GSHP Design Recommendations - Residential & Light Commercial

These **residential** closed-loop ground source heat pump (a.k.a geothermal or ground-coupled heat pumps) design guidelines were developed in conjunction with a project sponsored by the Tennessee Valley Authority in conjunction with a TVA Ground Source Heat Pumps promotion. Previous guidelines were verified and adjusted according to data gathered during this effort and previous similar projects. A set of recommendations for loop sizing, piping guidelines, piping arrangements, and antifreeze precautions is provided. They attempt to balance the conflicting constraints of installation cost and efficiency. These guidelines have recently been extended to regions beyond the TVA service territory.

Loop Lengths

Table 1 provides recommendations for ground loops in the Tennessee Valley Authority service area and beyond. The values use results from this TVA sponsored project coupled with a previous Alabama Power project and the resulting recommendations for Alabama (Kavanaugh, 1991). The length of the trench or bore must be based on the amount of pipe in the trench, burial depth, and average ground temperature and conductivity. The table provides extremes of pipe length per length of trench from 10 ft/ft (i.e. 1000 ft. of pipe in a 100 ft. long trench) to 2 ft/ft. The table was developed for an average burial depth of 5 ft. and ¾" high-density polyethylene (HDPE) pipe. The extremes of normal ground temperature are 44^o F for the northern continental US and 70^o in southern USA (not including southern Florida and Texas and all of Hawaii). These lengths should provide a maximum loop temperature of 90^o F entering the heat pump in normal applications. In homes with excessive run times this temperature will be 3^o to 5^{o}F higher. The table also includes recommendations for vertical ground loops in **ft. of bore per ton** for ¾" and 1-1/4" HDPE, which will operate about 5^{o}F cooler than the horizontal loops.

Table 1. Recommended Lengths of Trench or Bore Per Ton For GCHPs

Multiply length of trench by pitch to find required length of pipe.

See Tables 4 and 5 for Thermal Conductivity of Soils and Rocks.

	Pitch	**Ground Temperature - ^{o}F**						
Coil Type (See Figure 1 for Details)	**Ft. of Pipe per Ft. Trench (or Bore)**	**44 to 47^o F**	**48 to 51^o F**	**52 to 55^o F**	**56 to 59^o F**	**60 to 63^{o}F**	**64 to 67^{o}F**	**68 to 70^{o}F**
Horz. 10-Pitch Slinky	10	125	120	115	120	125	150	180
Horz. 6-Pipe/6-Pitch Slinky	6	180	160	150	160	180	200	230
Horz. 4-Pipe/4-Pitch Slinky	4	190	180	170	180	190	220	260
Horz. 2-Pipe	2	300	280	250	280	300	340	400
Vertical U-tube (3/4" Pipe)	2	180	170	155	170	180	200	230
Vertical U-tube (1" Pipe)	2	170	160	150	160	170	190	215
Vertical U-tube (1¼" Pipe)	2	160	150	145	150	160	175	200

Table 1 based on k=0.6 Btu/hr-ft-^{o}F for horizontal loops and k=1.2 Btu/hr-ft-^{o}F for vertical loops and an annular fill/grout conductivity of 0.85 in vertical loops. For other conditions:

L/Ton(Corrected) = L/Ton (Table 1) × CF(k-ground) × CF(k-annulus)

Ground Therm. Cond. (Btu/hr-ft-^{o}F)	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Horz. Loop, **CF(k-ground)**	**1.22**	**1.0**	**0.89**	**0.82**	**---**	**---**	**---**	**---**	**---**
Vert. Loop, **CF(k-ground)**	**---**	**---**	**1.23**	**1.10**	**1.0**	**0.93**	**0.87**	**0.83**	**0.79**
Annulus Ther. Cond. (Btu/hr-ft-^{o}F)	0.4	0.6	0.8	0.85	1.0	1.2	1.4	No Correction for Horz. Loop	
Vert. Loop, **CF(k-annulus)**	**1.2**	**1.08**	**1.01**	**1.0**	**.98**	**.93**	**0.91**		

