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Groundwater Heat Pump Equipment Selection Procedures

for

Architects, Designers, & Contractors

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Extension Service
Mechanical Engineering Department

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GROUNDWATER HEAT PUMP EQUIPMENT SELECTION PROCEDURES

For Architects, Designers, and Contractors

Engineers at the Utah Water Research Laboratory and the Mechanical Engineering Department at Utah State University have investigated the use of groundwater heat pumps for residential space heating and cooling in the Utah climate. They have found that this type of system conserves energy and may cost less for Utah home owners to operate than many conventional heating and cooling systems. Since the use of groundwater heat pumps will probably become more widespread in the near future, building and heating contractors should become more informed about what a groundwater heat pump is and how it works. The purpose of this publication is to answer some common questions about heat pumps and help the contractor feel more confident about working with this relatively new heating and cooling system.

How Does a Groundwater Heat Pump Work?

A groundwater heat pump operates in a manner similar to a household refrigerator. The major difference between the two systems is that a heat pump can either deliver heat to or remove heat from an enclosed space by reversing the flow direction of the refrigerant. Thermal energy is removed from the groundwater and is used to heat a home in the winter. Thermal energy is removed from the home and delivered to the groundwater to provide cooling in the summer.

There are several different types of heat pumps commonly identified by their heat source and heat sink respectively, such as air-to-air, water-to-air, and water-to-water. A groundwater heat pump for residential use can be of the water-to-air or the water-to-water type, the water-to-air type being more common.

In Figure 1, a groundwater heat pump extracts heat energy from incoming groundwater and delivers heat energy (H_h) into the home. When the heat pump is operating as an air conditioner, however, heat energy (H_c) is removed from the home and delivered to the outgoing groundwater, which is usually discharged back into a second water well drilled an appropriate distance from the source well.

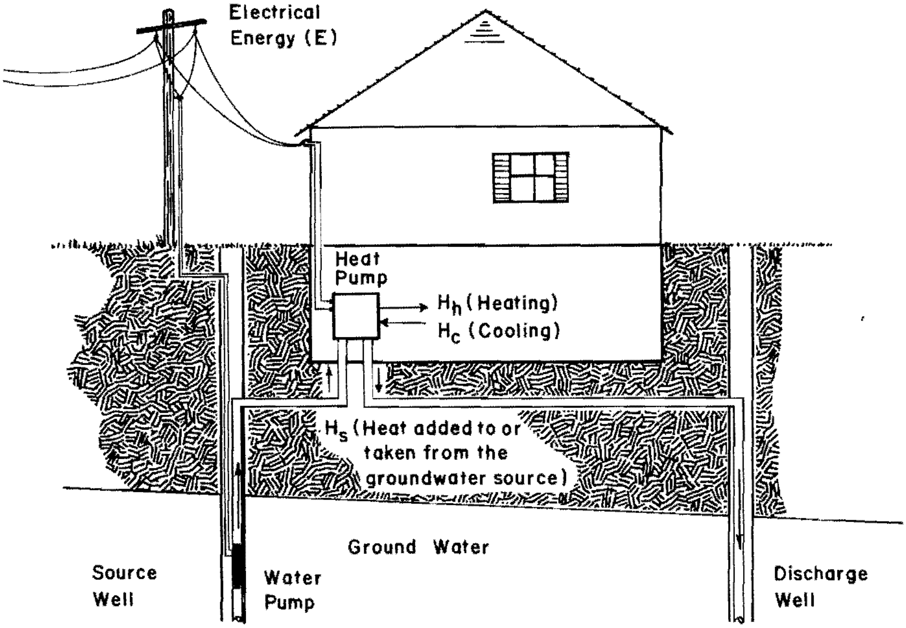

Figure 1. How a groundwater heat pump works.

Heat Pump Cycle

The heat pump cycle is shown schematically in Figure 2 for the heating mode. As the groundwater, which in this case acts as a heat source, passes through heat exchanger (5), thermal energy is transferred from the warmer groundwater to the colder circulating refrigerant thereby causing it to pass from a liquid to a vapor. After passing through the reversal valve (1), the warm, low-pressure refrigerant vapor enters the compressor (2), which adds energy to the vapor in the form of work and discharges the hot, high-pressure gas into heat exchanger (3). Air from the fan is blown across the heat-exchanger coils to extract heat from the hot gas thereby producing hot air, which is delivered to the living space; the refrigerant gas condenses to a liquid as the air removes heat from it. Then, the moderately hot, high-pressure liquid leaves heat exchanger (3) and expands to a much lower pressure in the expansion device (4). During the expansion process, a small fraction of the refrigerant flashes into a vapor thereby also cooling the portion that remains liquid. Finally, the cold refrigerant completes the cycle by passing through heat exchanger (5) where it once again absorbs heat from the warmer groundwater.

When the heat pump system is operating in the cooling mode as shown schematically in Figure 3, the refrigerant flow direction is changed by switching the

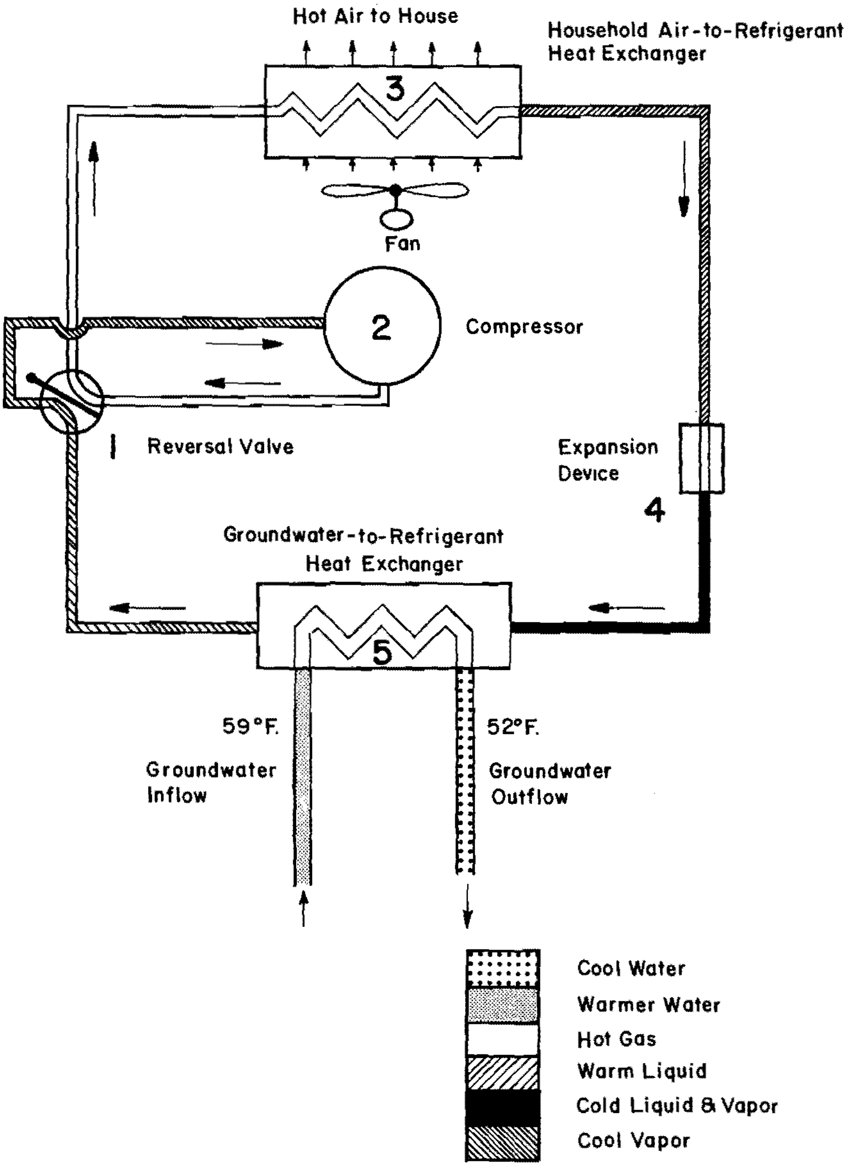

Figure 2. Heating mode water-to-air heat pump.

