Updating and Debugging the Federal Renewable Energy Screening Assistant: Ground Coupled Heat Pump Algorithm

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Abstract

Updating and debugging the Federal Renewable Energy Screening Assistant: Ground-Coupled Heat Pump Algorithm. ZACHARY JAMES(University of Maryland, College Park, MD 20742) T. Brown (National Renewable Energy Laboratory, Golden, Colorado 80401).

The federal government is the largest consumer of energy in the United States. The Federal Energy Management Program, (FEMP), was created to help reduce federal energy consumption. FEMP works with other federal agencies, to evaluate, plan and finance renewable energy projects within the federal sector to reduce energy spending. To aid in achieving these goals the Federal Renewable Energy Screening Assistant, or FRESA, has been developed. FRESA is a computer program that allows facility managers to screen their building for renewable energy technology implementation. This gives them useful information on where to direct their efforts. FRESA was originally written in 1996 and the program is in need of some updating and debugging. One of the renewable technologies that FRESA screens for is a ground-coupled heat pump, (GCHP.) To determine if a GCHP is cost-effective, FRESA performs a series of calculations to return a life cycle cost analysis of a GCHP project. A literature search, an evaluation of the current calculation methods, and a sample screening of a current FEMP project have been done in order to determine which parts of the program need updating or debugging. The results of this research are recommendations as to what needs to be changed in the program to make it a more effective tool.

Category (circle one): Physical - Life – Engineering

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Introduction

The U.S. Department of Energy's Federal Energy Management Program (FEMP) acts as a consultant to government agencies to assist them in reducing energy and water consumption. FEMP accomplishes this by helping to evaluate, plan, and finance projects that reduce traditional energy use and increase the implementation of renewable energy in federal buildings. The first step FEMP takes in energy-saving projects is the screening of renewable energy technologies.

To aid government agencies in this process, FEMP created the Federal Renewable Energy Screening Assistant, or FRESA. This computer program allows federal building managers to evaluate the use of different renewable energy resources based on basic inputs about the building's location, size, and energy use. Some of the renewable energy technologies the program considers are ground-coupled heat pumps, solar water heating, photovoltaics, wind power, daylighting, and biopower. The program was first introduced in 1996 and has been modified several times since.

FRESA takes the user's input and calculates the system size, initial cost, and energy savings. FRESA uses these to perform a life-cycle cost analysis of a particular technology. In the years since the program's development, great advancements and more accurate methods for design of renewable technology systems have caused some of the calculations in the FRESA program to become outdated. With use of the program, it has also become clear that there are some errors in the calculations, which should be fixed. The focus is to make FRESA as accurate and informative as possible without affecting its ease of use.

One system that FRESA can evaluate the initial feasibility of is a ground-coupled heat pump. A heat pump transfers heat from a low-temperature area to a high-temperature area. In application to building heating, the heat pump takes heat from outside air and transfers it to the interior of the building. In summer, the heat pump reverses its operation, and takes the heat from the building and expels it into the outdoor air. In the heating scenario, a compressor is used to liquefy the heat transfer medium. Then the medium enters an exchanger, which is usually a system of pipes exposed to the outdoor air. The compressed medium can then easily absorb the heat from the outside air, causing it to evaporate and expand. The evaporated fluid transfer medium is then compressed and liquefied. This process gives off heat to a condenser located inside the building, and this heat is then circulated throughout the building using a ventilation system. In summer the operation of the system is reversed and the expanded medium absorbs the air inside the building and then transfers it to the exterior (Ingersoll, 1954).

A ground-coupled heat pump consists of a buried-loop heat exchanger, a heating and cooling ventilation system, and the actual heat pump itself (Figure 1). The buried loop allows a heat-conducting medium to flow through the soil. This fluid either releases or absorbs heat from the soil, depending on the season. The heat pump compresses or expands the fluid being used, to allow for greater heat transfer in the heat exchanger loops. This allows for the maximum exchange of the heat from the soil into the building or from the building into the soil. The ventilation system then distributes the change in temperature around the building by moving air over coils that contain fluid that's been through the ground loop (Kavanaugh, 1997).

Ground-coupled heat pumps were originally developed for use in residential applications, where the ground heat exchanger was small, and therefore easy to install. With more research and better installation techniques, these systems are now being implemented on much larger scales in commercial applications (ASHRAE, 1995).