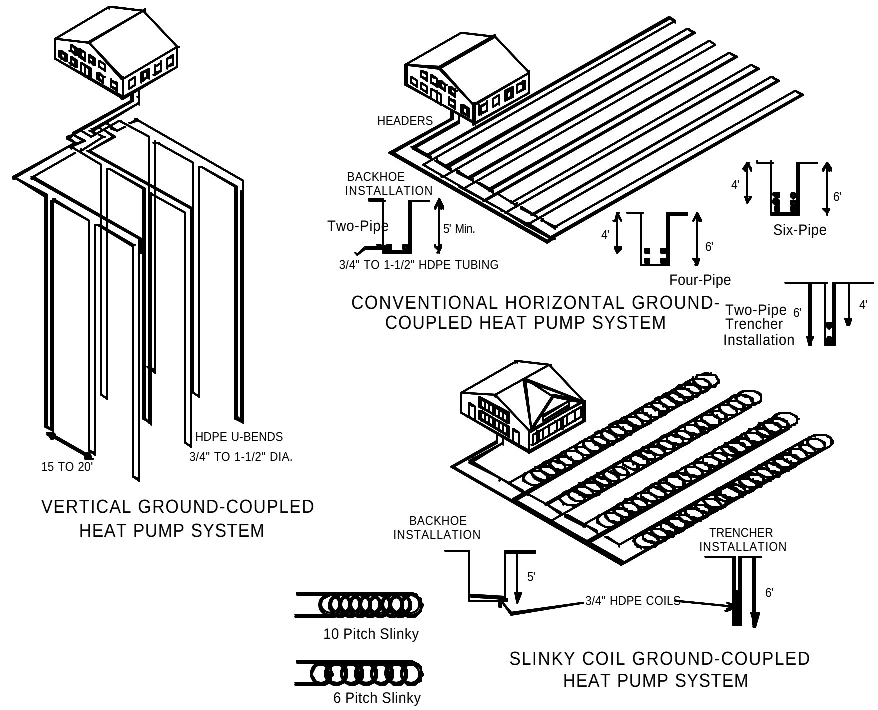

Figure 1. Ground-Coupled (Geothermal) Heat Pump Types
(Groundwater and Surface Water Systems Not Shown)

Heat Pumps

The minimum efficiency for air heat pumps rated under ARI Standard 210/240 is 10 Btu/whr. Since water-to-air heat pumps appear to cost more according to the results of the TVA GSHP promotional and the NRECA/UA study, an efficiency equivalent to a 10 SEER should at the very least be the minimum required.

In order to arrive at a minimum recommended EER, the performance of a line of compressor is used as the basis for the design of a 3 ton heat pump. The Appendix A contains the performance data of a nominal 2.5 and 3.0 ton Copeland reciprocating compressor. The Appendix A also contains the details of a computation that results in an SEER of 10.2 and a cooling capacity of 37,300 Btu/h for the 3.0 ton compressor at ARI 210/240 conditions. The indoor fan is 1/3 hp and outdoor is ¼ hp, both have 60% efficiency.

Using a 2.5 ton compressor from the same series, a water-to-air heat pump is able to achieve an EER of 13.7 at ARI 330 (˜14.5 @ ISO 13256-1/GLHP) conditions using the identical indoor fan motor. Calculations also include the ARE 330 pump penalty at 9 gpm with a 12 ft. head loss through the water coil. To be consistant, the minimum EER is adjusted down to 13.5 since the air heat pump SEER was 10.2 rather than the minimum or 10. The heat pump should have the capability to operate at the extended low range of 32^{o}F called for by ARI 330 or ISO 13256-1. The recommendations for the heat pump are:

- A minimum EER of 14 Btu/whr at ISO 13256-1 GLHP conditions (77ºF/25ºC Entering Water Temperature). Data should be in ARI Directory not in manufacturer's literature.
- A maximum head loss of 12 ft. of water at 3 gpm per nominal ton.
- Extended range capability to operate with an entering liquid temperature of 100^{o}F in cooling and in heating at 32^{o}F.