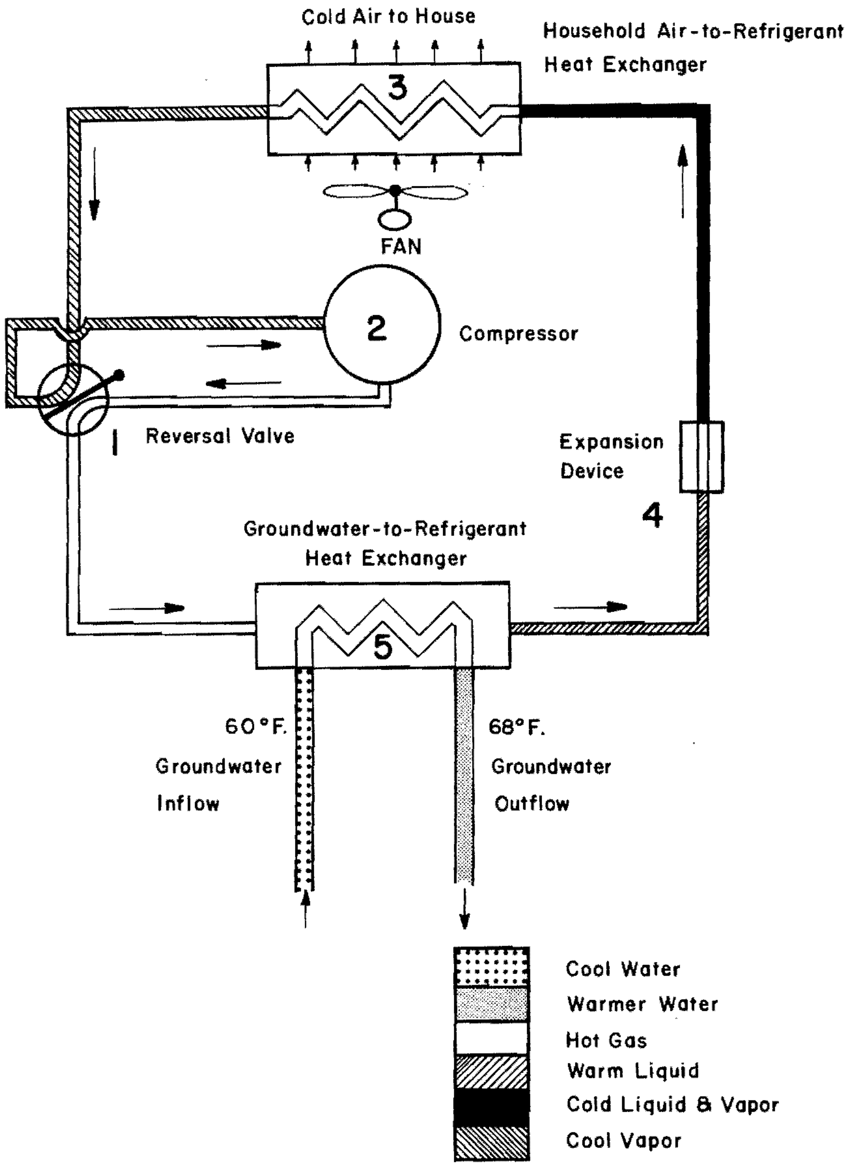

Figure 3. Cooling mode water-to-air heat pump.

position of the reversal valve (1). This flow reversal causes the heating mode source and sink to become the cooling mode sink and source, respectively. Thus, in heat exchanger (3) the fan blows unconditioned warm air across the coils and, in the process, the air temperature is lowered as heat is absorbed by the colder refrigerant, which is transformed into a vapor by the time it leaves heat exchanger (3). The resulting warm, low-pressure refrigerant vapor then enters the compressor (2), which compresses it to a hot, high-pressure gas. After passing through the reversal valve (1), the gas enters heat exchanger (5) where it is condensed and leaves as a fairly hot high-pressure liquid. Then, in expansion device (4) the high-pressure liquid expands to a lower pressure and emerges as a cold liquid mixed with a small amount of cold gas. Finally, the circuit is completed when the cold refrigerant again enters heat exchanger (3) where it is transformed into a vapor while it cools down the air which is fan-driven across the heat exchanger coils.

As indicated by the above description, one of the primary attractions of the heat pump system is the fact that the same equipment components can be used for either heating or cooling a conditioned living space.

Coefficient of Performance

The coefficient of performance (COP) is a measure of heat pump efficiency in the heating mode. The higher the COP, the more efficient the heat pump is. By definition, the coefficient of performance is the heating or cooling output in KWh divided by the electrical energy input in KWh. Referring to Figure 1, the COP may be written as:

$\mathrm{COP} = H_h/E$ for the heating mode and

$\mathrm{COP} = H_c/E$ for the cooling mode.

Since groundwater heat pumps utilize electrical energy to remove "free heat" from the groundwater, the COP normally exceeds 1.0. Typical air-to-air heat pump COPs relate closely with outside air temperatures and range from about 1.3 to 2.4 over an average year. The COP of a typical groundwater heat pump ranges from about 2.7 to 3.4 and does not vary significantly with outside *air* temperatures, but the COP varies with *groundwater* temperature, as indicated in Figure 4. This graph, used in conjunction with Table 1, is for estimation purposes only; actual COPs may be different for each manufacturer. Individual manufacturer's data should be consulted for actual efficiency values.

A groundwater heat pump is normally more efficient than an air-to-air heat pump. It is estimated that groundwater heat pumps are about 37 percent more economical to operate in Utah homes than air-to-air heat pumps and 70 percent more economical than electric heating. Although a groundwater heat pump cannot presently achieve a significant cost savings over natural gas, the Utah homeowner may want to consider installing a groundwater heat pump system even in natural gas service areas because of the strong possibility of large price increases for natural gas in the future. Furthermore, if a well must be drilled for culinary water for the home, a groundwater heat pump could also use the same well to heat the home.

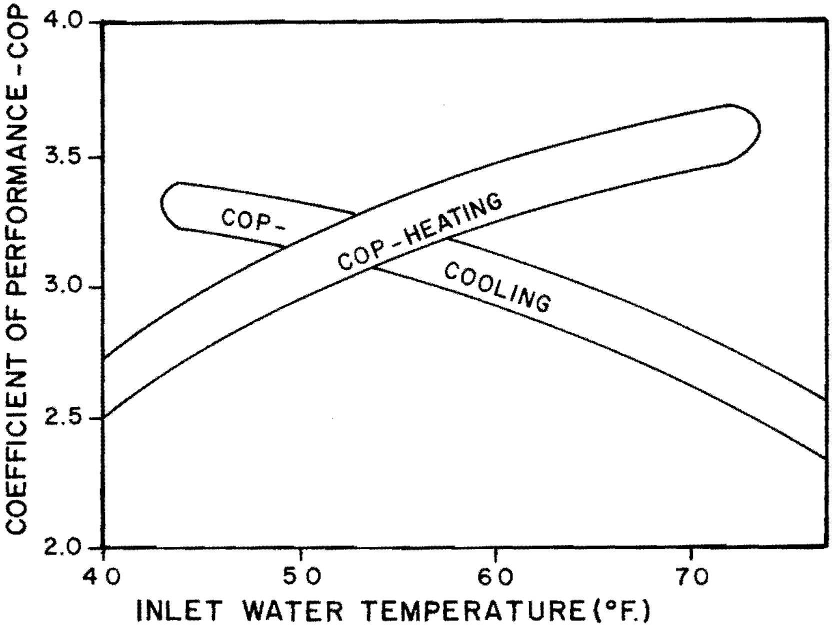

Figure 4. Heating/cooling efficiency.

