	$173,804		($1,604,130)
19	$178,376		($1,425,754)
20	$183,012		($1,242,742)
21	$177,714		($1,065,028)
22	$192,484		($872,544)
23	$197,324		($675,219)
24	$202,235		($472,984)
25	$207,220		($265,765)
26	$212,279		($53,486)
27	$217,415		$163,929
28	$222,629		$386,559
29	$227,925		$614,483
30	$233,302		$847,786
31	$238,764		$1,086,550
32	$244,313		$1,330,863
33	$249,949		$1,580,812
34	$255,677		$1,836,488
35	$261,496		$2,097,985
36	$267,410		$2,365,395
37	$273,421		$2,638,816
38	$279,531		$2,918,347

Table 10.12 Payback Period- Pessimistic

Pessimestic Pay back Period			
Year	**Saving**	**Cost**	**Total**
0		($4,088,000)	($4,088,000)
1	$104,439		($3,983,561)
2	$107,004		($3,876,558)
3	$109,547		($3,767,011)
4	$112,071		($3,654,940)
5	$114,575		($3,540,365)
6	$117,061		($3,423,303)
7	$119,530		($3,303,773)
8	$121,983		($3,181,790)
9	$124,420		($3,057,370)
10	$126,843		($2,930,528)
11	$129,252		($2,801,276)
12	$131,648		($2,669,628)
13	$134,032		($2,535,597)
14	$136,405		($2,399,192)
15	$138,767		($2,260,425)
16	$141,120		($2,119,305)
17	$143,464		($1,975,841)
18	$145,800		($1,830,042)
19	$148,128		($1,681,914)
20	$150,449		($1,531,465)
21	$142,765		($1,388,699)
22	$155,075		($1,233,624)
23	$157,381		($1,076,243)
24	$159,682		($916,561)
25	$161,980		($754,580)
26	$164,276		($590,305)
27	$166,569		($423,736)
28	$168,861		($254,875)
29	$171,151		($83,723)
30	$173,442		$89,718
31	$175,732		$265,450
32	$178,023		$443,474
33	$180,316		$623,790
34	$182,610		$806,400
35	$184,907		$991,307
36	$187,207		$1,178,514
37	$189,510		$1,368,023
38	$191,816		$1,559,840



Grout Volume & Cost Calculator

This calculator has been developed to allow you to quickly look at the volume and cost of the grout you would like to use on a given project or you can compare the costs of multiple grouts simultaneously.

● Volume ○ Volume & Cost ○ Comparison Metric Units ☐

▼ Grout Details

▼ Sand Details

► Bore Details

Bore Diameter 4.72 in U-Bend Diameter 1¼" U-Bends/Bore 1

TG Lite (1.00 Btu/ hr ft °F)

Bore Depth 460 ft Number of Bores 351 Loss to Formation 20 %

Material Quantities

TG Lite (1.00 Btu/ hr ft °F)

Fresh Water (gal)	Yield (gal/bag)	% Sand (by weight)	% Solids (by weight)
18.5	32.6	55%	66%

Grout Volume / Bore 378 gal x Number of Bores 351 = Total Grout Volume 132,546 gal