The ground-coupled system allows for the transfer of heat out of the building and into the soil in summer. In winter it reverses itself and transfers heat from the earth into the building.

This technology can be very effective if installed correctly. Soil temperature extremes are much less than the air temperature extremes during the course of the year, and this allows the heat pump to operate much more efficiently (Figure 2). This results in a decrease in the energy required to heat and cool the building when compared with a conventional air-source heat pump (Kavanaugh, 1997). In addition, ground-coupled heat pumps are quieter, and usually more aesthetic than a conventional above ground air-source system. The ground-coupled heat pump system does not use an outdoor heat exchanger, just the one below the ground, so all of the above-ground equipment associated with a conventional system is eliminated (Oklahoma State University, 1988).

Methods and Materials

The first step in editing the program was to do some reading of background material on FRESA and ground-coupled heat pumps. Next, the program had to be looked over to determine the current methods that FRESA uses. FRESA has been changed and edited by many different people, so it is difficult to figure out what the program is doing in some places. The code has not been commented, to allow for easy understanding of the calculations. In addition, FRESA was used to screen a possible project at the Eastern Neck National Wildlife Refuge Visitors Center, which FEMP is evaluating, to pinpoint FRESA’s strengths and weaknesses. After the areas that needed updating or fixing had been found, a literature search was conducted to find the most recent methods of performing this type of calculation and recommendations for updating the program were made.

Results

FRESA begins its ground-coupled calculation by doing its own estimation of the building's annual energy loads. There are three methods of estimating energy loads. All of these methods are explained in detail in the American Society for Heating, Refrigerating and Air-conditioning Engineer's, or ASHRAE's, Fundamentals (1997). The degree-day method is the simplest but also the least accurate. The bin method is also concise and can be modified to account for as much accuracy as is required. The third option is the hour-by-hour method, which is very complex and demanding (ASHRAE, 1993).

FRESA currently uses a bin method, combined with several nomographs which are published in the *Architect's and Engineer's Guide to Energy Conservation in Existing Buildings* (Department of Energy, 1980). The bin method simulates the energy loads for every one-degree temperature range, and then sums them, based on the number of hours in a given year at each temperature. This summing of all the individual loads gives an accurate estimate of the annual heating and cooling loads for the building.

The modified bin method, currently used by FRESA, calculates the load at several one-degree outdoor temperature intervals and then multiplies that load by the number of hours in a year the building experiences that temperature interval. A normal distribution of temperatures is assumed for the building. This is used, in combination with curve fits of temperature patterns for five different geographical locations, in order to come up with the building's temperature distribution. It is also assumed that if the outside temperature is between 64ºF and 78ºF, then there is no need for heating or cooling. For each one-degree temperature interval, the program calculates the heating load if the temperature is below 64ºF, or the cooling load for temperatures above 78ºF. This is done by summing all the heat loads, such as interior lighting, building occupancy, ventilation requirements, outside temperature, infiltration, and fenestration.

The bin method is ideal for the purposes of FRESA. The inputs required for the bin method are easy to acquire and straightforward. It also produces very accurate results without excessive complexity. The framework for an accurate calculation of loads is in place; FRESA just needs some editing to remove all the errors in the written code.

The sample screening of the Eastern Neck National Wildlife Refuge was used to determine what was wrong with the load calculations. The results from the screening suggest that the load numbers FRESA is outputting are twice what would be expected. The heating and cooling loads were related as would be expected for this region with heating being the primary load. This indicates that the load calculations are working correctly except for double counting somewhere in the program.

The assumed values for the different building types that FRESA considers, for cooling load from active electricity, amount of hot water demand and fresh air ventilation requirements, are all taken from the Energy 10 program. This program has also been developed under the Department of Energy. Energy 10 has been updated recently so the assumption is that these values are current.

Also, the balance temperature range noted earlier (64ºF to 78ºF) is a bit generous. Studies suggest the range be from 62ºF to 67ºF, which is a much more reasonable range of only 5ºF (Oklahoma State, 1988).