Table 1. Utah groundwater temperatures for four selected cities.

City	Average Ground-water Temperature	Range
Logan	53.6°F	48.2-59.0°F
Salt Lake City		
Residential	57.6°F	50.9-64.4°F
West of Airport	77.4°F	73.9-81.5°F
Moab	63.0°F	
St. George	66.2°F	55.4-75.2°F

Why Use Groundwater

Heat pumps that use groundwater as the heat source have two basic advantages over heat pumps that use air as the heat source. First, water has the highest specific heat of any common substance; its specific heat is four times greater than that of air. Second, groundwater temperatures are fairly constant the year round, with annual temperature changes from 10 to 20°F in shallow groundwater. The temperature variation for deep groundwater is even less. Air temperatures, however, are usually too low for economical use in the winter when heat is needed and too high in the summer when cooling is needed. When an air-to-air heat pump operates in these extreme temperatures its efficiency is reduced, and a greater quantity of electricity is consumed.

A side advantage of a groundwater heat pump is that the water which leaves the heat pump may be used to irrigate a lawn or garden provided such uses are approved in the well permit obtained from the State Division of Water Rights. This is another way of recharging the underground water formation. If the source well water flow is large enough, it may be also used for drinking provided the water is of good quality.

A common auxiliary feature of many groundwater source heat pumps is a secondary heat exchanger coil to provide domestic hot water. A groundwater heat pump provides hot water at the same efficiency as it does for space heating. In addition, excess heat that is absorbed during the cooling cycle can be used to heat water as a free by-product of air conditioning.

Heat Pump Reliability

One of the major concerns of the heating or building contractors is the reliability and maintenance of groundwater heat pumps. Some contractors have undoubtedly already installed air-to-air heat pump units in Utah homes and have probably had few installations or maintenance problems. Since the major components of a groundwater heat pump are the same as an air-to-air unit, groundwater heat pump maintenance requirements are similar. However, since a groundwater heat pump has a water-to-refrigerant heat exchanger through which groundwater flows, corrosion and scaling may occur in the heat exchanger piping if the groundwater is of poor quality. Iron, calcium, magnesium, salts, and suspended solids can result in corrosion, scaling, and encrustation. Some manufacturers design their equipment to reduce the effects of poor water quality. One way to prevent scale is to use cupronickel instead of copper tubing. The cupronickel expands and contracts with temperature, and its surface tends to flake off mineral deposits and scale with each cycle.

The compressor is an important component in any heat pump. Its main function is to pump refrigerant vapor from a relatively low suction pressure to a higher delivery pressure. The suction and delivery pressures are a function of the heat pump design and groundwater temperatures. Under a large difference between the delivery and suction pressures, the compressor must work harder for the same flow rate, which requires more electrical input, and higher mechanical stresses in a crankshafts, bearings, and valves. These high stresses often caused compressor failures in the early heat pump models. In recent years, however, compressors have been developed which have better bearings and improved valving. Improved motor insulations have been developed, and better motor cooling methods are being used. In short, compressors are much more rugged and are protected by much better controls. In fact, the extra durability of today's heat pumps has lessened the requirement for numerous protective controls, and thus lowered the number of parts which can cause problems. For example, 20 years ago heat pumps had many relays; today, most have only three.

Most of the controls and protective devices necessary for efficient and safe groundwater heat pump operation are provided by the manufacturer and are located within the heat pump enclosure. Usually the only control for which the contractor is responsible is the room temperature thermostat (recommended or supplied by the manufacturer) which the contractor must install, connect, and adjust. If a water storage tank is installed, the contractor must also install the tank temperature control. Most of the electrical connections are self-contained and prewired within the heat pump unit. Most heat pumps require a 220V, 60Hz power supply from a separate circuit breaker at the main box. Individual manufacturer's electrical ratings should be consulted.

The reliability of heat pumps is clearly improving, as evidenced by a preventative maintenance and service program conducted by the American Electric Power Company (AEP) in which detailed maintenance reports have been shared by individual heat pump manufacturers on a regular basis since 1961. The important results of the program are summarized in Table 2. Annual maintenance costs for four different manufacturers are compared for the in-warranty period (first five years) and the out-of-warranty period (next five years). The average for all manufacturers is also compared. Annual maintenance costs have decreased substantially for all manufacturers except manufacturer D whose data were erratic.

As far as the reliability of individual components of the heat pump, compressor failure constitutes the major percentage of maintenance costs, as indicated in Table 3. Fans have the next highest maintenance cost percentage, followed by refrigerant leaks and flow controls. The prime targets for improved reliability continue to be compressors and fans, especially fan motors and compressor controls.

Another indication of improved heat pump reliability is its sales volume history. Shortly after 1952, the year heat pumps were made commercially available, sales were slow but increased steadily until about 1963. Then, as a result of a high number of heat pump failures in the 1950s models, sales growth nearly came to a stand still. No one wanted a product with such low reliability and high service costs. But the heat pump industry perservered; improved designs were

Table 2. Heat pump maintenance-cost trend-line values, five-year intervals, in 1976 dollars.[a]

Model Year	In Warranty					Out of Warranty				
	All MFG.	MFG. A	MFG. B	MFG. C	MFG. D	All MFG.	MFG. A	MFG. B	MFG. C	MFG. D
1957	$131	$150	$214	$109	$34	$228	$271	$270	$369	$59
1961	109	96	121	94	42	201	163	189	242	179
1966	83	57	60	75	93	168	87	121	143	180
1971	56	35	29	55	93	135	46	77	85	–
1976	29	22	14	36	–	102	25	49	50	–

[a] Actual dollars spent on maintenance were less, depending on the year analyzed. Adjustments to 1976 dollars were necessary for comparison purposes.

Table 3. Heat pump component failures, percent of total cost.

Major Group	First 5 yrs. (0-4th yr.)	Next 5 yrs. (5-9th yr.)	Last 5 yrs. (10-14th yr.)	Average (0-9 yrs)	Average (9-14 yrs)
Compressors (Mechanical, Electrical, Controls)	43%	57%	55%	50%	52%
Fans	18%	16%	19%	17%	17%
Refrigeration Leaks	15%	9%	9%	12%	11%
Refrigeration Flow Controls	7%	7%	6%	7%	7%
Supplemental Heating	6%	4%	5%	5%	5%
Misc.	11%	7%	6%	9%	8%

developed, components were made more rugged, and installations were improved. The industry had corrected its faults and was ready to push forward after eight years of readjustment (Figure 5). As a result of the heat pump industry's great push to improve their products, heat pump shipments rose sharply in the early 1970s and have skyrocketed ever since.

Water Wells and Groundwater Availability

The wells and well pump are an integral part of a groundwater heat pump system. The first questions that come to mind are, "Is there enough groundwater available in a particular location for use by a groundwater heat pump?" and "How deep must the wells be drilled?" An experienced well driller is probably best suited to answer both questions. The map in Figure 6 can serve as a rough guide in locating major groundwater formations in Utah. Groundwater also may be found in many other more localized areas throughout the state. The homeowner should realize that the deeper the wells must be drilled to reach groundwater the more costly his total heat pump system will be, and he should decide for himself whether or not drilling deep wells is economically feasible.

It is necessary to obtain a well permit for a groundwater heat pump system. To acquire the well permit (water right) the home owner must file an application with the Utah Division of Water Rights and receive approval of the application. The normal period for such an application is about 120 days.

Where water rights are not being permitted for consumptive purposes, no such auxiliary uses as irrigation could be made from approved groundwater heat pump wells.