Total Grout Volume 132,546 gal ÷ Yield 32.6 gal/bag = Grout Bags Required 4,066

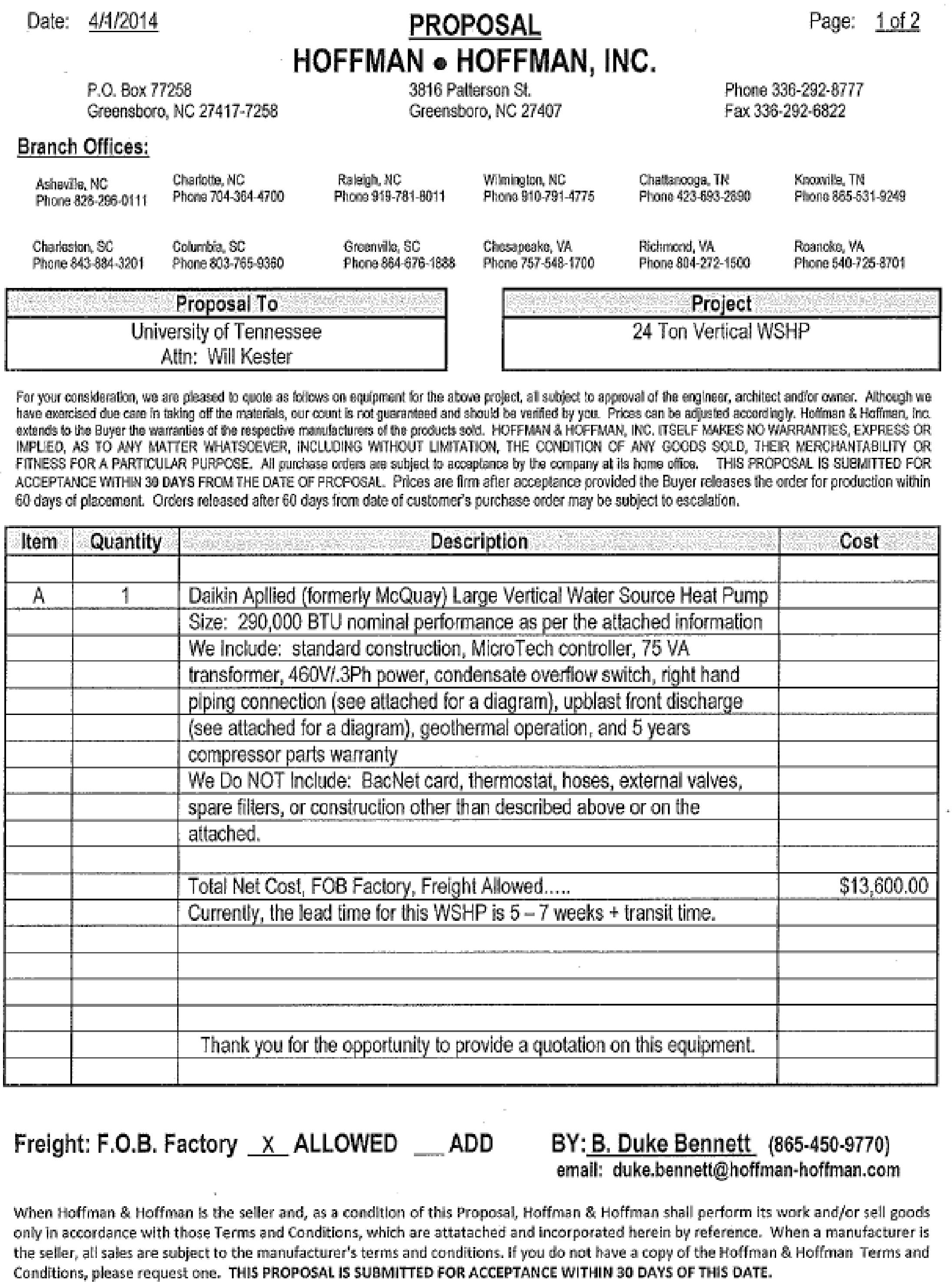
Grout Bags Required (rounded to whole pallet) 4,104 Pallets of Grout Required 76 Trucks of Grout 4.5

Sand Required 1,016,500 lb ÷ Sand Unit Weight 50 lb = Sand Bags Required 20,330

Sand Bags Required (rounded to whole pallet) 20,358 Pallets of Sand Required 377 Trucks of Sand 22.2

Figure 10.2 Grout Volume Calculator[11]

Figure 10.3 Heat Pump Quote[8]



Date: 4/1/2014

PROPOSAL

HOFFMAN • HOFFMAN, INC.

Page: 1 of 2

P.O. Box 77258
Greensboro, NC 27417-7258

3816 Patterson St.
Greensboro, NC 27407

Phone 336-292-8777
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Branch Offices:

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Phone 910-791-4775

Chattanooga, TN
Phone 423-693-2690

Knoxville, TN
Phone 865-531-9249

Charleston, SC
Phone 843-884-3201

Columbia, SC
Phone 803-765-9360

Greenville, SC
Phone 864-676-1888

Chesapeake, VA
Phone 757-548-1700

Richmond, VA
Phone 804-272-1500

Roanoke, VA
Phone 540-725-8701

Proposal To
University of Tennessee Attn: Will Kester

Project
24 Ton Vertical WSHP

For your consideration, we are pleased to quote as follows on equipment for the above project, all subject to approval of the engineer, architect and/or owner. Although we have exercised due care in taking off the materials, our count is not guaranteed and should be verified by you. Prices can be adjusted accordingly. Hoffman & Hoffman, Inc. extends to the Buyer the warranties of the respective manufacturers of the products sold. HOFFMAN & HOFFMAN, INC. ITSELF MAKES NO WARRANTIES, EXPRESS OR IMPLIED, AS TO ANY MATTER WHATSOEVER, INCLUDING WITHOUT LIMITATION, THE CONDITION OF ANY GOODS SOLD, THEIR MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. All purchase orders are subject to acceptance by the company at its home office. THIS PROPOSAL IS SUBMITTED FOR ACCEPTANCE WITHIN 30 DAYS FROM THE DATE OF PROPOSAL. Prices are firm after acceptance provided the Buyer releases the order for production within 60 days of placement. Orders released after 60 days from date of customer's purchase order may be subject to escalation.

