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INVESTIGATION OF HEAT PUMP EFFICIENCIES
USING GROUNDWATER AND/OR GROUND COIL
IN THE GULF COAST REGION

BY

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FINAL REPORT

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EXECUTIVE SUMMARY

This project examines the energy efficiencies of five different water source heat pump systems. This is further supported by an experimental effort in which an existing residence is retrofited with a heat pump and other energy sources: well water as a heat source/sink, vertical geothermal well as heat source/heat sink/storage, horizontal buried metal and plastic ground coils to use as heat source/heat sink, and a solar assist system. The energy elements are operated individually and in combination configurations to determine performance, and cost effectiveness of the energy alternatives are explored.

The use of well water is a much better selection than a ground coil on the Gulf Coast. The theoretical and actual efficiency of a heat pump using a well water system is better than efficiencies using a ground coil or geothermal well on the Texas Gulf Coast. According to ground temperature estimates a coil would have to be buried 30 to 50 feet below the surface and have a length in excess of 1200 feet for a 3 ton heat pump in order to yield water temperatures that would provide heat pumps with EER's and COP's similar to those using well water. This would have unreasonable cost and the environmental effects of using the ground as a heat sink would be the same for both types of systems.

The vertical well closed system offers the greatest potential for future installations. The installation at our

test site followed the recommendations of other test.

However, several modifications seem warranted for better performance with lower installation cost in the Gulf Coast Region.

Several advantages can be derived by installing several smaller shallower wells in parallel flow to replace the one large well. For example, four 4 inch 100 foot deep wells could replace the 360 foot well. Lighter, less expensive PVC casing could be used and the size of drilling rig required is smaller. This would reduce cost considerably. The pumping pressure would drop and therefore pump cost would be minimized. Water would be pumped through four parallel dip-pipes.

The solar assist system on the vertical geothermal well as installed is not recommended at this time. The high cost of installation and moderate energy savings make it undesirable. Additional expenditures on these type systems would be more wisely used to purchase a heat pump with a higher COP and/or installing larger and more wells to further improve efficiency.

The information is available to the public, especially builders, prospective homeowners and community education projects concerning energy. Two public workshops were held, with good attendance, on August 13, 1981 and March 26, 1982 at Lamar University for this purpose.

The commercialization of this project is highly probable. Heat pump manufacturers are returning to the production of watersource heat pumps which were abandoned in

the years of cheap and abundant energy. However, use of the types of units is limited in this area because of the lack of familiarity of providing water and service.

In addition to providing test results that show water to air heat pumps an attractive option, this report provides practical recommendations for actual installations. The extensive instrumentation incorporated into the test system allows speedy evaluation of how changes in system design effect performance of the water to air heat pump. This avoids the practice of attempting to evaluate performance based on utility bills that are greatly effected by environmental variations and homeowner habits. This report also included the results of our test in areas of house design considerations and recommendations on how to apply them in new home designs and retrofits to existing structures.

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1.0 INTRODUCTION

The present state of technology and construction techniques in the housing industry is dependent on non-renewable energy sources for heating and cooling. Some of the more enterprising home owners and builders have effectively used systems that employ renewable sources. However, most home owners in the United States are forced, for primarily economic reasons, to use existing and often inefficient systems in their homes. The vast majority of Americans cannot afford the added initial cost of energy efficient features such as passive solar designs or active systems. Builders do not have the economic motivation to incorporate what often appears to be elaborate systems into their houses. Manufacturers of heating and cooling equipment prefer to market products that their production and service divisions are familiar with. Homeowners who can afford the added cost of active and passive systems are often more interested in aesthetics than energy efficiency.

The result is the present situation in the battle of excessive energy consumption in the U.S. There are a small number of homeowners saving a lot of energy, a few saving a little bit and a large number unwilling or unable to use recent technological advances to help them consume fewer Btu's. In order to improve this situation intermediate technologies (those technologies that lie somewhere between existing energy

wasteful systems and exotic expensive ones) must be implemented. Many technologies must be used because of the variety of needs, climates and financial situations.

The suggested design features of a home for the Texas coast differ somewhat from those which solar home builders are more commonly using around the country, because of the uniqueness of our climate. The more common means of using solar energy are less advantageous in the Gulf Coast region because of the relatively small heating demand and the large cooling load in a high humidity climate. Figure 1-1 shows the energy demand in the United States overall, for residential and for Texas.

Figure 1-1 Percentage of Energy Consumption

The conversion of solar energy to heat is a much simpler process than the utilization of the sun's rays to cool a home. In addition, the high humidity of this area deters the use of evaporative cooling. Therefore, the present state of technology permits cooling by vapor compression refrigeration or absorption cycles in this region. Presently, the systems that use the sun to provide the energy to drive such cooling equipment are expensive and unrefined.

The practical option at this time is to build homes that are much better insulated and are designed to utilize factors in our climate that optimize the efficiency of existing heating and cooling equipment. Arrangement of the houses in terms of window, door and garage placement is an important factor. The goal of this type of home is not complete energy independence, but a house that uses much less energy, is comfortable, reasonable in cost and can be mass produced by the ordinary builder.