A good feature of a groundwater heat pump system which utilizes a source well and a recharge well is that there is no net depletion of the groundwater aquifer. The same water which is pumped from the source well and enters the water-to-refrigerant heat exchanger is discharged into the ground via a second well. The only change is a slight increase or decrease in temperature depending upon whether the heat pump is cooling or heating the house. Of course, the two wells should be spaced a sufficient distance apart to prevent large amounts of recycled water from being pumped again around through the heat pump thereby decreasing its efficiency. A minimum well separation distance of about 50 feet should be adequate to prevent recycling, for most groundwater formations. Most building lots should be able to accommodate two wells 50 feet apart within their boundaries. The wells need not be close to the house, and since the water is at ground temperature it is not necessary to insulate the pipes. The pipes should be buried deep enough to prevent freezing in the winter.

A decrease in the amount of well water used by the heat pump system results from the addition of an underground tank immediately adjacent to the well in the surrounding soil. The heat pump then uses the water stored in the

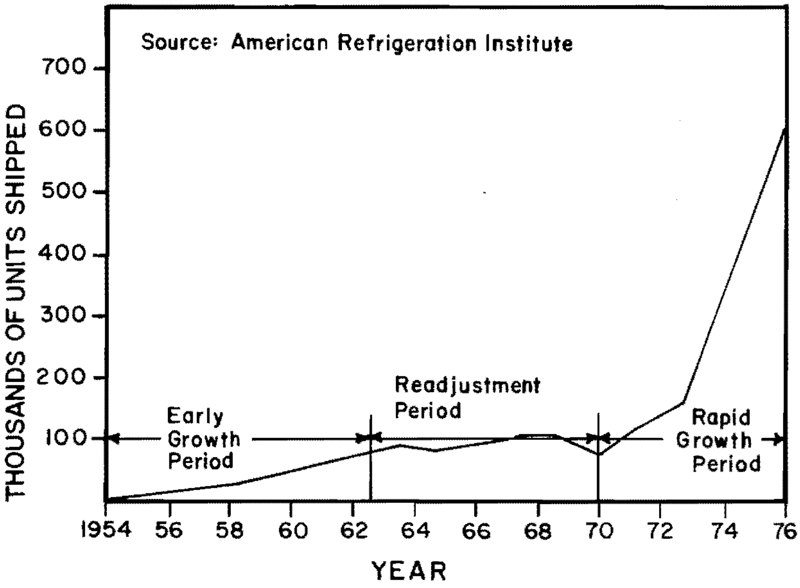

Figure 5. Industry shipment of unitary heat pumps.

tank and from the heat exchanger the water is returned to the tank to be reused by the heat pump. In the heating mode, for example, the heat pump would extract heat energy from the water in the tank until the water temperature is lowered to a predetermined lower limit, say 40 degrees, then a heat sensor would signal the well pump to begin adding warmer groundwater to the tank, thus displacing the colder water which would be returned to the aquifer. The well pump would continue pumping warmer water into the tank until a higher selected temperature was reached. Of course, the advantages of using a storage tank system are the smaller water requirements from the aquifer and the smaller amount of electricity consumed by the well pump. In fact, during the spring and fall seasons, the heat pump can often operate solely from the water in the tank since the house is heated at night and cooled in the daytime. A general rule for sizing the storage tank is one gallon per square foot of living space to be conditioned.

Heating Load Calculations

The heat that flows through a given residential building component may be estimated by means of a simple formula

$$q = U A (t_i - t_o)$$

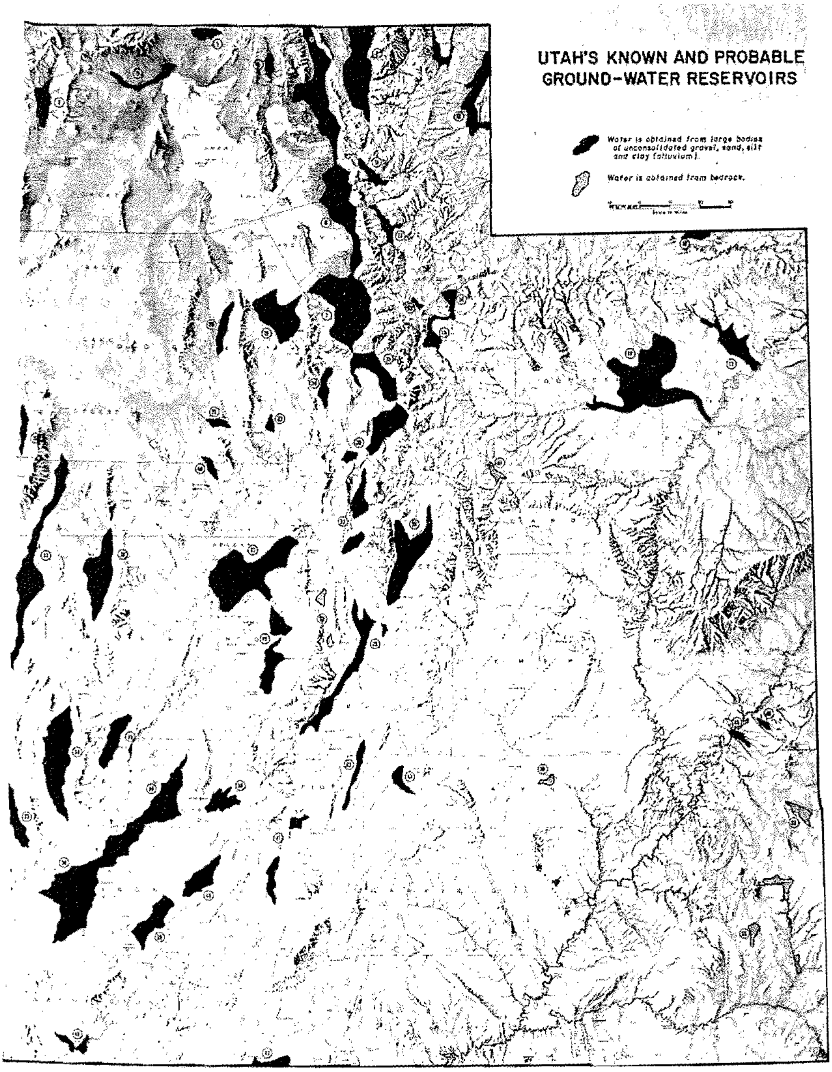

Figure 6. Distribution of groundwater aquifers in Utah.

where:

q = heat transmitted in Btu/hr
U = the overall heat transmission coefficient in Btu/hr sq. ft. $^{\circ}$F
A = area in sq. ft. measured perpendicular to the direction of heat flow
t_i = inside design temperature in $^{\circ}$F
t_o = outside design temperature in $^{\circ}$F

The usual direction of heat flow in a residential building is perpendicular to a window or a wall or a roof or a floor. The value of U depends, in general, upon the kinds of materials through which the heat flows. Table 4 contains values of U for a variety of typical Utah residential building components. The value of the inside design temperature, t_i, depends on the season for which the load estimate is being made: the U.S. Department of Energy recommends 65°F in the Winter and 78°F in the Summer.

The value of the outside design temperature, t_o, to be used in the heat transmission formula depends not only upon the season but also upon the locality and upon whether or not the component is above grade or below grade (soil level). For above grade walls, windows, or roofs,

$$t_o = \begin{cases} T_H, {}^{\circ}F, & \text{for heating season as given in Table 5} \\ T_c, {}^{\circ}F, & \text{for cooling season as given in Table 5} \end{cases}$$

The design values listed in Table 5 for T_c and T_H are based on average yearly climatological data records for a variety of Utah towns at a variety of altitudes. It is interesting to compare values of T_c and T_H for St. George and for Woodruff to see the extremes in Utah.