Pumps, Piping and Antifreeze

This project revealed that contractors were prone to installing excessive numbers of pumps. This may be a result of undersized piping, excessive amounts of viscous antifreeze solutions, or added insurance. Since a 15 EER, 3-ton heat pump will only require a total power (compressor and fan) of 2400 watts, the addition of a second 1/6 hp pump (which draws 200 watts) will reduce system efficiency by 8%. Table 2 is provided as a guideline to insure adequate liquid flow rate with the least possible number of pumps. The table is to be used in conjunction with Table 1 and applies to loops with 0 to 15% propylene glycol solutions (by volume). This solution has the reputation of being the most difficult of the commonly used solutions to pump. However, it is no more difficult to pump than ethyl alcohol and pumping penalties can be mitigated by adding only the required levels. Table 3 gives recommended levels of antifreeze solutions for loops installed according to Table 1 assuming all lines are located below grade. Shorter loops may require higher levels of antifreeze solutions. **See ASHRAE 1999 Applications Handbook, p. 31.25 for more details regarding antifreeze recommendations. Any exposed piping above the frost line must be insulated with a close cell insulation with Ultraviolet (UV) protection (paint or wrap).**

Table 2
RECOMMENDED GCHP PIPING ARRANGEMENTS AND PUMPS

	Nominal Heat Pump Capacity (Tons)				
	2	3	4	5	6
	Required Flow Rate In GPM				
	5-6	7 - 9	10-12	12-15	15-18
Coil Type	**Number of Parallel Loops**				
Slinky (10 pitch)	3-4	4-6	6-9	8-10	8-10
6-Pipe	3-4	4-6	6-9	8-10	8-10
4-Pipe	2-3	4-6	5-8	6-9	6-10
2-Pipe	2-4	3-5	4-6	5-8	6-10
Vert.-3/4" PE	2-3	3-5	4-6	5-8	6-10
Vert.-1" PE	2-3	2-4	3-5	4-6	4-6
Vert.-1-¼"PE	1-2	1-2	2-3	2-3	2-4
Trench Ft.	**Header Diameter HDPE, DR 11 Pipe**				
Less 100'	1 ¼"	1 ¼"	1 ¼"	1 ½"	1 ½"
100-200'	1 ¼"	1 ¼"	1 ½"	1 ½"	1 ½" - 2"
	Number & Size Of Pumps Required				
	1-1/12 hp	1 - 1/6 hp	1-1/6 hp (1½" hdrs.) 2-1/12 hp (1¼"hdrs.)	2 -1/6 hp	2 -1/6 hp

Pipe sizing assumes 20% antifreeze solutions and heat pump water coil head loss $\leq$ 12 ft.

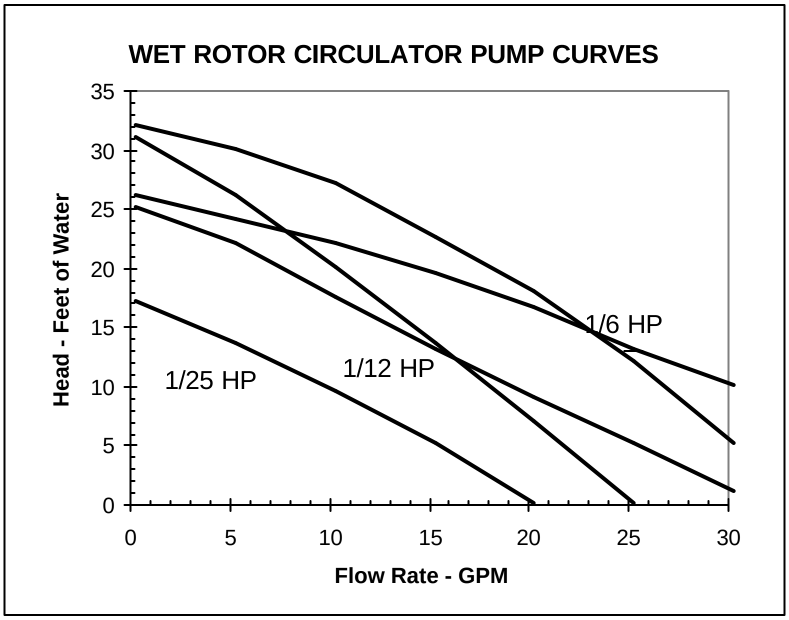

Figure 2. Grundfos Circulator Pump Curves
(Other Manufacturers have similar products)