This project examines the energy features of a idealized single family residence for the Gulf Coast, with extensive consideration of water source heat pump options and supplementary residential energy conservation systems. This is further supported by an experimental effort in which an existing residence is retrofited with a heat pump and other energy sources: well water as a heat source/sink, vertical geothermal well as heat source/heat sink/storage, horizontal

buried metal and plastic ground coils to use as heat source/
heat sink, and a solar assist system. The energy elements
are operated individually and in combination configurations
to determine performance, and cost effectiveness of the
energy alternatives are explored.

2.0 FIELD EXPERIMENTAL DESCRIPTION

The test site is located at 3334 Canal, Groves, Texas. The calculation of the test house results in a cooling load of 42,220 Btu/hr based on indoor design condition of 75°F with a relative humidity of 50%, and outdoor design condition of 95°F day bulb temperature with 79°F wet bulb temperature. A Geosystem model SWP 301 water source heat pump was selected for this test. Under ARI (American Refrigeration Institute) standards, with 10.5 gallons per minute water source, it will deliver 40,000 Btu/hr of cooling with an EER of 8.8 and 62,000 Btu/hr of heating with a COP of 3.2.

Two types of horizontal coils have been designed, constructed, and are operational on the test site. A 1000-foot 1½ in. polyethylene ground coil and a 600-foot ¾ in. copper tubing coil buried in a depth of 4-foot as shown in Figure 2-1, have been the heat source/sink for a heat pump system. Temperature ranges for this type of system at the four-foot level are from a high of 82°F in mid-September to a low of 56°F in mid-February.

The second type of earth coil under study is a vertical coil approximately 360 feet in length, as shown in Figure 2-6. Placement of the coil is with a conventional water well drilling machine. The vertical heat exchanger consists of a 5-inch PVC pipe which is capped at both ends and pressurized at approximately 15 PSIG. This sealed and pressurized heat exchanger allows a low power pump to circulate water through both the heat pump and vertical heat exchanger system.

The vertical heat exchanger requires a smaller land surface area and has a quite different thermal environment from the horizontal pipe. For this region (Jefferson County), the earth temperature at depths greater than 50 feet is a constant 69°F.

Both types of earth coupled systems have unique and quite different thermal characteristics when solar assist is considered. The well with its average temperature of 70°F is a much better source for the heat pump than the earth coil which may be at 56°F in the heating season.

2.1 EARTH COIL

The earth coil system connected to the Geosystem's water to air heat pump is designed to study and compare the performance of several different coil arrangements. The coil system consists of five loops (Figure 2-1), each approximately 325 feet in length. Three loops are 1½ inch polyethylene pipe and two loops are 3/4 inch copper tubing and all buried three to four feet beneath the ground surface. These loops are connected to an indoor manifold (Figure 2-2). This manifold allows water from the heat pump to be circulated through in any of the following arrangements:

1. 3-parallel 325' polyethylene loops;
2. 1-975' polyethylene loop;
3. 2-parallel 325' copper loops; and
4. 2-parallel 325' copper loops in series with a 325' polyethylene loop.

Figure 2-1 Coil System

- a. 3-parallel 325' polyethylene loop: 1-4, 2-3 and 5-6
- b. 1-975' polyethylene loop: 1-4-3-2-5-6
- c. 2-parallel 325' copper loops: 1-4 and 2-3
- d. 2-parallel 325' copper loops in series with a 325' polyethylene loop:

1-4	}	5-6
2-3		

The loops are located at different depths in order to determine how burial depth effects performance.

Flow and temperature recording instruments are located in the manifold room. The data from these instruments is used to determine which arrangements and which flow rated yield maximum heat transfer to and from the ground. This data is then compared with the power consumption of the circulating pump and heat pump to determine which coil arrangement is most efficient.

In addition to the data taken on water flow and temperature, thermocouples have been placed in the ground near and on the pipe surfaces. This allows determination of the ground's heat transfer characteristics under different conditions. Thermocouples have also been placed in the ground to a depth of six feet. This will yield additional information that will help optimize the performance of future ground coil installations.

2.2 VERTICAL GEOTHERMAL WELL WITH SOLAR ASSIST

Figures 2-4 and 2-6 detail the vertical type heat exchanger system being studied. The internal configuration is an open system in which the fluid is discharged from the heat pump directly inside a larger (5 in. dia.) PVC pipe by means of a smaller (1½") diameter pipe running the length of the well. Depending upon the type of test being studied, the water may be discharged to the top or bottom. Five Fafco

Supply Manifold

copper

Return Manifold

Figure 2-2 Manifold Layout

solar collectors are installed as shown of Figure 2-3.

During the heating season, the well, in addition to gain heat from the ground, is used as a storage tank to receive the heat that is collected during the daytime.

Figure 2-3 Solar Collectors

2.3 SHALLOW WELL SYSTEM

Water is pumped from the supply well into a surge tank, located in manifold room, to ensure an adequate water supply without the pump continuously working. From this tank the water goes through the supply manifold (Figure 2-2) into the house. As the water enters the house, it travels

through the in-house manifold (Figure 2-5) and to the heat pump. The water then travels outside through the return manifold (Figure 2-2) to the (return) shallow well.