The degree day information given in Table 5 is useful for estimating the fuel requirement during the heating or cooling season. The degree day may be defined in the following way: During one day, there are as many degree days as there are degrees Fahrenheit temperature difference between 65°F and the average outdoor air temperature for the day. Thus, if the average outdoor air temperature is 40°F, 25 degree days would accrue during that day. The formula for calculating the fuel requirements is

$$F = \frac{24 \times DD \times q}{\eta \times (t_i - t_o) \times H}$$

where

F = quantity of fuel required for period desired (units depend on H)
DD = degree days for period desired (from Table 5)
q = total heat loss in Btu/hr (found using $q = UA\,(t_i - t_o)$)

Table 4. Approximate transmission coefficients, U (Btu/hr - sq. ft. - ^{o}F).

Item	Description	U
A. Walls with 1/2 in. gypsum wall board (sheetrock) on inside:		
(1)	8 in. concrete block, 1/2 in. mortar, 4 in. brick,	
(a)	no insulation in core	0.1710
(b)	mineral wool or vermiculite in core	0.1402
(2)	2 x 4 studs, 16 in. centers, no insulation, plus:	
(a)	1/2 in. plywood, 3/4 in. wood siding	0.2834
(b)	1/2 in. celotex, 4 in. brick	0.3167
(3)	2 x 4 studs, 16 in. centers, R-11 insulation, plus:	
(a)	1/2 in. plywood, 3/4 in. wood siding	0.0713
(b)	1/2 in. celotex, 4 in. brick	0.0736
(4)	2 x 6 studs, 16 in. centers, R-19 insulation, plus:	
(a)	1/2 in. plywood, 3/4 in. wood siding	0.0494
(b)	1/2 in. celotex, 4 in. brick	0.0506
(5)	2 x 6 studs, 24 in. centers, R-19 insulation, plus:	
(a)	1/2 in. plywood, 3/4 in. wood siding	0.0465
(b)	1/2 in. celotex, 4 in. brick	0.0475

Notes: (i) Walls (1a), (2a), and (2b) were typically used during 1950-1960 home construction in Utah.

(ii) Thickness changes of up to 1/2 in. will not change U values significantly.

Item	Description	U
B. Windows:		
(1)	Single sheet, fixed (non-opening)	
(a)	without storm window	1.1000
(b)	with storm window, 3/4 to 4 in. air gap	0.5500
(2)	Single sheet, movable, average fit	
(a)	without storm window	2.2000
(b)	with movable storm window	0.7400
(3)	Two sheets, fixed, 1/4 to 1/2 in. air gap	
(a)	without storm window	0.6200
(b)	with storm window, 3/4 to 4 in. air gap	0.3538
(4)	Two sheets, movable, 1/4 to 1/2 in. air gap	
(a)	without storm window	0.9140
(b)	with storm window	0.3846
(5)	Three sheets, 1/4 to 1/2 in air gap, no storm window	
(a)	fixed	0.3500
(b)	movable	0.5160

Note: The estimated U-values for movable windows exceed those of fixed windows because infiltration losses have been included.

Table 4. Continued.

Item	Description	U
C. Basement wall, heated, 8 in. thick:		
(1)	No insulation	0.6462
(2)	Fiber glass, 1 in.	0.2270
(3)	Polyurethane foam, 1 in.	0.1282
(4)	Fiber glass, 3.5 in.	0.0866
D. Basement Floor, 8 in. thick concrete, vinyl floor tile plus		
(1)	No insulation	0.5128
(2)	Fiber glass, 1 in.	0.2080
(3)	Polyurethane foam, 1 in.	0.1219
E. Ceiling and Roof: Flat or pitched cathedral ceiling (U values for pitched case are based on horizontal ceiling area.)		
(1)	1/2 in. gypsum, 2 x 4 or 2 x 8 ceiling joists, 5/8 in. plywood deck, built-up gravel or asphalt shingles or wood, shingles, no insulation	0.3058
(2)	As above, 1/2 in. insulation board	0.2212
(3)	As in (1) plus 1 in. polystyrene insulation	0.1345
(4)	As in (1) plus 1 in. polyurethane insulation	0.1050
F. Ceiling and Roof: Pitched roof over flat ceiling: asphalt shingles, 2 x 4 ceiling rafters, 1/2 in. gypsum, 5/8 plywood deck plus:		
(1)	No insulation	0.2183
(2)	R-9 insulation	0.0868
(3)	R-11 insulation	0.0739
(4)	R-19 insulation	0.0465
(5)	R-30 insulation	0.0308
(6)	R-38 insulation	0.0247

η = utilization efficiency of heating/cooling unit (η = COP for heat pumps, 0.75 for gas furnace, 1.0 for electric resistance heating)
t_i = inside design temperature in °F
t_o = outside design temperature in °F (from Table 5)
H = heating value of fuel, Btu per unit volume (H = 3413 Btu/KWH for electricity)
24 = 24 hours per day

Monthly heating and cooling degree days are given in Table 6 for four selected Utah cities. For example, the quantity of natural gas required by a home in Salt Lake City during the month of February assuming a utilization efficiency of 75 percent and a total heat loss of 60,000 Btu/hr is

$$F = \frac{24 \text{ hrs/day} \times 664 \text{ deg. days} \times 60{,}000 \text{ Btu/hr}}{0.75 \times (68\text{-}5)^{\circ}\text{F} \times 1{,}000 \text{ Btu/cubic feet}}$$

Table 5. Annual Utah weather design data for heating/cooling load calculations.

City	Elevation ft.	Design Heating Temp., T_H, °F	Heating Degree Days, HDD	Design Cooling Temp., T_C, °F	Cooling Degree Days, CDD
Alpine	4935	2	4695	89	608
Alton	6980	3	5355	84	160
Blanding	6036	7	4720	90	600
Bluff	4320	9	3600	95	1155
Cedar City	5618	1	4215	89	819
Coalville	5550	-8	4956	89	124
Delta	4653	0	4467	95	764
Duchesne	5520	-9	4817	89	386
Emery	6250	3	5239	85	252
Fillmore	5160	3	4223	95	909
Green River	4070	-1	4038	98	1057
Heber	5580	-9	4946	89	166
Kanab	4985	9	3639	94	982
Laketown	5980	-6	5589	86	99
Levan	5315	0	4526	90	624
Logan	4785	2	4888	90	584
Manti	5740	-1	4695	88	367
Moab	3965	9	3647	97	1521
Monticello	6820	4	5216	85	260
Morgan	5070	-7	4840	91	278
Ogden	4350	9	4592	93	946
Panguitch	6720	-8	5090	86	97
Price	5680	1	4684	92	644
Provo	4470	1	4550	93	681
Richfield	5270	-1	4436	92	407
Roosevelt	5104	-5	4866	92	537
St. George	2760	19	2889	102	2047
Salt Lake City	4222	5	4487	95	927
Scipio	5306	-9	4361	91	449
Spanish Fork	4720	7	4382	94	892
Tooele	5070	9	4362	91	859
Tropic	6280	5	4925	88	306
Vernal	5280	-6	5217	90	342
Wendover	4237	11	4608	95	1137
Woodruff	6315	-19	5580	85	34
Zion Natl Park	4050	17	2946	100	2067

Note: Design temperatures and degree days have been corrected according to ASHRAE correction factors.

Table 6. Monthly heating and cooling degree day normals for four selected Utah cities.

City	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Annual
							Heating						
Logan	0	6	106	325	616	844	922	734	650	394	206	85	4888
Salt Lake City	0	4	79	302	583	807	860	664	590	356	178	64	4487
Moab	0	0	16	192	511	769	837	596	458	208	56	4	3647
St. George	0	0	5	106	417	657	685	471	365	155	27	1	2889
							Cooling						
Logan	245	207	56	6	0	0	0	0	0	0	13	57	584
Salt Lake City	363	300	99	11	0	0	0	0	0	0	30	124	927
Moab	505	425	173	16	0	0	0	0	0	11	108	283	1521
St. George	598	546	303	56	0	0	0	0	0	29	152	363	2047

so, F = 20,236 cubic feet of natural gas. Using 1979 Mountain Fuel Supply Co. natural gas prices, the fuel bill for the month would be $37.08.