Table 3
RECOMMENDED LEVELS OF ANTIFREEZE SOLUTIONS
FOR GCHP SYSTEMS

Recommended % Volume of Propylene Solutions

Coil Type	Pitch Ft. pipe/Ft.trench	% by Volume 60 to 63°F Ground	% by Volume 52 to 59°F Ground	% by Volume 44 to 51°F Ground
Slinky	10	10	15	20
6-Pipe or Eqv. Slinky	6	10	15	20
2-Pipe	2	10	15	20
Vertical (3/4" Pipe)	2	0	10	20
Vertical (1 ¼" Pipe)	2	0	10	20

Warning more antifreeze will be required if loops are shorter than those recommended in Tables 1 and 2.

Example Design:

Design the vertical ground coupling grid and the pumping loop for a four-ton (48,000 Btu/hr) heat pump system. The home is located in Nashville and the header pipes can be brought into the equipment room where the unit will be located. The driller can bore 4.5-inch holes to a depth of 175 feet in the light limestone and clay at the site. The owner wants the drilling site to be located 75 feet from the house. Thermally enhanced grout with of thermal conductivity or 0.85 Btu/hr-ft-F is used to fill the annular region between the U-tubes and borehole walls.

<u>Solution</u>:
The soil temperature is estimated to be 58ºF in Nashville (See Figure 5). Table 1 suggests bore lengths of 170 ft/ton for ¾ inch U-bends, 160 ft/ton for 1 inch, and 150 ft/ton for 1-1/4 in. (bores will be deep-greater than 100 feet). However, 1-1/4 inch U-bends will be very difficult to install into a 4.5 inch bore hole and are eliminated from consideration. Therefore, either 680 feet (170 ft/ton x 4 tons) of ¾ inch U-bend coupling or 640 (160 x 4 tons) feet of 1-inch coupling is required. One inch will be used in this example. Also, Table 1 is based on a soil conductivity of 1.2 Btu/hr-ft-F, which is an approximate average between limestone and clay, and a bore fill (or grout) conductivity of 0.85 Btu/hr-ft-F. If the ground conductivity is higher (i.e. more limestone than clay), the loops should be reduced as noted in the footnote for Table 1 or lengthened if the ground conductivity was lower than 1.2 Btu/hr-ft-F. Also, the loop lengths would need to be lengthened if the bore fill (or grout) conductivity is lower than 0.85 Btu/hr-ft-F as noted in the lower footnote of Table 1.

The layout will be dictated by drilling conditions. The total length of 640 feet requires four bores since the driller can only drill to 175 feet. This can be accomplished with four 160 to 165 feet holes. Table 2 suggests either 3, 4 or 5 parallel circuits for the grid. Three and five circuits will not divide evenly into the four U-bends. Therefore, four circuits (one per U-bend) will be used in an arrangement similar to Figure 3.