Figure 2-4 Vertical Wells

Figure 2-5 In-house Manifold

Figure 2-6 Vertical Well Design

3.0 TEST RESULTS

Test results indicate the heat pump performed near manufacturer's ratings. Results show that the use of shallow ground water wells permits the water to air heat pump to operate at much higher efficiencies than the ground coils in any arrangement, or the geothermal well. With the ground coil arrangement and geothermal well, the water to air heat pump exhibits the characteristic of air-to-air models of having the EER drop off appreciably under condition of high loads. With the shallow well arrangement the heat pumps efficiency showed little evidence of change due to load. Appendix 6-3 shows the results of tests performed on three days in late July during peak summer conditions. Using the ground coil arrangement with an indoor thermostat setting of 76° the heat pump ran continuously. The characteristic low thermal diffusivity of the soil resulted in an unfavorable heat build-up in the ground around the coils as shown in Figure 3-1. This caused the water to return to the heat pump at 106°F, resulting in high compressor head pressure, increased electrical demand and decreased refrigeration performance.

This adverse condition was not as severe in periods of lighter loads. In periods of moderate loads (unit off as much as it is on) the heat had time to diffuse out of the ground surrounding the coil thus allowing the heat pump to operate with EER's between 8.0 and 9.0. Under these conditions the ground coil performance matched the performance predicted by the computer simulation.

Figure 3-1 Temperature Variations in Earth Coil

Figure 3-2 Water Temperature vs. Efficiency

The performance characteristics of the geothermal well is similar to those of the ground coil, although this 5 inch closed well yielded slightly improved results. During continuous operation the ground coil EER dipped to as low as 6.3 and a water exit temperature of 119°F. Under these same conditions the geothermal well had an EER of 7.2 and an exit temperature of 117°F. This was a result of a ground temperature build-up near the well caused by the lack of heat pump off time that would allow the heat to dissipate. When the heat pump on-off cycle was 50%-50% the EER increased to a value of between 8.6 to 9.0, slightly better values than those of the ground coil system.

The high cost of the geothermal well makes it a less desirable option than the shallow well system and ground coil. However, its performance and heat transfer characteristics in the cooling mode indicate that its performance in the heating mode may exceed the ground coil system. The earth temperature around the coil, with the exception of the upper 20 feet, is between 68° and 75° in the Beaumont area. The ground temperature around the horizontal coil varies between 56° and 83°F. Therefore, the year round performance of the geothermal well will make it a much more desirable option. Because of the small area of ground needed it is more desirable in high density housing areas. It is also much easier to add a solar assist system for improved winter efficiency. Summer performance can also be increased by increasing the recommended sizing from 100 ft. of depth per ton to 125 ft. per ton.

The variation in EER's in the heat pump performance using the shallow ground water wells is much less noticeable.. The heat pump operated at high EER's regardless of load. The primary factor in performance using this system is water flow rate. The efficiency of these heat pumps are closely related to exit water temperature. The higher the exit temperature, the lower the EER. Therefore, under conditions of a constant load the EER can be increased by either lowering the entering water temperature or increasing the flow rate and thereby decreasing the ΔT across the heat exchanger.

Since the well water holds a constant 69°F temperature, flow rate becomes the primary factor effecting EER. Several considerations that effect heat pump efficiencies and water flow rate are: heat pump rating, well pumps, wells, piping, water control and filters. The results of testing, and recommendations in the areas are as follows.

3.1 HEAT PUMP RATING

The heat pump used in this test was a Geosystem Model SWP 301 manufactured by Commande Aire of Waco. The EER at standards established by the American Refrigeration Institute is 8.8 and the COP (coefficient of performance) on the heating cycle is 3.2. Along with the obvious considerations of quality and price, the EER and COP should be primary in selecting a heat pump. As our testing indicates the ARI rating of 8.8 can be improved upon for this unit. However ARI rating is used to

compare the performance of one unit over another. In rating water to air heat pumps the ARI cooling cycle standards are: 85°F entering water, 95°F exit water, 80°F dry bulb and 67° wet bulb air entering the unit. Most heat pump manufacturers supply performance data if conditions differ from standard ones.

In our test EER was improved from 8.8 to 11.3 by supplying 69°F water to the heat pump. (Actually the EER of the heat pump itself was higher than 11.3, but in order to obtain true EER the power consumption of the well pump was added to total consumption. ARI conditions do not consider the power consumed by water pumps.) Similar improvements in EER can be expected from heat pumps of other manufacturers. For example a FHP Model EM52 heat pump has an ARI rating of 11.8 EER, but 13 or 14 can be expected if sufficient amounts of 69°F water are supplied to this model. Likewise the COP can be improved over the ARI ratings if the water supplied is warmer than the standard of 60°F.

3.2 WELL PUMPS

The well (or jet) pump used in this test was a $\frac{1}{2}$ HP Teel Jet Pump with a shallow well ejector. There is a wide variety of this type of pump available on the market. This pump can also operate with a convertible ejector that can be located in the well below the water table or on the pump itself. Because the water table was so near the surface

(12 ft.) at the test site the shallow well ejector yielded more water at a higher pressure while consuming less power. These types of ejectors can not be used if the water table is greater than 25 feet below the pump.