The quantity of electricity required by a groundwater heat pump (COP = 3.2) for the same home during February is

$$F = \frac{24 \text{ hrs/day} \times 664 \text{ deg. days} \times 60{,}000 \text{ Btu/hr}}{3.2 \times (68\text{-}5)^{\circ}\text{F} \times 3413 \text{ Btu/KWH}}$$

so, F = 1390 KWh of electricity. Using 1979 Utah Power and Light all electric home rates, the fuel bill for the month would be $47.36.

If the building component being analyzed is below grade, then

$$t_o = \begin{cases} 54^{\circ}\text{F for Logan} \\ 58^{\circ}\text{F for Salt Lake City} \\ 63^{\circ}\text{F for Moab} \\ 66^{\circ}\text{F for St. George} \end{cases}$$

are the recommended values for four typical Utah locations; these values of t_o are taken to be equal to that of the average local groundwater temperature. Since the heat transmitted through below grade structures is usually such a small fraction of the total for a given building and since groundwater temperatures do not vary significantly with the season or greatly with the geography, one may choose from the four listed temperatures a value of t_o that corresponds with a similar climate. Also note that below-grade heat transmission is comparatively small because design values for t_o are close to inside design temperatures.

In practice, one applies the heat transmission formula separately to each of the building components and then the total heating or cooling load is simply the summation of the separate parts. Table 7 is a worksheet that is designed to aid in the calculation procedure. Use of the worksheet is mainly self-explanatory. As already noted in Table 4, the U-values for pitched roof-ceiling combinations are based on horizontal ceiling areas.

In northern parts of Utah the heating load will be dominant and will thus determine the size of the heat pump unit.

Choosing a heat pump unit that is smaller than the heating load calls for will mean the unit cannot supply enough heat some of the time; choosing a unit that is larger than calculations call for will cause the unit to run only part of the time even during maximum heating periods, thereby resulting in reduced efficiency. The heat pump should therefore be sized as close to the calculated value as possible. Heating loads should be used to size the heat pump for any Utah climate because the heating load exceeds the cooling load for virtually all regions of the state.

Table 7. Heating/cooling load calculation worksheet.

Location ____________ Altitude ____________ Season ____________

Design t_i ____________ °F Design t_o ____________ °F Degree Days ____________

Item	U-Value (Table 4)	Area, ft^2	$t_i - t_o$ °F	q, Btu/hr
I. Above Grade Structures: Use t_o from Table 5.				
A. Ceiling/Roof Combination				
B. Vertical External Walls				
C. Horizontal Foundation Overhang				
D. Vertical External Basement Walls				
E. Windows, Fixed				
F. Windows, Movable				
G. Doors, Wooden				
H. Doors, Sliding Glass				
I. Miscellaneous:				
II. Below-Grade Structures: Use t_o from Table 6.				
A. Vertical External Basement Walls				
B. Basement Floors				
C. Miscellaneous				
III. Total Load:				

Note: The above calculations neglect solar loads which are usually negligible during the heating season but may be significant during cooling season.

After the heating load calculations have been completed and the heat pump sized, this information should be shared with the manufacturer from which the customer is purchasing the heat pump so that the proper size unit can be selected. Some manufacturers may even require a set of construction plans on the home so that they can perform the heat load calculations and size the unit themselves. In either case, contractor and manufacturer should be in close contact so that the proper equipment can be selected.

Once the heat pump has been selected, the proper duct sizes must be determined. Since heat pumps circulate warm air at lower temperatures than do conventional gas and electric furnaces, a larger volume of air must be circulated to provide the same total heating requirement. This calls for larger air ducts than conventional furnaces require. Figure 7 shows the typical range of cubic feet per minute (cfm) of air required for a range of heat pump capacities in Btu/hr. This graph, which is based on actual groundwater heat pump manufacturers' data, can be used to estimate the approximate cfm required once the heat pump size has been determined.

To obtain the proper duct size for a specific cfm value, use Table 8 which lists the proper supply diameters, rectangular duct choices and return diameters for a range of airflow values. Suppose that a duct must deliver 2000 CFM of air. This means that the supply diameter would need to be around 18 inches. The approximate rectangular duct choices are 8 x 40, 10 x 30, 12 x 24, 14 x 20 and 16 x 17 inches. The proper return diameter is 22 inches, and the rectangular choices for the return are 12 x 36, 14 x 30, 16 x 26, 18 x 23 and 20 x 20 inches.

Calculation of Water Flow Requirement

In order for a groundwater heat pump to operate at its specified heating and cooling capacity and efficiency, the proper groundwater flow rate through the water-to-refrigerant heat exchanger must be maintained. The groundwater aquifer, well and pumping system must be able to supply the required flow rate. A rule of thumb for estimating the required water flow rate is 2½ to 3 gallons per minute (gpm) for every 12,000 Btu/hr of heating or cooling required. This flow rate also depends upon the groundwater temperature to some extent, but we will use the standard 3 gpm/ton in all flow rate calculations for the example problem. Based on this value, the flow rate can easily be obtained using Figure 8. For example, suppose the heating load is 30,000 Btu/hr. From Figure 8, the required flow rate is 7.5 gpm. If the manufacturer specifies a lower flow rate than 3 gpm/ton, use the manufacturer's value for the calculation.

Well Pump and Supply/Return Pipe Sizing

An important component of any groundwater heat pump system is the well pump. If the heat pump is to operate properly and efficiently, the well pump must be able to supply the required volume of water to the water-to-refrigerant

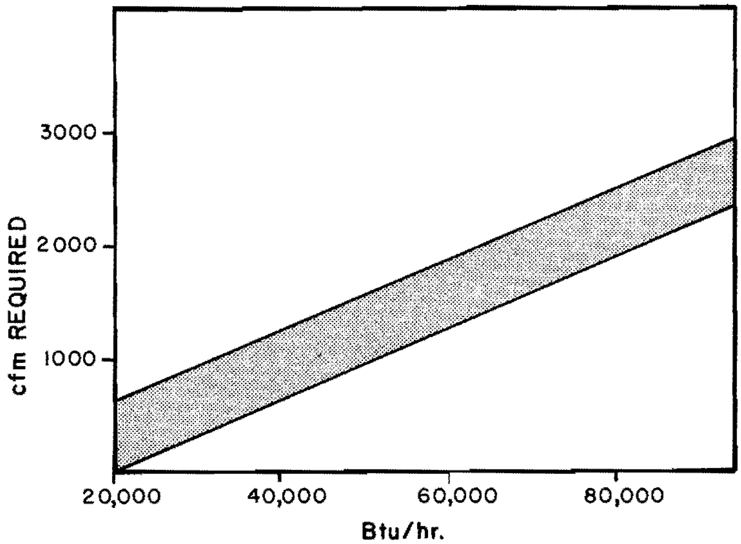

Figure 7. Typical airflow required (heating and cooling).

Table 8. Duct sizing guide.