Once FRESA has all of the loads calculated, the heat pump for the ground-coupled system may be sized. For most climates within the United States, the loads for heating far outweigh those for cooling. A decision must be made in order to find a compromise between oversizing to meet heating requirements or undersizing to meet cooling loads and supplementing the heating load with electric or furnace heating. One disadvantage of oversizing to meet cooling load is that the initial cost of the system is much higher due to longer piping length and a larger heat pump and circulation pump. Another negative is that, when the system is oversized for cooling, the heat pump cycles frequently, which results in insufficient moisture removal from the cooled air. The idea is to size the system for as much heating as possible without these two factors becoming an issue. FRESA sizes the heat pump for the system through an iterative process, which finds the best possible life cycle cost for the system. This is a complex method and this could be a factor in FRESA's outputs being inaccurate. Oklahoma State suggests oversizing the ground-coupled heat pump system by no more than 25 percent above the designed cooling load. A safe calculation for the size of the heat pump then would be 125 percent of the design cooling load rounded up to the nearest ton of refrigeration. This leads to the calculation for the ground heat exchanger length.

Currently FRESA uses the calculation methods found in the *Closed-Loop / Ground-Source Heat Pump Systems-Installation Guide* to size the ground heat exchanger (Oklahoma State, 1988). The procedures in this guide are targeted at a horizontally installed ground heat exchanger, shown in Figure 3. These configurations can be more cost-effective in situations where there is plenty of open land to install the large ground heat exchangers. These type of exchangers only require shallow (6-to-10-ft.-deep) trenches, which require use of a common backhoe to dig. A vertically installed ground heat exchanger (Figure 4) requires bores of much greater depth. The use of specialized digging tools, for the vertical exchanger, costs more per length of installed ground exchanger piping. A vertical system may incur a greater installation cost, but there are other factors to be taken into account. The major one, which in this case allows for ruling out of horizontal set ups all together, as far as FRESA is concerned, is the cost of the land area needed for a horizontal exchanger. Commercial horizontal exchangers need vast expanses of land for cooling and heating. Another advantage to a vertical installation is that they are better documented. The data from these sources can be used after the program is rewritten to ensure that the projected cost figures that FRESA outputs are accurate. The calculation itself also becomes much simpler with the assumption of a vertical heat exchanger. Soil temperature varies with depth, and it can be assumed for vertical exchangers that the average ambient temperature is the ground temperature (Kavanaugh, 1997). However, horizontally installed heat exchangers encounter only one depth. This requires a complex calculation for the soil temperature, which is a function of both time of year and depth, thus complicating the bin calculation.

The procedure for designing the heat exchanger that would be better suited for the FRESA program is given in *Ground-Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings* (Kavanaugh, 1997). This ASHRAE sponsored publication uses a straightforward method for calculating the length of the bore needed to install a vertical ground heat exchanger, which is described in detail in Appendix D. In addition to this calculation being directed towards vertical systems, it also takes into account long-term change in soil temperature due to system use. This could be significant if the heating and cooling loads aren't balanced.

The length of the bore directly relates to the system's cost. The longer the bore, the greater the drilling expenses and the longer the length of pipe that needs to be purchased. This means that accurate calculation of this length is very important in achieving an accurate estimate of the installation cost for the system.

One input to FRESA that is specific to the ground-coupled heat pump calculation is the soil type. The user can input one of four options. These options are rocky soil, heavy wet soil, heavy dry soil, and light dry soil. For each of these options there is a predetermined conductivity and resistance assigned to each type. With field research since FRESA's design, these values in the program are currently out of date (Kavanaugh, 1997). Table 1 compares the current values with more accurate and currently accepted values.

Now that the heat pump is sized and the heat exchanger is designed, again the bin method is used to calculate the energy used with the ground-coupled system. The program not only needs to be used to calculate the energy required by the heat pump's compressor, but also needs to be used to evaluate how much energy is required to pump the heat exchanger medium through the system. This could be a significant amount of power because, for heat transfer in the ground exchanger to achieve maximum heat transfer, there must be turbulent flow in the exchanger pipes. To find the power used by the circulation pump, the head loss through the whole system must be found. Using some design guidelines from Kavanaugh, these values can be estimated per length of bore. From the assumptions made earlier about the type and size of the pipe, the flow rate can be determined. For a one-inch diameter pipe there must be a 2 gpm flow rate per ton of peak block load in order to achieve turbulent flow. The turbulent flow (Reynolds number above 2500) allows for maximum heat transfer between the fluid and the pipes.