In selecting a pump, manufacturers' performance must be matched to heat pump demand. The pump must deliver the recommended flow rate (preferable the amount on the high end of the recommended range) at pressure that will overcome losses in the piping and heat pump heat exchanger. The Geosystems SWP301 heat pump used in the test required 7.5 to 10.5 gpm. The well pump was sized to deliver 10.5 gpm. At this rate calculated pressure losses were 13.5 psi in the heat exchanger, 9.0 psi in the filter and 5 psi in the piping system. The total pressure drop across the system is 27.5 psi. The pump must be able to deliver 10.5 gpm at 27.5 psig discharge pressure when located approximately 15 ft. above the ground water level in the well. Although large water flow rates maximize heat pump efficiencies, oversizing of pumps is not recommended. Large pumps may exceed the capacity of the well itself and consume more power in their larger motors.

3.3 WELLS

In research programs at Lamar University several wells are presently in use. Recommendations are based on the performance of these wells. On campus at Lamar there are two

wells with 2 inch schedule 40 PVC casings and a 2 inch well screen 5 feet in length. The first well is approximately 70 feet deep. It has a capacity of 9.0 gpm and a water temperature of 71°F. The second well is 90 feet deep, yields 8.0 gpm and 74°F water. Both wells use a 21 foot 1½ inch PVC suction pipe and 1½ inch foot valve. The total cost of the wells was \$500. At the Groves test site two 4 inch PVC cased wells are used. One well is 100 feet deep and has 10 feet of well screen at the base. Another well is 25 feet of casing without a well screen. Both of these wells have a capacity of 12 gpm with a 25 foot 1½ PVC suction pipe. The 100 ft. well yields 72°F water and cost \$990. The 25 foot well was drilled in 1959, but a similar well would cost \$250 to \$300. The water from this well is 69°F.

The 25 foot well is recommended because of cost and performance. It is also possible to dig and install in Texas coastal regions with rental equipment for less than \$100. The 69°F water also yields higher efficiencies in the cooling cycle. In the Beaumont-Port Arthur area screens are not recommended on these shallower wells because of the small particle size of the sand strata. Because of this it is possible to drill this type of well without heavy drilling equipment. The performance of this type of well far exceeds the screened well for re-injection purposes.

3.4 PIPING

It is essential to have piping systems from the supply

well to the heat pump and to the return well that offer minimal flow resistance. This will increase flow rate which results in increased efficiency. There is, however, a possibility that by minimizing flow resistance the pump may exceed the capacity of the well. This occurs when the draw-down of the well falls below the well pump suction. The result is air is drawn into the pump and causes a growling sound known as "cavitation". Operation of a pump for prolonged periods under this condition will cause it to fail. It is recommended that a short section of clear PVC pipe be placed in the discharge piping and that water flow be regulated to eliminate bubbles in the system. If possible, this problem can also be eliminated by lengthening the well pump suction pipe.

The following summarizes recommendations for piping:

- 1) Follow pump manufacturers recommendations for wiring and piping size.
- 2) Well casings should be a minimum of 3-inch pipe for pumps of 1/3 HP or larger.
- 3) Foot valves on pump suction are recommended over above ground check valves.
- 4) 1 1/2" is the recommended pipe size from filter to heat pump and from heat pump to return well for flows in excess of 8 gallons per minute. 1 inch pipe is acceptable for these flow rates and it is recommended for flow rates lower than 8 gpm.

5) All valves should be gate valves to minimize pressure losses.

6) Elbows and flow through side branches of trees should be minimized.

7) Outdoor piping should be buried 3 inches below surface.

8) Supply well and return well should be separated by a minimum of 50 feet.

9) Piping should be extended down into return well to standing water level. This reduces the head which the well pump operates against.

6.5 WATER FLOW CONTROL

In order to reduce the amount of water, and power needed to pump it, on the water to air heat pumps it is necessary to control the flow. Standard procedure is to operate the pump with a pressure switch. We received satisfactory performance by regulating the flow between 30 and 40 psig. Most well pumps come with a pressure switch that has both adjustable pressures and on-off differentials. A surge tank (minimum size 12-gallon) should be placed in the discharge piping to prevent constant cycling.

Three flow control arrangements were tested and evaluated. The first used was an adjustable water regulating valve that operates by opening when compressor head pressure rises and closing when it drops. The second and third type of control was achieved with a solenoid valve that is nor-

mally closed, and opens when voltage is supplied. This valve is wired in such a way that it is open whenever the heat pump compressor is on. In the second case the valve was placed on the heat pump heat exchanger outlet and in the third case it was placed on the inlet. We recommend the use of the third type of water control (solenoid on heat exchanger inlet) for several reasons.

- 1) Water regulating valves have higher pressure drops which restrict water flow.
- 2) Solenoid valves are less expensive than water regulating valves.
- 3) In placing the solenoid valve on the inlet the amount of piping always under pressure is reduced. This makes maintenance easier and reduces the possibility of leaks.

CAUTION: A solenoid valve of proper size should be selected. Care should be taken that the valve be of a design where pressure drop is negligible at design flow rates.

3.6 FILTERS

Previous water to air heat pump installations with shallow ground water wells in the upper Texas Gulf Coast have encountered the problem of iron build-up in the water piping and heat pump heat exchanger. In order to assure proper heat transfer, and limit build-up and corrosion problems in all parts exposed to this water, filtration

is recommended on heat pumps with copper tube heat exchangers. A local filter firm recommended a 12-inch tube filter with a 20 micron retention be placed on the pump discharge. This filter was installed with a by-pass pipe.