Req'd cfm	Supply Dia. In.	Standard Rectangular Choices					Return Dia. In.
35	5	2¼ x 10	3 x 8	3½ x 6	4 x 5½	5 x 5	5
60	5	2¼ x 10	3 x 8	3½ x 6	4 x 5½	5 x 5	6
100	6	3¼ x 10	4 x 8	5 x 6	5½ x 5½	–	7
150	7	3¼ x 14	4 x 11	5 x 8½	6 x 7	6½ x 6½	8
210	8	4 x 15	5 x 12	6 x 10	7 x 8	8 x 8	9
225	8	4 x 15	5 x 12	6 x 10	7 x 8	8 x 8	10
280	9	5 x 15	6 x 12	7 x 10	8 x 9	8½ x 8½	10
305	9	5 x 15	6 x 12	7 x 10	8 x 9	8½ x 8½	12
395	10	6 x 15	7 x 13	8 x 11	9 x 10	9½ x 9½	12
410	12	7 x 18	8 x 16	9 x 14	10 x 12	11 x 11	12
655	12	7 x 18	8 x 16	9 x 14	10 x 12	11 x 11	14
680	14	8 x 22	9 x 19	10 x 17	11 x 15	12 x 14	14
995	14	8 x 22	9 x 19	10 x 17	11 x 15	12 x 14	16
1325	16	8 x 30	10 x 22	12 x 18	14 x 16	15 x 15	18
1450	16	8 x 30	10 x 22	12 x 18	14 x 16	15 x 15	20
1750	18	8 x 40	10 x 30	12 x 24	14 x 20	16 x 17	20
2000	18	8 x 40	10 x 30	12 x 24	14 x 20	16 x 17	22
2250	20	10 x 38	12 x 30	14 x 26	16 x 22	18 x 19	22
2600	20	10 x 38	12 x 30	14 x 26	16 x 22	18 x 19	24
2900	22	12 x 36	14 x 30	16 x 26	18 x 23	20 x 20	24
3400	22	12 x 36	14 x 30	16 x 26	18 x 23	20 x 20	26
	24	14 x 38	16 x 32	18 x 28	20 x 25	22 x 22	
	26	16 x 38	18 x 32	20 x 30	22 x 24	24 x 24	

heat exchanger. There are two main factors which determine the proper size for the well pump: water flow rate and lift (height which the pump must lift the water out of the ground). The following formula is used to calculate the correct size (horsepower) well pump to use:

$$hp = \frac{QH}{(3956)e} = \frac{QH}{2637}$$

where:

hp = well pump horsepower
Q = water flow rate, gallons per minute
H = lift, feet
e = pump unit efficiency (typically 0.67)

For ease of use, this formula is presented in graphical form in Figure 9. To illustrate the use of Figure 9, assume a water flow rate of 10 gpm and a lift of 200 feet. For this example, the required horsepower is found to be about ¾ hp. In practice it is better to oversize a well pump somewhat than to undersize it. An oversized well pump will be more rugged and will compensate for friction losses in the pipes, fittings, elbows, and heat exchanger.

The pipes which deliver the groundwater to the heat pump and back into the discharge well must have a large enough inside diameter to accommodate the required water flow rate and to allow for friction losses. Figure 10 shows the relationship between the minimum required inside pipe diameter and the previously calculated flow rate. Figure 10 applies to schedule 40 steel pipe and includes 6.44 ft. of friction loss per 100 ft. of pipe. If smoother pipe such as copper or plastic is used, Figure 10 should probably be used in most cases even though the friction loss is lower. This will allow some extra capacity to compensate for any additional friction losses without adding greatly to the costs.

Design Example

Now that all the basic design procedures for a groundwater heat pump system have been outlined, we will go through a complete design example. In order to calculate the heating load using the formula $q = UA\ (t_i - t_o)$, we must know the total square footage of those areas of the house that will be actively heated. The inside and outside design temperatures must also be known. Let's use the following data for our "design house":

Location	Salt Lake City, Utah
House style	rectangular, one-story
Floor area	1500 sq. ft. (30 x 50 ft.)
Basement	1500 sq. ft. heated
Walls	1024 sq. ft., 2 x 4 studs on 16 in. centers, R-11 insulation, 1/2 in. plywood, 4 in. brick

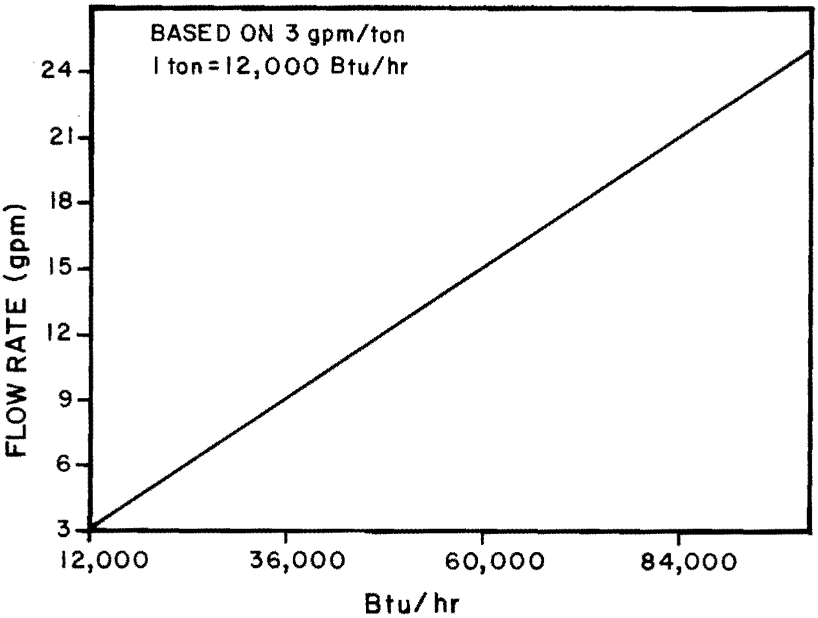

Figure 8. Well water flow rate required.

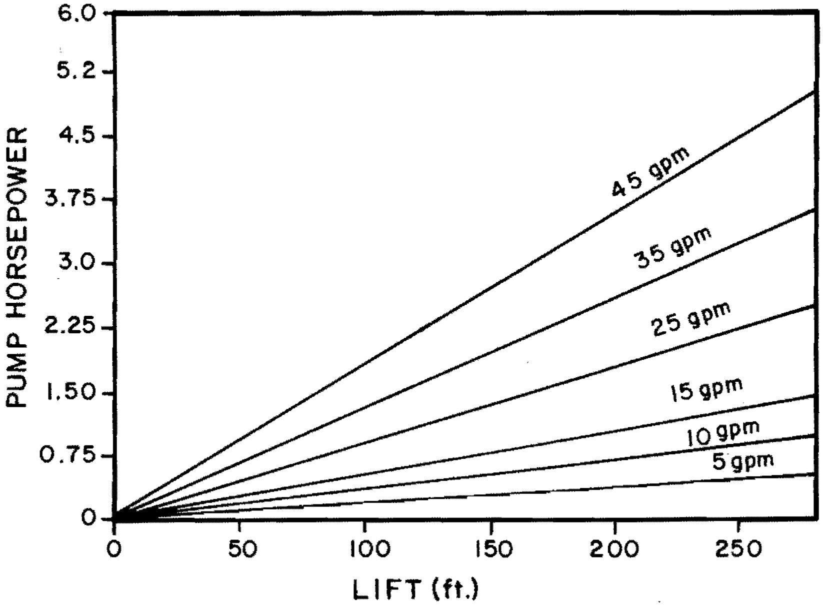

Figure 9. Minimum well pump horsepower required. (e = 0.67)

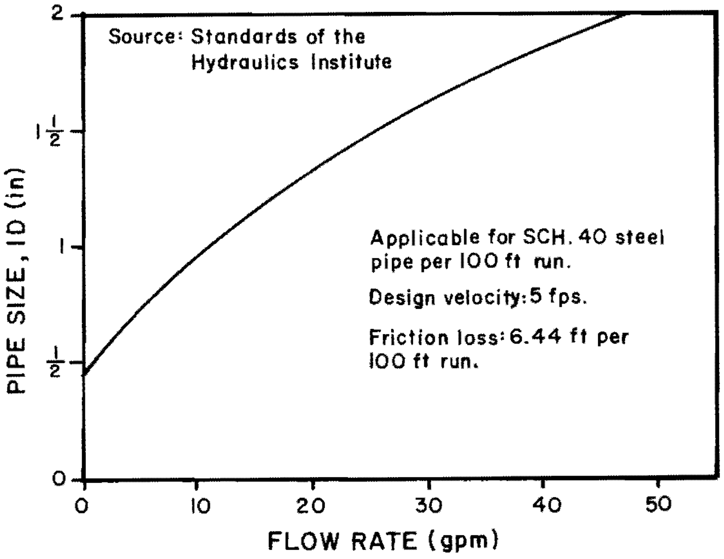

Figure 10. Supply and return well water pipe size required.