Item	Quantity	Description	Cost
A	1	Daikin Apllied (formerly McQuay) Large Vertical Water Source Heat Pump	
		Size: 290,000 BTU nominal performance as per the attached information	
		We Include: standard construction, MicroTech controller, 75 VA	
		transformer, 460V/.3Ph power, condensate overflow switch, right hand	
		piping connection (see attached for a diagram), upblast front discharge	
		(see attached for a diagram), geothermal operation, and 5 years	
		compressor parts warranty	
		We Do NOT Include: BacNet card, thermostat, hoses, external valves,	
		spare filters, or construction other than described above or on the	
		attached.	
		Total Net Cost, FOB Factory, Freight Allowed…..	$13,600.00
		Currently, the lead time for this WSHP is 5 – 7 weeks + transit time.	
		Thank you for the opportunity to provide a quotation on this equipment.	

Freight: F.O.B. Factory _X_ ALLOWED ___ ADD

BY: B. Duke Bennett (865-450-9770)
email: duke.bennett@hoffman-hoffman.com

When Hoffman & Hoffman is the seller and, as a condition of this Proposal, Hoffman & Hoffman shall perform its work and/or sell goods only in accordance with those Terms and Conditions, which are attatached and incorporated herein by reference. When a manufacturer is the seller, all sales are subject to the manufacturer's terms and conditions. If you do not have a copy of the Hoffman & Hoffman Terms and Conditions, please request one. **THIS PROPOSAL IS SUBMITTED FOR ACCEPTANCE WITHIN 30 DAYS OF THIS DATE.**

ENFINITY™ Heat Pump

DAIKIN

Job Information	*Technical Data Sheet*
Job Name	UT Large Vertical WSHP
Date	4/1/2014
Submitted By	Duke Bennett
Software Version	09.00
Unit Tag	WSHP 001

Unit Overview

Model Number	Voltage V/Hz/Phase	Air Flow CFM	Fluid Flow gpm	Cooling Capacity Btu/hr	Cooling Efficiency EER	Heating Capacity Btu/hr	Heating Efficiency COP
WLVW1290	460/60/3	9670	72.50	298985	9.82	415708	3.75

Unit

Model Number:	WLVW1290
Unit Type:	R-410A, Large Vertical, Geothermal Range
Unit Construction:	Standard Construction
Approval:	ETL, CETL

Refrigerant Type	Refrigerant Weight
R-410A	220.0 oz

Unit Performance

Air & Water Flow

Airflow	Total External Static Pressure	Fluid Flow	Fluid Type	Fluid Pressure Drop
9670 CFM	0.83 inH₂O	72.50 gpm / 3.00 gpm/ton	Water	19.07 ft H₂O

Cooling Performance

Fluid Temperature		Air Temperature				Capacity		Heat of Rejection	EER
Entering °F	Leaving °F	Entering		Leaving		Total Btu/hr	Sensible Btu/hr	Btu/hr	
		Dry Bulb °F	Wet Bulb °F	Dry Bulb °F	Wet Bulb °F				
85.0	96.1	80.0	67.0	59.2	56.8	298985	213548	402865	9.82

Heating Performance

Fluid Temperature		Air Temperature		Capacity	Heat of Absorption	COP
Entering °F	Leaving °F	Entering Dry Bulb °F	Leaving Dry Bulb °F	Total Btu/hr	Btu/hr	
70.0	61.6	70.0	109.9	415708	304979	3.75

Electrical

Unit Voltage	Minimum Voltage	Total Unit MCA	Total Unit Full Load Current
460/60/3	416 V	61.60 A	53.70 A

Compressor RLA	Compressor LRA	Motor FLA	Maximum Recommended Fuse Size / HACR Breaker Size
23.1 A	150.0 A	9.70 A	80.0 A

ENFINITY™ Heat Pump

Physical

Unit

Length	Height	Width	Weight		Connections	
			Shipping	Operating	Water, FPT	Condensate, FPT
30.00 in	67.00 in	80.38 in	1297 lb	1257 lb	1.500 in	1.250 in

Cabinet

Construction Type	Piping Hand	Condensate Drain Pan
Standard 1/2" Fiberglass Insulation	Right Side Pipe Connections	Galvanized Steel

Fan				Controls
Type	Motor		Drive	Type
	Type	Horsepower	Type	
DWDI FC	Standard	7.500 hp	Belt	Microtech III Base Controller

Airstream

Air		Filter
Discharge	Return	(Quantity) Height x Width x Depth
Upblast Front	None	(6) 25 in x 20 in x 1 in

Options

Heating

Heat Exchanger: Copper Inner - Steel Outer Tube

Controls

Control Transformer: 75VA Control Transformer

Condensate Overflow: Standard - Condensate Overflow Sensor

Warranty

Unit Warranty: Extended 4 years Parts (Refrigerant Circuit)

AHRI Certification

All equipment is rated and certified in accordance with AHRI / ISO 13256-1 and tested, investigated, and determined to comply with the requirements of the standards for Heating and Cooling Equipment UL-1995 for the United States and CAN/CSA-C22.2 NO.236 for Canada.