After the equivalent of six weeks of pumping the following information was observed:

1. No noticeable iron build-up in piping system.
2. Filter pressure drop had increased from 5 psi (new) to 12 psi at 30 psig pump discharge pressure.
3. This caused the flow rate to drop from 11.0 gpm for a new filter to 8.5 gpm.

Although the length of time for this test is too short to determine if 20 micron retention filters are adequate, it is recommended that a 30 inch tube filter be used. The additional cost of the larger filter is warranted because of resulting increased efficiency of the heat pump. As previously mentioned the water flow rate greatly effects EER in the well system. By minimizing pressure drop across the filter the flow rate and correspondingly the heat pump efficiency is increased.

To illustrate this point, a test was run on the system with the filter by-passed. The flow rate was increased from 8.5 to 12 gpm (well maximum). At this increased flow the water outlet temperature dropped from 82°F to 78°, head pressure dropped from 190 psig to 183, total power consumption

decreased from 4400 watts to 4100 and EER increased from 10.0 to 11.3.

As previously stated heat pump manufacturers are marketing models with tube-in-tube cupra nickel coils. The design of these models make them extremely resistant to corrosion and build-up. In these water-to-air heat pumps filtration is unnecessary.

3.7 ECONOMICS

Based on the results of this investigation, the cost effectiveness of the heat pump options can be estimated as in Table 3-1. (Electricity cost is 6 cents per kwh)

Table 3-1
Economics for Beaumont

Heat Pump Option	Heating		Cooling	
	\$/Mbtu	Cost Effectiveness	\$/Mbtu	Cost Effectiveness
Air to Air	8.793	1	8.571	1
Horizontal Coil	6.348	1.385	7.059	1.214
Vertical Coil	6.127	1.435	6.667	1.286
Open loop well water	5.862	1.500	5.000	1.714

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

The scope of this report and the testing being carried on at Lamar University is quite broad. Conclusions can be drawn from much of the work but much of it requires additional research before the potential for actual application can be realized. Major conclusions that can be drawn at this point indicate a critical need to make minor adjustments to housing layout and building procedures. Also our work has shown that water-to-air heat pumps are more efficient and cost effective than present standard methods of heating and cooling. The potential of these units is far greater than air-to-air systems. The simplicity of the water-to-air heat pump system is also attractive.

4.1.1 HOUSE DESIGN

A primary method of reducing residential energy cost is by heating and cooling load reduction. Our studies have shown that the use of concrete walls with earth berms effectively reduces air conditioning requirements. Construction techniques are simple, although not standard, and the problem with water penetration is easily remedied. When the earth and concrete wall is coupled with other recommendations from this and previous studies, the resulting design provide a house with an energy savings of 50 to 70% over standard housing.

Important concepts to be generally followed are:

- 1) Long axis of house should be east-west. This provides

smaller east and west walls.

2) Berm east and west walls and locate garage and/or workshop on west end of house. Windows are omitted on both walls.

3) Windows should be located on south and north walls.. South window area is large and shaded with an overhang to minimize the summer overheating. Both south and north windows are used for ventilation. These walls may be partially bermed.

4) Windows should have movable insulation.

5) A minimum of R-30 insulation is used in the ceiling and attic space is vented.

6) Bermed walls should have rigid polystyrene insulation with a minimum of R-5 located outside concrete walls. Walls that are not bermed should have a minimum of R-11 insulation.

7) Domestic hot water should be heated by a heat exchanger with the heat pump compressor discharge and an additional hot water storage tank.

4.1.2 WATER-TO-AIR HEAT PUMPS

The experimentation at Lamar has shown that water-to-air heat pumps perform better than almost all air-to-air models. Water-to-air heat pump design is becoming more sophisticated. In 1980, when the this project began, most models carried ARI ratings ranging between 8.0 and 9.0 EER (cooling) and 2.8 to 3.2 COP (heating). In March of 1982 a unit of comparable size and price to the one used in this project with an EER of 10.9,

COP of 3.9 and a cupra-nickel heat exchanger can be purchased. This performance can only be matched by air-to-air heat pumps with elaborate and expensive compressor and coil design. Water to air models with EER's above 12 can be purchased.

Our work has shown that presently the best method for supplying water is the shallow well. Better methods for both closed and open cycle systems are possible but untested. These will be discussed in our recommendations.

The shallow well (20-30 feet) without a screen performs the best in the Beaumont area both as a supply and return. The cost of having these wells dug and pumped out is much less than having a deeper (50-150 ft.) screened type well installed. The shallower wells also have the potential of being done by a homeowner and a friend in one day for less than \$100 in materials and "mud" pump rental (jet pump cost excluded).

The performance of the jet type pump was satisfactory. The one-half horsepower size proved sufficient for a heat pump of the size used in the test. However, with a solenoid valve for water flow control and no filter a 1/3 horsepower jet pump is sufficient and power consumption is reduced. The exact size of the pump should be determined by calculating head loss in the water system at design flow rates.

A.1.3 VERTICAL GEOTHERMAL WELL

In terms of performance and installation cost the 360 foot vertical geothermal well and 1000 ft. horizontal ground

coil did not match the shallow well system. However these closed loop systems have several features that can be used more advantageously in future installations. The availability and purity of ground water are not critical as in shallow well systems. Pumping costs in our study were approximately one-half those of the jet pump.