Windows	200 sq. ft., two sheets, fixed without storm window 56 sq. ft., single sheet, movable, without storm window
Basement walls above grade	160 sq. ft., 8 in. thick, polyurethane foam, 1 in.
Basement walls below grade	960 sq. ft., 8 in. thick, polyurethane foam, 1 in.
Basement floor	1500 sq. ft., 8 in. thick, polyurethane foam
Ceiling and Roof	1500 sq. ft., pitched roof over flat ceiling, asphalt shingles, 2 x 4 ceiling rafters, 1/2 in. gypsum, 5/8 in. plywood deck, R-19 insulation
Groundwater depth	100 ft.

From Table 5, the outside design temperature for Salt Lake City is 5°F. The inside design temperature is a matter of choice and depends upon the occupants' desired level of comfort. Let's use 68°F as our inside design temperature. From Table 4 the U value for the walls is 0.0736; for the two-sheet windows, 0.6200; for the single sheet windows, 2.200; for the basement walls above and below grade, 0.1282; for the basement floor, 0.1219; and for the ceiling and roof 0.0868. Now we are ready to calculate the total heat loss using the formula $q = UA(t_i - t_o)$. Table 9 summarizes the calculation.

Therefore, the example house requires a heat pump that is rated at 35,000 Btu/hr, or approximately 3 tons.

Table 9. Summary of calculation.

		U	A	ΔT	Q
Walls		0.0736	1024	(68-5)	4,748
Windows	(2 sheets)	0.6200	200	63	7,812
	(1 sheet)	2.200	56	63	7,762
Basement walls above grade		0.1282	160	63	1,292
Basement walls below grade		0.1282	960	(68-51)[a]	2,092
Basement floor		0.1219	1500	(68-51)	3,108
Ceiling and roof		0.0868	1500	63	8,203

Total heat loss = 35,017 Btu/hr

[a] Winter groundwater temperatures from Table 1 are used for outside design temperatures when calculating heat loss through basement walls below grade and basement floor.

Next we will determine the required size of ducts. We see from Figure 7 that for a heating load of 35,000 Btu/hr the required air flow is around 900 cfm. Referring to the duct sizing guide in Table 8, a supply diameter of 14 inches is needed which can be satisfied by rectangular duct choices of 8 x 22, 9 x 19, 10 x 17, 11 x 17, 11 x 15 or 12 x 14 inches. The proper return diameter is 16 inches which can be satisfied by rectangular choices of 8 x 30, 10 x 22, 12 x 18, 14 x 16 or 15 x 15 inches.

Using the general rule of 3 gpm per 12,000 Btu/hr of heating required, we see from Figure 8 that the required water flow rate is 8.75 gpm.

As for the well pump, Figure 9 indicates that for a 100 ft. lift and a flow rate of 8.75 gpm, the required horsepower is about 0.375 hp.

And finally, from Figure 10, the minimum required inside supply and return pipe diameter is approximately 1 inch.

Summary

The future looks promising for groundwater heat pumps in Utah—especially in the southern portion of the state and in areas where natural gas is not readily available. Groundwater heat pumps are more efficient than conventional furnaces, and they provide cooling as well as heating. The major disadvantage of a groundwater heat pump system is the initial cost. Nevertheless, a typical groundwater heat pump having an average COP of 3.2 will pay for itself in as little as six or seven years as a result of the cost savings over conventional electric heating. A groundwater heat pump is also more efficient than an air-to-air heat pump because of the high heat capacity of water and groundwater temperatures remain fairly constant the year round. The reliability of heat pumps has improved greatly since they were made commercially available in 1952. Compressors, which are the heart of heat pumps, remain the major source of maintenance troubles, but they too have been much improved over earlier years. Groundwater availability and depth depend on the location, so local groundwater experts or well drillers should be consulted. Using the information and methods described herein, adequate heat pump equipment can be selected for home heating applications.

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2. A Groundwater Heat Pump Anthology. National Water Well Association, 500 W. Wilson Road, Worthington, Ohio 43085, $3.00.

3. The Unitary Heat Pump Industry - 25 Years of Progress. Joseph A. Pietsch, ASHRAE Journal, July 1977. (See the reference librarian in any University library.)

4. Heat Pumps. ASHRAE Journal, September 1979.

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6. Heat Pump Technology, June 1978, U.S. Department of Energy, Division of Buildings and Community Systems, Washington, D.C. 20545.

7. Demonstration of Building Heating with a Heat Pump Using Thermal Effluent, May 1977, Peter W. Sector. Directorate of Military Construction Office, Chief of Engineers, Washington, D.C. 20314.

Water Source Heat Pump Manufacturers

Company	Utah Distributor
American Air Filter 215 Central Avenue Louisville, Kentucky 40201 (502) 637-0325	Midgley-Huber, Inc. 44 W 8th South Street Salt Lake City, Utah 84101 (801) 322-2537
Carrier Corporation Carrier Parkway P.O. Box 4808 Syracuse, New York 13221 (315) 432-6000	Continental Air Conditioning, Inc. 2861 W 2700 S Granger, Utah (801) 972-4014
Mammoth Division Holland Plant 341 East 7th Street Holland, Michigan 49423 (616) 392-7021	Long-Deming-Utah, Inc. 80 West Louise Avenue Salt Lake City, Utah 84115 (801) 487-0808
McQuay-Perfex, Inc. 13600 Industrial Park Blvd. Minneapolis, Minnesota (612) 553-5330	AA Maycock 3300 W 7th Street P.O. Box 36 Salt Lake City, Utah 84101 (801) 364-1926
Solar Energy Resources Corp. 10639 Southwest 185th Terrace Miami, Florida 33157 (305) 233-0711	(No Local Distributor)
International Energy Conservation Systems, Inc. 1775 Central Florida Parkway Regency Industrial Park Orlando, Florida 32809 (305) 851-9410	Gunther's 31 N 100 W American Fork, Utah 84003 (801) 756-9683
Thermal Energy Transfer Corp. 5515 Old Three C Highway Westerville, Ohio 43081 (614) 890-1822	(No Local Distributor)

Company	Utah Distributor
Weatherking, Inc. 4501 East Colonial Drive Box 20434 Orlando, Florida 32814 (305) 894-2891	Andrew Mang Co. P.O. Box 666 1465 Boston Street Aurora, Colorado 80040 (303) 366-5453
Wescorp, Inc. 15 Stevens Street Andover, Maryland 01810 (617) 470-0520	Alan Posen & Associates, Inc. 1942 Market Street Denver, Colorado 80202 (303) 534-3577
Vanguard Energy Systems 9133 Chesapeake Drive San Diego, California 92123 (714) 292-1433	(No Local Distributor)
York Division P.O. Box 1592 York, Pennsylvania 17405 (717) 846-7890	Ted R. Brown & Associates, Inc. 1401 Major Street P.O. Box 1356 Salt Lake City, Utah 84110 (801) 486-7241
Gervais Equipment Energy Company 9295 Fargo Rd. Safford, New York 14143 (716) 343-0352	
ENSCO, Inc. P.O. Box 280 Monroe, N. Carolina 28110 (704) 289-6431	
Phoenix Envir-Temp. 651 Vernon Way El Cajon, CA 92020 (714) 579-3884	

Utah Information Sources

1. Any Utah State University Extension Office. Phone 801+750-2200 for the location of the nearest office.

2. Contact the personnel in the Geothermal Studies Branch, Utah Division of Water Rights, 231 East Fourth South, Salt Lake City, Utah 84111. Phone 801+533-6071.

3. Contact either Dr. Clyde or Dr. Vendell; their USU phone numbers are given inside the front cover.