After the heat exchanger is designed, the head loss for the system needs to be found. Head loss through the heat pump should not exceed 12 feet, so a good assumption would be 10 feet for use in the code. Pipe friction losses can be minimized by keeping the bore length per parallel circuit between 150 and 300 ft. Flow setter or balancing valve losses should not have a head loss in excess of 5 feet of water. All other valves should be assumed to have low head loss.

Pump motors should be energy efficient models, so a high efficiency can be assumed for use in the program. Once head loss is summed, using all of these guidelines, the power that is required to circulate the fluid can be found. Then using the motor efficiency of the pump, the electricity use can be found. FRESA does this currently but some of these guidelines and values for head losses in the equipment need to be introduced into the program.

FRESA uses all of this calculated data to return an answer as to the economic viability of ground-coupled heat pump installation. This includes a system size report, installation costs, and long-term energy savings. The program then puts these numbers into a life-cycle cost analysis and outputs economic data concerning a ground-coupled system.

The economics section of the code is necessary in order to get meaningful system cost savings. One revision that needs to be made to it is a self-check. As shown in the Eastern Neck Wildlife screening, the program output a energy savings value that was much larger than the electricity use of the building which was inputted into the program. There needs to be a calculation that recognizes this as being incorrect before supplying the user with an answer as to the economic viability.

In the life-cycle cost analysis FRESA assumes costs for the different equipment necessary for the ground coupled heat pump. Several case studies that outline system size and system cost for each installed item have been used to check the validity of the numbers FRESA uses now. The results of this can be found in Table 2. The price of the heat pump should be $850 per ton instead of about $650 per ton. Also, for the circulating pump, FRESA assigns a cost of $200 per system. To make this more accurate this number should be factored in to the cost of installed ground heat exchanger per ft. Since the amount of pumping power required is directly proportional to the length of the ground heat exchanger this would give a much accurate value for cost of the circulation pump than a flat rate for each system. A good estimate for this cost is $6.50 per ft. of installed ground heat exchanger. The cost for fittings and other miscellaneous costs already in FRESA, is good enough for its purposes. For a larger commercial system this cost is low, but when averaged over a range of residential and large commercial projects this number should be correct (Caneta, 1998).

Discussion and Conclusion

FRESA has great potential to make FEMP's processes of screening renewable implementation projects much more efficient. Enabling the building manager to have some fairly accurate figures he or she can refer to when it comes time to propose a project saves FEMP all the time of doing preliminary screenings for every renewable technology. It also provides direction for the building manager and lets him or her focus on a particular project once its deemed feasible.

With the implementation of the changes suggested here and refinements in the program, FRESA will become a powerful tool in the task of applying renewable energy technologies in the federal sector.

Acknowledgements

I'd like to thank the Department of Energy and the National Renewable Energy Lab for providing me with this opportunity.

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References

"Bin Method," 1993 *ASHRAE Handbook-Applications*, Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers Inc., 1993.

Caneta Research Inc., The Cadmus Group Inc., & The Science Applications International Corp. (1998). Operating Experiences with Commercial Ground-Source Heat Pump Systems, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

"Ground-Coupled Heat Pumps," 1995 *ASHRAE Handbook-Applications*, pg 29.13. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers Inc., 1995.

Kavanaugh, Stephen P., Rafferty, Kevin (1997). Ground-Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

Ingersoll, Leonard R., Zobel, Otto J., & Ingersoll, Alfred C. (1954). Heat Conduction: With Engineering, Geological and Other Applications. Madison, Wisconsin: University of Wisconsin Press.

Oklahoma State University. (1988). Closed-Loop/Ground-Source Heat Pump Systems: Installation Guide. Oklahoma: Oklahoma State University.

U.S. Department of Energy. (1980). Architects and Engineers Guide to Energy Conservation In Existing Buildings. Washington D.C.: U.S. Department of Energy.