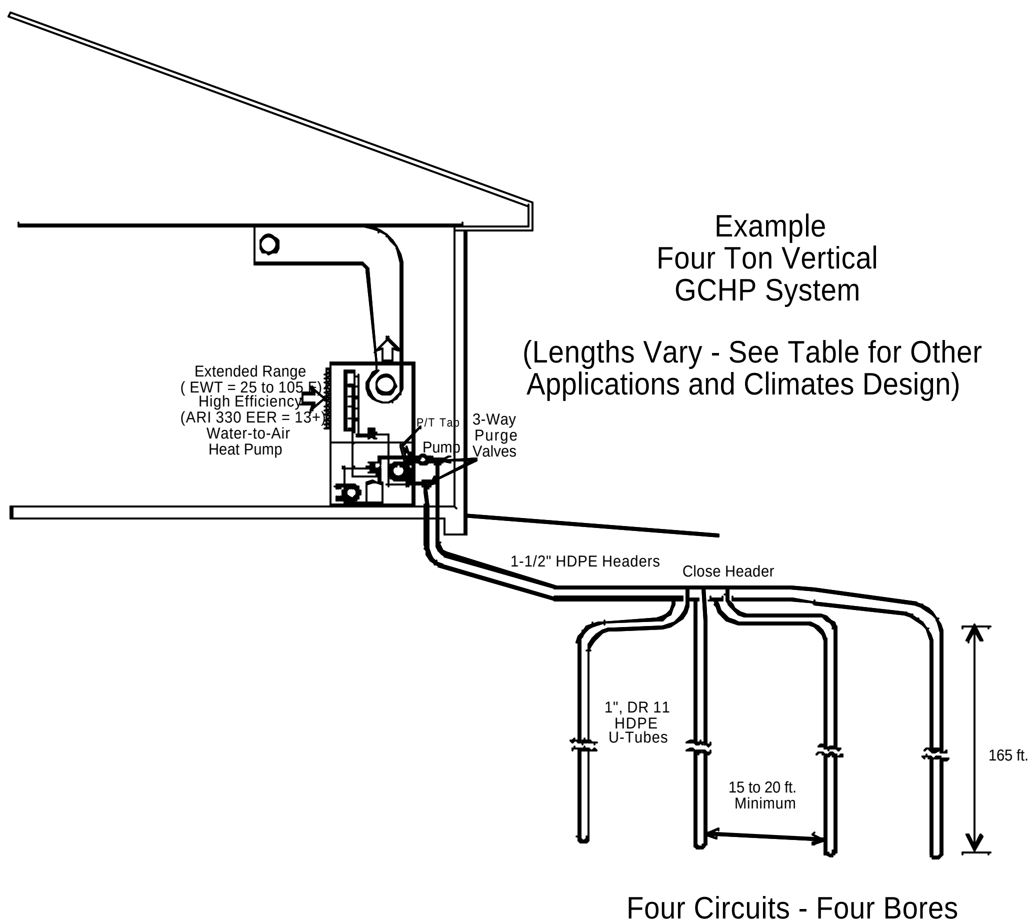

Figure 3. Four Ton Vertical GCHP

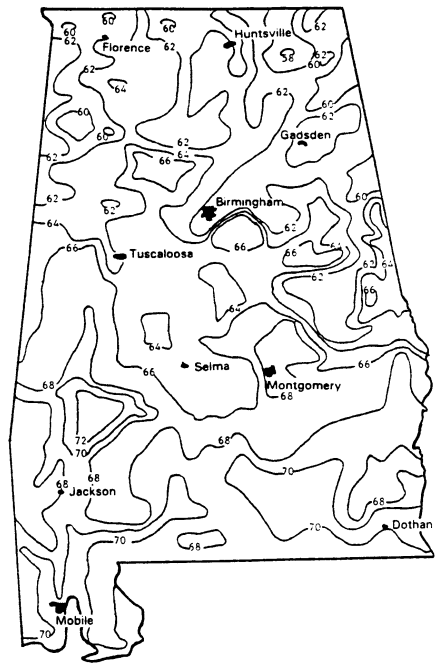

Figure 4. Groundwater Temperature Profiles for Alabama (Chandler)