The vertical well has two major advantages over the closed horizontal system. First it requires very little land area which is becoming more and more a limiting factor. Secondly, because of its depth, seasonal variations in ground temperature near the surface (15 ft. and less) do not adversely effect the vertical wells performance.

The major disadvantage of the vertical well is its cost. It requires a contractor with large heavy equipment for installation. Although the cost of \$10/ft seems unreasonable, local drillers at this time will not accept less.

Two additional disadvantages accompany the vertical well as installed. The return water temperature to the heat pump will not be as favorable as in the shallow well. The poor heat transfer characteristics of the ground cause the temperature of return water under normal operating conditions to a range from 80°F to 100°F in the cooling cycle and 50°F to 65°F in the heating cycle. This, of course, results in poorer heat pump efficiencies.

The second disadvantage is the depth of the well. In addition to requiring a large drilling rig the piping cost is high for schedule 40-5" dia. PVC. In shallower wells lighter

pipe can be used. The pressure drop experienced across 360' of 1" PVC results in a considerable portion of the pumping cost. These problems however can be minimized in future installations and should be tested. Methods of dealing with them are discussed in the recommendations.

The solar-assist system performed adequately. However the amount of heat storage in the ground around the vertical well is limited. In periods of moderate to heavy night time heating loads, the base well temperature returned to normal (temperature without solar assist) 4 to 5 hours after solar gain was no longer available. On a clear day in late February the collectors delivered an average 14,400 Btu/hr between 12:00 noon and 5:00 p.m. and raised the base well temperature to 85°. At midnight the outdoor temperature was 34° and the base well temperature was 57°F.

4.1.4 HORIZONTAL GROUND COIL

The horizontal ground coil as installed proved to be the least desirable systems. However it has been installed in two local homes with satisfactory results. The cost of materials and installation is about equal to that of the vertical well. The horizontal coil can be arranged so that flow is parallel in a large number of loops or manifolds to minimize pressure losses and pumping cost. The coil can also be installed with rental equipment and does not require an experienced contractor as does the vertical well.

It appears that the pipe thermal conductivity is not critical because of large thermal resistance of the ground. Therefore, using copper gives only a small advantage in terms of heat transfer over PVC or plastic piping.

The coil is effected to a large degree by seasonal temperature variations. At a four foot depth our measurements varied from 56°F (February) to 85°F (August). This adversely effects heat pump performance. Another major disadvantage is the size of yard space required in a time when land is becoming increasingly expensive. One way to save some of yard space for piping is laying double pipes in one trench as shown on Figure 4-1. In general, 350-400 ft. of piping is required for one ton of cooling.

Figure 4-1 Double piping in one trench

4.2 RECOMMENDATIONS

The recommendations for the shallow well systems are discussed in chapter six at length. However, additional recommendations are emphasized here. The first recommendation is to select a heat pump that incorporates a tube-in-tube type cupra-nickel heat exchanger for the water coil. The durability of this type of coil has proven itself in the Typhoon Heat Pumps manufactured in the 1950's. Water pressure drops are normally small in properly designed units. This requires less pumping power.

However, caution must be used in applying these units. Manufacturers using this type of heat exchanger normally use capillary tubes rather than expansion valves in the refrigerant system. These tubes are effective over a limited range of evaporator and condensor operating temperatures. Therefore, care must be taken to inspect manufacturer's performance data and determine if the unit will operate effectively at well water temperatures.

As second recommendation is to test the feasibility of using submersible pumps in place of jet type pumps. The design of these pumps allow them to deliver much higher flow rates with much less pumping power. The smallest locally available pump of this type is 1/3 horsepower and its rated performance is larger than what was required for the tested heat pump. Although maintenance problems are typically

greater for submersibles, the large reduction in pumping cost warrants investigation.

The vertical well closed system offers the greatest potential for future installations. The installation at our test site followed the recommendations of previous testing elsewhere. However, several modifications seem warranted for better performance with lower installation cost in the Gulf Coast Region.

Several advantages can be derived by installing several smaller shallower wells in parallel flow to replace the one large well. For example, four 4-inch 100 foot deep wells could replace the 360 foot well. Lighter, less expensive PVC casing could be used and the size of drilling rig required is smaller. This would reduce cost considerably. The pumping pressure would drop and therefore pump cost would be minimized. Water would be pumped through four parallel dip-pipes. As a rule of thumb, 100 ft. per ton in length is required for vertical well.

The solar assist system on the vertical geothermal well as installed is not recommended at this time. The high cost of installation and moderate energy savings make it undesirable. Additional expenditures on these type systems would be more wisely used to purchase a heat pump with a higher COP and/or installing larger and more wells to further improve efficiency.

Two suggestions for ground coil installations are recommended. Our system utilized three ground loops with parallel water flow. At least four loops should be used to further minimize pressure losses and enhance heat transfer. A parallel flow could also

be achieved by using a manifold scheme similiar to flow in solar collectors. A second suggestion is the use of polybutalene pipe to replace polyethylene used in this test.

The use of well water is a much better selection than a ground coil on the Gulf Coast. The theoretical and actual efficiency of a heat pump using a well water system is better than efficiencies using a ground coil or vertical well on the Texas Gulf Coast.

There is no code restriction in the Jefferson County at this time. In the areas, if the code limits to use well water or the wells producing from aquifers will not supply enough water to drive a residential water source heat pump, then, the closed-loop earth-coupled heat exchanger should be used.