Appendices

Appendix A: List of Variables

L_h= required bore length for heating (ft.)
L_c= required bore length for cooling (ft.)
q_a= net annual average heat transfer to the ground (Btu/h)
C_{fh}= heat pump correction factor for heating
C_{fc}= heat pump correction factor for cooling
q_{lh}= building design heating block load (Btu/h)
q_{lc}= building design cooling block load (Btu/h)
R_b= thermal resistance of bore (h ft ºF/Btu)
R_{ga}= effective thermal resistance of the ground, annual pulse (h ft ºF/Btu)
R_{gm}= effective thermal resistance of the ground, monthly pulse (h ft ºF/Btu)
R_{gd}= effective thermal resistance of the ground, daily pulse (h ft ºF/Btu)
PLF_m= part load factor during design month
F_{sc}= short-circuit heat loss factor
t_g= undisturbed ground temperature (ºF)
t_p= temperature penalty for interference of adjacent bores (ºF)
t_{wi}= liquid temperature at heat pump inlet (ºF)
t_{wo}= liquid temperature at heat pump outlet (ºF)

Appendix B: Tables

	Current Values		Recommended	
Soil Type	diffusivity	conductivity	diffusivity	conductivity
Rock	0.05	2.0	1.0	1.25
Heavy Wet	0.025	0.75	0.45	0.7
Heavy Dry	0.02	0.5	0.5	0.7
Light Dry	0.011	0.2	0.95	0.75

Table 1. Soil constants for use in FRESA

Equipment	Recommended	FRESA
Heat Pump Cost	$860/ton	$685/ton
Circulating Pump	$6.50/ft	$200/system
Installed Pipe	Included in circulating pump cost	$0.70/ft
Fittings	$250/system	$250/system
Miscellaneous	$800/system	$800/system

Table 2. Equipment cost figures

Cooling EER	C_{fc}	Heating	C_{fh}

		COP	
11	1.31	3.0	0.75
13	1.26	3.5	0.77
15	1.23	4.0	0.8
17	1.2	4.5	0.82

Table 3. Heat pump correction factors.

Grouts without Additives	k (Btu/h ft ºF)	Thermally Enhanced Grouts	k (Btu/h ft ºF)
20% Bentonite	0.42	20% Bentonite – 40% Quartzite	0.85
30% Bentonite	0.43	30% Bentonite – 30% Quartzite	0.7 to 0.75
Cement Mortar	0.4 to 0.45	30% Bentonite – 30% Iron Ore	0.45
Concrete @ 130/150 lb/cf	0.6/0.8	60% Quartzite – Flowable Fill	1.07
Concrete (50% quartz sand)	1.1 to 1.7		

Table 4. Thermal conductivity of typical grouts and backfills.

# Of bores per parallel loop	One	Two	Three
2 gpm/ton	1.06	1.03	1.02
3pgm/ton	1.04	1.02	1.01

Table 5. Short circuit heat loss factors for various flow rates and numbers of bores per parallel loop

System Flow (gpm/ton)	Temperature Rise in Cooling (ºF)	Temperature Drop in Heating (ºF)
3.0	10	6
2.5	13	7.8
2.0	15	9

Table 6. Liquid temperature change through GCHP units

Eqv. Full-Load Hrs. Heating/Cooling	Bore Separation (ft)	Ground Temp. (t_g) & Entering Water Temps. (Htg. & Clg.)					
		t_g=50ºF (EWT=35/80)		t_g=60ºF (EWT=45/85)		t_g=70ºF (EWT=60/95)	
		k_g=1.0	k_g=1.5	k_g=1.0	k_g=1.5	k_g=1.0	k_g=1.5
		Δt_g (ft/ton)	Δt_g (ft/ton)	Δt_g (ft/ton)	Δt_g (ft/ton)	Δt_g (ft/ton)	Δt_g (ft/ton)
1500/500	15	-4.4	-4.4				
	20	-2.3	-2.3				
	25	-1.2	-1.2				
1000/1000	15	12.9	11.8	NR	11.8		
	20	5.4	4.3	4.7	4.7		
	25	3.4	1.9	2.5	2.4		
500/1000	15	15.1	15.1	NR	12.8	NR	NR
	20	7.8	8	6.7	6.7	6.7	6.7
	25	4.1	4.3	3.5	3.5	3.5	3.5
0/2000	15			NR	NR	NR	NR
	20			10.3	10.4	10.4	10.5
	25			5.4	5.5	5.4	5.5