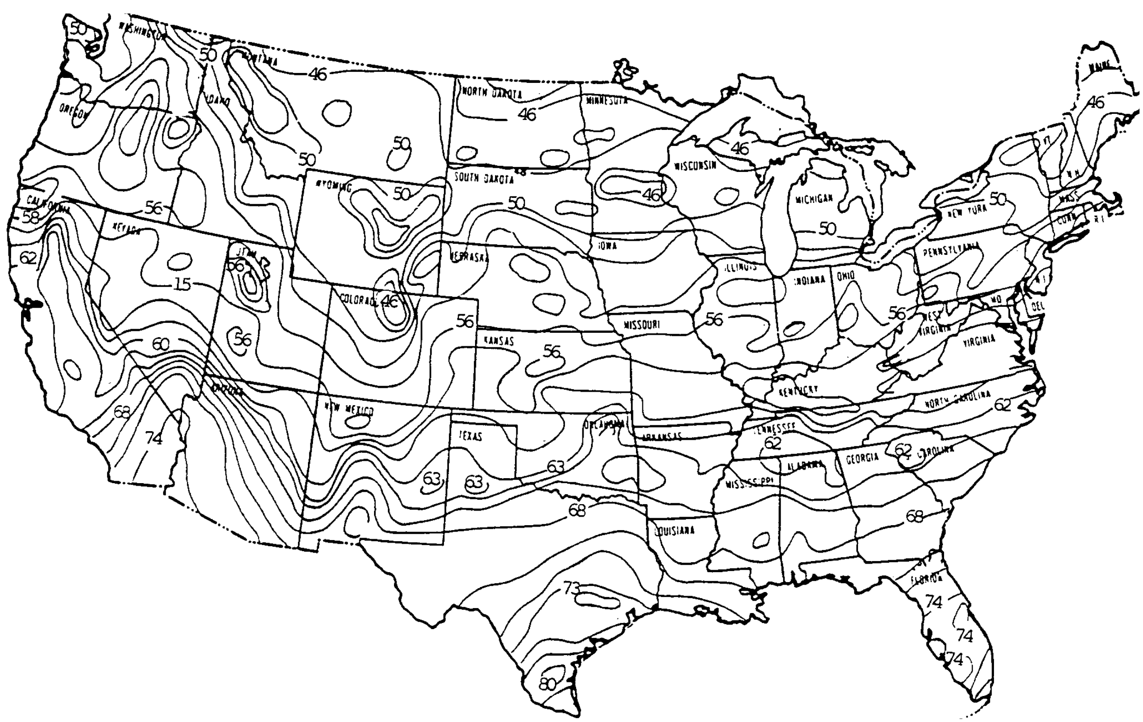

Figure 5 Approximate Groundwater Temperatures in the USA (NGWA)