Certified Drawing	LVC-LVW-290 Specs
The Water Source Heat Pump product represented on this document will conform to the drawings and specifications set out below, in accordance with the express, written Limited Warranty. Purchaser's acceptance of this drawing certifies that the conforming equipment meets the order specifications. No changes may be made to this document without the prior, express, written authorization of the manufacturer.	Group: **WSHP** Type: **Large Vertical** Date: **October 2013**

Daikin Enfinity™ Large Vertical WSHP

Models LVC/LVW – Unit Size 290

Cabinet - Heavy gauge G-60 galvanized steel.

Fan Section - Three DWDI forward curved fans, solid steel shaft mounted in ball bearings. Motor to be three phase, Open- Drip Proof (ODP) type with variable pitch sheave and adjustable base.

Insulation - All interior framework and panels are lined with 1/2" thick, 1½ lb. dual-density fiberglass insulation. ~~Optional (IAQ) closed-cell foam insulation.~~

Filters - Standard 1" factory-installed filter rack with 1" throwaway filter. Optional 2" filter rack with duct collar for field -installation.

Refrigerant Circuit - All units have a dual refrigerant circuit with scroll compressors, thermal expansion valve, coaxial heat exchanger, finned tube airside coil, reversing valve and service valves.

Electrical - The control enclosure includes fan relay, compressor relays, 24-volt control transformer, reversing valve solenoid coil, lockout circuits and control circuit board.

Safety Controls - Low and high refrigerant pressure switches and low refrigerant suction temperature (freezestat) sensor.

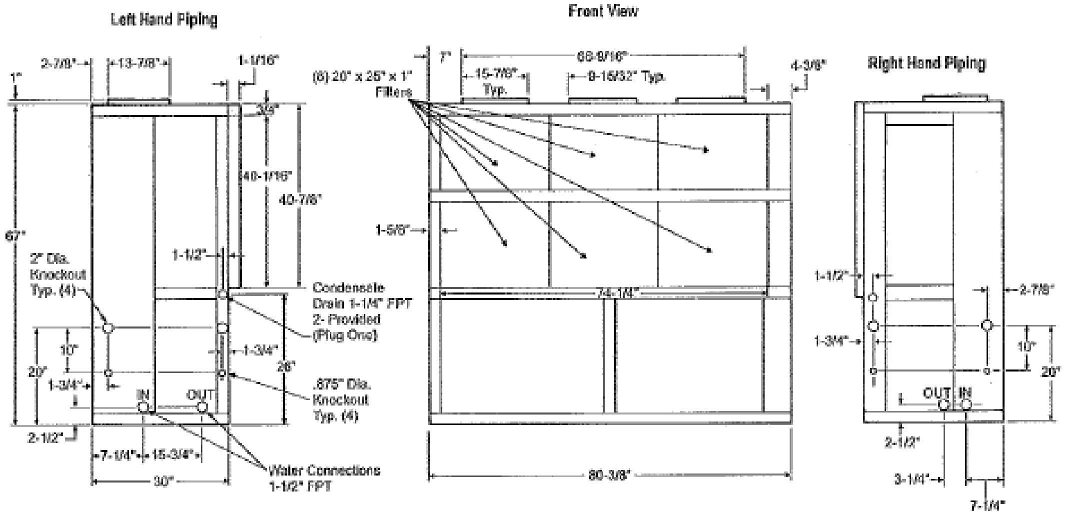
Schrader Connections - Four Schrader valves are located inside the end access panel – one on the low side and one on the high side of the refrigeration circuit – for charging and servicing. All valves are 7/16" SAE fittings.

MicroTech® III Controllers – Designed for flexibility, the control board is used in standalone applications in conjunction with the I/O expansion module for control of the second refrigerant circuit. ~~A separate LonWorks® or BACnet® communication module can be easily snapped onto the Microtech III board to allow communication with a building automation system.~~ The control system accomodates the use of a two-stage heat/two-stage cool 7-day programmable or non-programmable wall-mounted thermostat, offered as a field-installed option.

LED Annunciator – External LED status lights display fault conditions to provide easy troubleshooting and diagnosis, visible without removing the access panel.

External Pipe Connections – Supply and return pipe connections located outside the cabinet make pipe connections easy without removing access panels.

Dimensional Data



Overall Unit Dimensions: 80⅜" W × 67" H × 30" D

Notes:

1. The hand of unit is determined by looking at the return air (filter) side. The piping and electrical connections are always made on the "hand" side of the unit. The return air (filter) side is considered the "front" of the unit.
2. The fan motor is always located at the piping/electrical connection (hand) side of the unit.

DAIKIN