Table 7a. Long-term change in ground field temperature for 10 by 10 vertical grid with a 100-Ton Load

Eqv. Full-Load Hrs. Heating/Cooling	Bore Separation (ft)	Ground Temp. (t_g) & Entering Water Temps. (Htg. & Clg.)					
		t_g=50ºF (EWT=35/80)		t_g=60ºF (EWT=45/85)		t_g=70ºF (EWT=60/95)	
		k_g=1.0	k_g=1.5	k_g=1.0	k_g=1.5	k_g=1.0	k_g=1.5
		Δt_g (ft/ton)	Δt_g (ft/ton)	Δt_g (ft/ton)	Δt_g (ft/ton)	Δt_g (ft/ton)	Δt_g (ft/ton)
1500/500	15	318	248				
	20	276	216				
	25	258	202				
1000/1000	15	318	245	NR	313		
	20	237	186	245	225		
	25	220	172	263	206		
500/1000	15	379	294	NR	345	NR	NR
	20	277	216	326	254	336	259
	25	224	190	287	224	293	229
0/2000	15			NR	NR	NR	NR
	20			406	316	414	322
	25			325	252	332	257

Table 7b. Long-term change in ground field temperature for 10 by 10 vertical grid with a 100-Ton Load

Correction Factors for Other Grid Patterns			
1 x 10 Grid	2 x 10 Grid	5 x 5 Grid	20 x 20 Grid
C_f=0.36	C_f=0.45	C_f=0.75	C_f=1.14

Table 8. Correction factors for other grid patterns

Appendix C: Figures

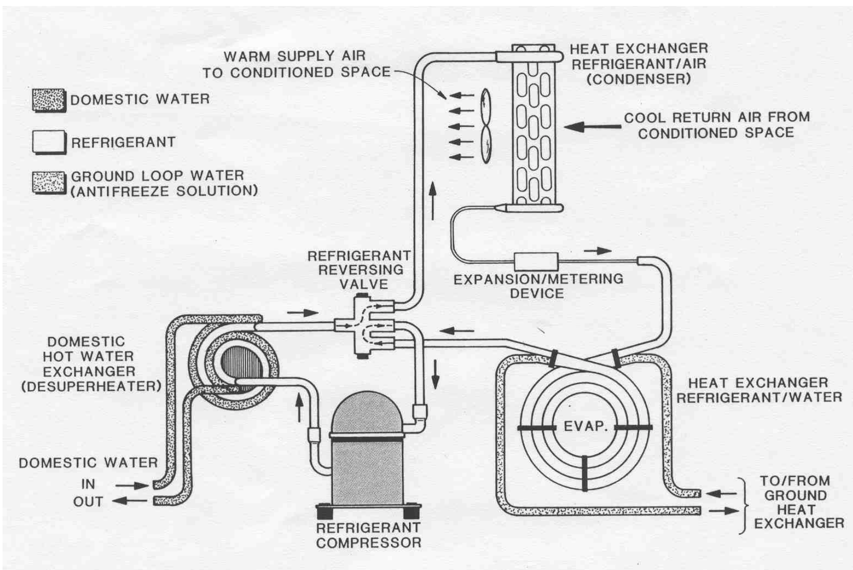

Figure 1. GCHP system (Heating Cycle)