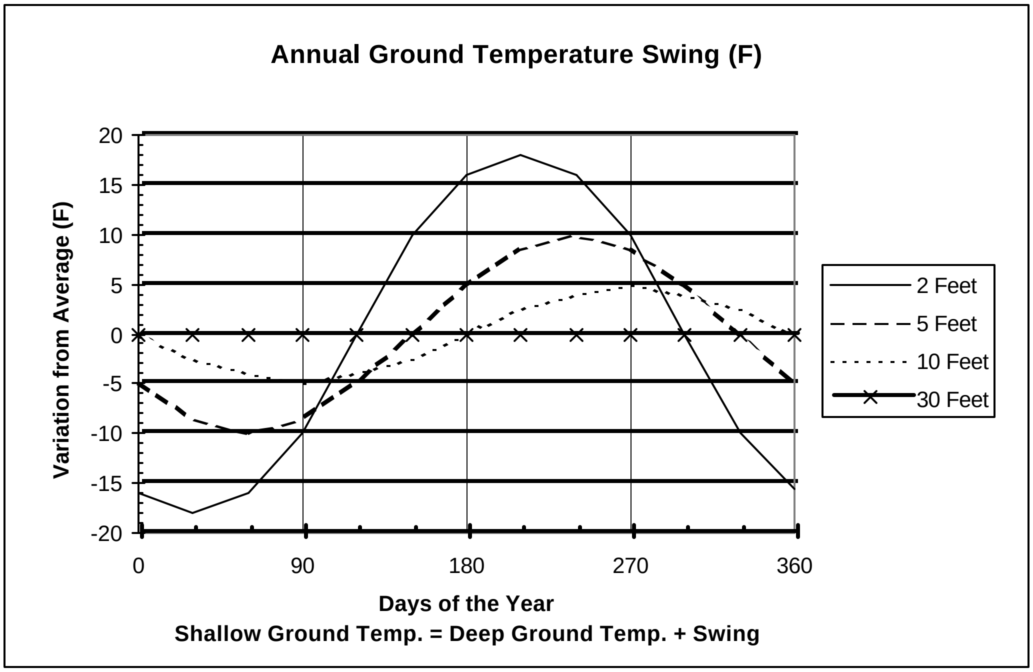

Figure 6 Ground Temperature Variation in Average Soil with Depth and Season

(Note: To find the soil temperature at any depth and time of the year, add the values in Figure 5, to temperatures shown in Figures 4 (Alabama) or 5 (USA).

TABLE 4 Thermal Conductivity and Diffusivity of Sand and Clay Soils

Thermal Conductivity (**k**) - **Btu/hr-° F-ft** and Thermal Diffusivity (a) - **ft²/day**

Soil Type	Dry Density	5% Moist **k**	5% Moist a	10% Moist **k**	10% Moist a	15% Moist **k**	15% Moist a	20% Moist **k**	20% Moist a
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

Coarse grain = 0.075 to 5 mm - Fine Grain less than 0.075 mm

TABLE 5 Thermal Properties of Rocks @ 77° F

Thermal Conductivity (**k**) - **Btu/hr-° F-ft** and Thermal Diffusivity (a) - **ft²/day**

Rock Type	**%**[1] Occurance in Earth's Crust	**k - All**[2] Ther. Con. Btu/h-ft-F	**k - 80%**[3] Ther. Con. Btu/h-ft-F	**c_p** Spec. Heat Btu/lb-F	r Density lb/ft³	a (k/ρc_p) Ther. Diff. ft²/day
Igneous Rocks						
Granite (10% Quartz)	10.4	1.1-3.0	1.3-1.9	0.21	165	0.9-1.3
Granite (25% Quartz)			1.5-2.1			1.0-1.4
Amphibolite		1.1-2.7	1.5-2.2		175-195	
Andesite		0.8-2.8	0.9-1.4	0.12	160	1.1-1.7
Basalt	42.8	1.2-1.4		0.17-0.21	180	0.7-0.9
Gabbro (Cen. Plains)		0.9-1.6		0.18	185	0.65-1.15
Gabbro (Rocky Mtns.)		1.2-2.1				0.85-1.5
Diorites	11.2	1.2-1.9	1.2-1.7	0.22	180	0.7-1.0
Grandiorites		1.2-2.0		0.21	170	0.8-1.3
Sedimentary Rocks						
Claystone		1.1-1.7				
Dolomite		0.9-3.6	1.6-3.6	0.21	170-175	1.1-2.3
Limestone		0.8-3.6	1.4-2.2	0.22	150-175	1.0-1.4
Rock Salt		3.7		0.20	130-135	
Sandstone	1.7	1.2-2.0		0.24	160-170	0.7-1.2
Siltstone		0.8-1.4				
Wet Shale (25% Qrtz.)			1.0-1.8			0.9-1.2
Wet Shale (No Qrtz.)	4.2	0.6-2.3	0.6-0.9	0.21	130-165	0.5-0.6
Dry Shale (25% Qrtz.)			0.8-1.4			0.7-1.0
Dry Shale (No Qrtz.)			0.5-0.8			0.45-0.55
Metamorphic Rocks						
Gneiss	21.4	1.0-3.3	1.3-2.0	0.22	160-175	0.9-1.2
Marble	0.9	1.2-3.2	1.2-1.9	0.22	170	0.8-1.2
Quarzite		3.0-4.0		0.20	160	2.2-3.0
Schist	5.1	1.2-2.6	1.4-2.2		170-200	
Slate		0.9-1.5		0.22	170-175	0.6-0.9

[1] Percentage of sedimentary rocks is higher near the surface.
[2] "All" represents the conductivity range of all samples tested.
[3] "80%" represents the mid-range for samples of rock.