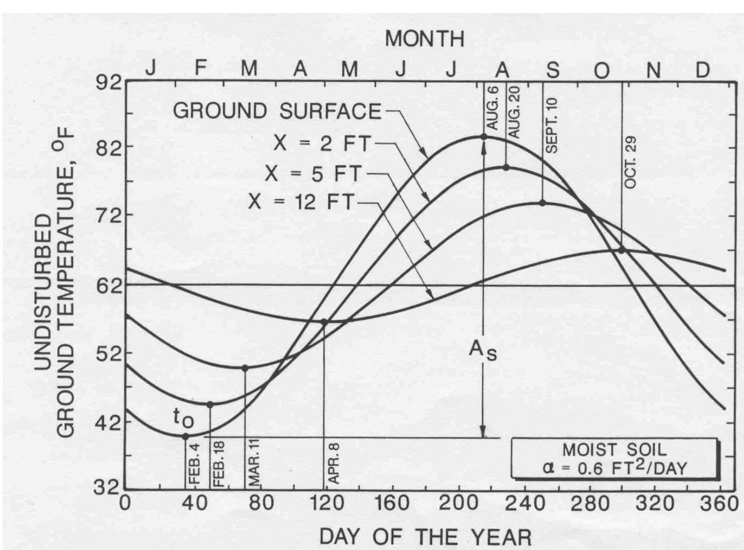

Figure 2. Yearly soil temperature for Stillwater, Oklahoma

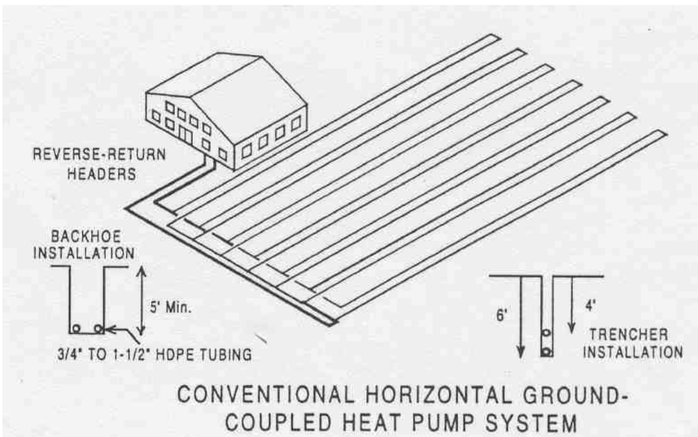

Figure 3. Horizontal Ground Heat Exchanger

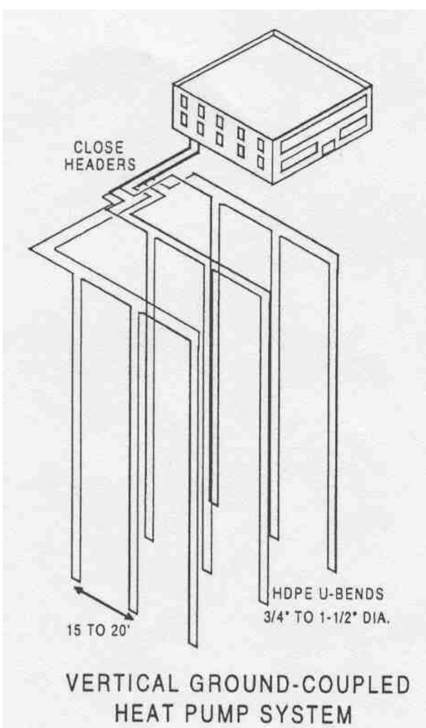

Figure 4. Vertical Ground Heat Exchanger

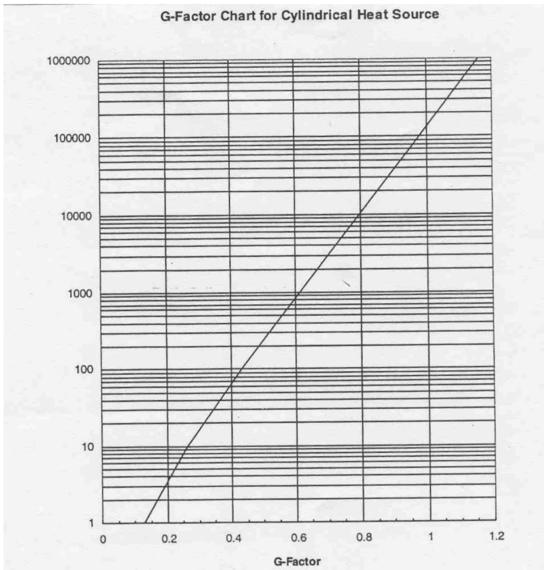

Figure 5. F_o vs. G for a cylindrical heat source

Appendix D: Heat Exchanger Length Calculation

To find the required vertical heat exchanger length of bore length, Kavanaugh uses:

$$L_h = \frac{q_a R_{ga} + (C_{fh} \times q_{lh})(R_b + PLF_n R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p} \tag{1}$$

$$L_c = \frac{q_a R_{ga} + (C_{fc} \times q_{lc})(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p} \tag{2}$$

where L_c is the length of bore required for cooling and L_h is the bore required for heating.

To use these equations, the net annual heat transfer to the ground, q_a, needs to be calculated. The net annual heat transfer to the ground is given by the following equation:

$$q_a = \frac{C_{fc} q_{lc} EFLhours_c + C_{fh} q_{lh} EFLhours_h}{8760} \qquad (3)$$

where 8760 is the number of hours per year.

The values q_{lc} and q_{lh} are each calculated using the bin method in the loads part of the code. These are the building design block loads for cooling and heating. Next, the equivalent full-load hours for heating and cooling need to be found. These are also calculated in the loads section of the program. The heat pump correction factors, C_{fc} and C_{fh}, are taken from Table 3 and everything is plugged into the above equation for net annual heat transfer.

The program currently uses a length calculation that involves a single value for the ground resistance. This neglects long-term heat changes in the soil that may arise over the life of the system. By using several values, which are based on three different pulses, a more accurate calculation for the length of bore can be found that takes into account the long-term temperature changes of the soil. These resistance values are labeled R_{ga} (annual), R_{gm} (monthly), and R_{gd} (daily). To solve for these, calculate τ, or the length of each pulse, for the three different time intervals:

τ_1= 3650 (10 yrs.); τ_2 = 3680 (1 month); τ_f = 3680.25 (6 hours).

Then the following equations are used to solve for the Fourier number for each of the pulses:

$$F_{o1} = \frac{4\alpha(\tau_f - \tau_1)}{d^2}$$
$$F_{o2} = \frac{4\alpha(\tau_f - \tau_2)}{d^2} \qquad (4,5,6)$$
$$F_{of} = \frac{4\alpha\tau_f}{d^2}$$

using the values of F_o find the G value associated with each of these Fourier values if found from a logarithmic fit of Figure 5:

$$G = 0.0769Ln(F_o) + 0.0901 \qquad (7)$$

Finally, to solve for the thermal resistances (R_{ga}, R_{gm}, and R_{gd}), use the equations:

$$R_{ga} = \frac{G_f - G_1}{k_g}$$
$$R_{gm} = \frac{G_1 - G_2}{k_g} \qquad (8,9,10)$$
$$R_{gd} = \frac{G_2}{k_g}$$

Next, a specific type of pipe needs to be assumed for use in the heat exchanger. A commonly used pipe for this purpose is one-inch diameter polyethylene tube (SDR-11). It is recommended that, for all purposes, FRESA assume this pipe's use in the ground heat exchanger to decrease calculation complexity.

Kavanaugh cites the work of Remund and Paul (1997), and their use of a method of solving for the pipe thermal resistance, R_b. The equation:

$$R_b = R_{bf} + R_p \tag{11}$$

is used to solve for this value, where R_{bf} is the backfill resistance taken from Table 4. This is intuitive because the resistances are in series, and therefore they should be added. The value of R_p for SDR 11 piping is 0.075 h ºF ft /Btu. Using this value and assuming a mediocre thermally advanced grout from Table 3, the value for R_b would be 0.775 h ºF ft /Btu.

Next the short-circuit heat loss factor, F_{sc}, which is the heat lost between adjacent pipes in the same borehole, needs to be found. This is done using Table 4. Since its been decided that the flow rate is 2 gpm, and the value of F_{sc} is 1.03.

Now the part load factor can be taken from the bin method load calculations.

$$PLF_m = \left(\frac{Load \times Hours}{PeakLoad \times 24h} \right) \times \left(\frac{DaysOccupiedPerMonth}{DaysPerMonth} \right) \tag{12}$$

For vertical installation, it is assumed that the ground temperature, t_g, is equal to the mean of the winter and summer average temperatures. Water inlet temperature is suggested to be 20 to 30 degrees higher than t_g in cooling, and 10 to 20 degrees lower than t_g in heating (both temperatures in Fahrenheit). An alternative method of finding the water inlet temperature would be to use Table 5. Finally, the temperature penalty due to bores affecting one another needs to be found. Table 6a can be used to estimate this value. Interpolation can be done with values not exactly matching the chart. Both of these charts are based on a 10 by 10 grid of vertical exchangers. Table 7 provides correction factors for different grid configurations.

With all of these values determined, equations 1 and 2 can be used to solve for the bore length required for heating and cooling.