5.0 REFERENCES

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6.0 Appendix

T E X A S Location	WINTER	SUMMER				
	Heating Degree Days 1960-80 Average 65F Base	Cooling Degree Days 1969-80 Average 65F Base	1% Summer Design Temp. Indoor 75F		2 1/2% Summer Design Temp. Indoor 78F	
			Outdoor Design Temp.	AC Operating Hours	Outdoor Design Temp.	AC Operating Hours
ABILENE	2646	2406	101	1600	99	1480
AMARILLO	4228	1428	98	1130	95	1030
AUSTIN	1772	2866	100	1860	98	1780
BEAUMONT	1525	2837	95	2020	93	1850
BROWNSVILLE	655	3904	94	2810	93	2590
CORPUS CHRISTI	1005	3570	95	2530	94	2270
DALLAS/ FORTH WORTH	2437	2680	102	1820	100	1700
EL PASO	2668	2138	100	1620	98	1490
GALVESTON	1216	2958	90	2530	89	2440
HOUSTON	1509	2746	96	2060	94	1880
LUBBOCK	3480	1758	98	1270	96	1170
MIDLAND	2691	2050	100	1570	98	1460
SAN ANGELO	2320	2441	101	1820	99	1700
SAN ANTONIO	1633	2940	99	1980	97	1830
VICTORIA	1280	3190	98	2290	96	2120
WACO	2152	2891	101	1780	99	1680
WICHITA FALLS	3018	2460	103	1570	101	1500

6.1 Heating/Cooling Degree Days for Texas Cities

6.2

Waterwell Temperature

(prepared by Doug Bacon, National Water Well Association)

Ground Water Temperatures
In Wells Ranging from 50' to 150' in Depth

— ° —
- - - ° - - - Inferred

6.3 SHALLOW WELL (Open Cycle) SYSTEM EER

Test Date July 24, 1981

Outdoor Air Temperature 98°F

Total P (compressor + blower + pump - recorder) = 4400 Watts

Air in: Dry bulb temp. = 78°F

Wet bulb temp. = 66°F

= 31.55 Btu/lbm

out: Dry bulb temp. = 59°F $v = 13.25 \text{ ft}^3/\text{lbm}$

Wet bulb temp. = 55°F = 0.0755 lbm/ft³

= 23.3 Btu/lbm

Air flow: 1295 cfm

$$\dot{Q} = 1295 \times 0.0755 \times 60 \times (31.55 - 23.3) = 48395 \text{ Btu/hr}$$

$$\text{EER} = \frac{\dot{Q}}{P} = 11 \text{ Btu/h/Watt}$$

Other data:

Enter Water temp. = 69°F

Exit Water temp. = 82°F

Water flow rate = 8.5 gpm

Heat pump runs continuously

6.4 GROUND COIL (Plastic) SYSTEM EER

Test Date July 23, 1981

Outdoor Air temperature 97°F

Total P (compressor + blower + pump - recorder) = 5240 Watts

Air in: Dry bulb temp. = 78°F

Wet bulb temp. = 67°F

= 31.55 Btu/lbm

Out: Dry bulb temp. = 60°F

v = 13.35 ft³/lbm

Wet bulb temp. = 59°F

= 0.0749 lbm/ft³

= 25.85 Btu/lbm

Air flow: 1280 cfm

$$Q = 1280 \times 0.0749 \times 60 \times (31.55 - 25.85) = 32788 \text{ Btu/hr}$$

$$\text{EER} = \frac{Q}{P} = 6.26 \text{ Btuh/Watt}$$

Other data:

Enter Water temp. = 106°F

Exit Water temp. = 119°F

Water flow rate = 8 gpm

Heat Pump runs continuously

6.5 GEOTHERMAL WELL SYSTEM EER

Test Date July 25, 1981

Outdoor Air temperature 98°F

Total P (compressor + blower + pump - recorder) = 5220 Watts

Air in: Dry bulb temp. = 78°F
Wet bulb temp. = 67°F
= 31.55 Btu/lbm

Out: Dry bulb temp. = 59°F $v = 13.3 \text{ ft}^3/\text{lbm}$
Wet bulb temp. = 58°F = 0.0752 lbm/ft³
= 25.01 Btu/lbm

Air flow: 1280 cfm

$$\dot{Q} = 1280 \times 0.0752 \times 60 \times (31.55 - 25.01) = 37770 \text{ Btu/hr}$$

$$\text{EER} = \frac{\dot{Q}}{P} = 7.23 \text{ Btuh/Watt}$$

Other data:

Enter Water temp. = 105°F

Exit Water temp. = 117°F

Water flow rate = 8.1 gpm

Heat pump runs continuously

6.6 Ground Temperature For Texas Cities

$$T(x,t) = T_m - A_s e^{-xr_1} \cos\left[\frac{2\pi}{365} \left(t - t_0 - \frac{xr_2}{2}\right)\right]$$

Where

$T(x,t)$ = temperature of soil at depth x and time t ;

T_m = mean annual earth temperature;

A_s = amplitude of surface temperature wave;

x = depth below surface (ft);

α = thermal diffusivity of soil (ft²/day)

t = time of year (days);

t_0 = phase constant (35 days);

$$r_1 = \sqrt{\frac{\pi}{365\alpha}} \quad ; \text{ and}$$

$$r_2 = \sqrt{\frac{365}{\pi\alpha}} \quad .$$

For Texas Cities:

	T_m	A_s	α
Austin	75	18	0.52
Beaumont	72	15	0.65
Brownsville	76	15	0.60
Corpus Christi	80	15	0.60
Dallas/Fort Worth	70	18	0.52
El Paso	69	18	0.52
Houston	76	18	0.60
Lubbock	62	15	0.52
San Antonio	74	18	0.52

City: Austin

		Temperature on 15th Day of											
		J	F	M	A	M	J	J	A	S	O	N	D
Air	AVG	50	53	61	68	75	82	84	84	79	70	59	52
	MAX	60	64	72	78	85	92	95	95	89	81	70	62
	MIN	40	43	50	57	65	71	74	73	69	59	48	41
Ground (x)	2	62	61	63	68	74	81	86	88	87	82	75	68
	4	67	64	64	67	72	77	82	85	85	82	78	72
	6	70	67	66	67	70	74	79	82	83	82	79	75
	8	73	70	68	68	70	73	76	79	81	81	79	76
	10	74	72	70	70	70	72	75	77	79	79	79	77
	12	75	73	72	71	71	72	74	75	77	78	78	77

City: Beaumont

		Temperature on 15th Day of											
		J	F	M	A	M	J	J	A	S	O	N	D
Air	AVG	52	56	61	69	75	81	83	83	79	71	61	55
	MAX	61	64	70	77	83	89	91	91	87	81	70	64
	MIN	44	47	53	60	67	73	75	74	71	61	51	46
Ground (x)	2	61	60	61	66	72	78	82	83	82	78	72	66
	4	64	62	63	65	70	74	78	81	81	78	74	69
	6	67	65	64	65	68	72	76	78	79	78	75	71
	8	69	67	66	66	68	71	74	76	77	77	75	73
	10	71	68	67	67	68	70	72	74	76	76	75	73
	12	72	70	68	68	68	69	71	73	75	75	75	74

City: Brownsville

Temperature on 15th Day of

		J	F	M	A	M	J	J	A	S	O	N	D
Air	AVG	60	63	68	74	79	83	84	84	81	75	68	62
	MAX	69	72	77	83	87	91	92	93	90	85	77	71
	MIN	51	54	60	66	71	75	75	75	73	66	59	53
Ground (x)	2	65	64	65	70	76	81	86	87	86	82	76	70
	4	69	66	67	69	73	78	82	85	84	82	78	73
	6	71	69	68	69	72	76	79	82	83	82	79	75
	8	73	71	70	70	72	74	77	80	81	81	79	77
	10	75	73	71	71	72	74	76	78	80	80	79	78
	12	76	74	73	72	72	73	75	77	78	79	79	78

City: Corpus Christi

Temperature on 15th Day of

		J	F	M	A	M	J	J	A	S	O	N	D
Air	AVG	56	59	65	72	77	81	83	83	81	74	65	58
	MAX	65	67	73	78	83	88	93	91	88	82	73	67
	MIN	48	51	57	65	71	74	76	76	74	66	57	50
Ground (x)	2	69	68	69	74	80	85	90	91	90	86	80	74
	4	73	70	71	73	77	82	86	89	88	86	82	77
	6	75	73	72	73	76	80	83	86	87	86	83	79
	8	77	75	74	74	76	78	81	84	85	85	83	81
	10	79	77	75	75	76	78	80	82	84	84	83	82
	12	80	78	77	76	76	77	79	81	82	83	83	82

City: Dallas/Fort Worth

Temperature on 15th Day of												
	J	F	M	A	M	J	J	A	S	O	N	D
AIR	AVG	45	49	57	65	73	81	85	78	68	56	78
	MAX	56	59	68	76	83	91	95	88	79	67	58
	MIN	35	38	46	55	63	71	74	68	57	45	38
Ground (x)	2	57	56	58	63	69	76	81	83	82	77	70
	4	62	59	59	62	67	72	77	80	80	77	73
	6	65	62	61	62	65	69	74	77	78	77	74
	8	68	65	63	63	65	68	71	74	76	76	74
	10	69	67	65	65	65	67	70	72	74	74	74
	12	70	68	67	66	66	67	69	70	72	73	73

City: El Paso

Temperature on 15th Day of												
	J	F	M	A	M	J	J	A	S	O	N	D
AIR	AVG	45	49	56	64	72	81	82	80	75	65	45
	MAX	57	62	69	78	86	95	94	92	87	78	58
	MIN	32	36	42	50	58	67	70	69	63	51	33
Ground (x)	2	56	55	57	62	68	75	80	82	81	76	69
	4	61	58	58	61	66	71	76	79	79	76	72
	6	64	61	60	61	64	68	73	76	77	76	73
	8	67	64	62	62	64	67	70	73	75	75	73
	10	68	66	64	64	64	66	69	71	73	73	73
	12	69	67	66	65	65	66	68	69	71	72	72

City: Houston

Temperature on 15th Day of												
	J	F	M	A	M	J	J	A	S	O	N	D
Air	AVG	50	54	61	68	74	80	83	82	78	69	54
	MAX	60	66	73	78	85	91	94	93	88	81	66
	MIN	40	42	50	57	64	70	72	72	68	57	43
Ground (x)	2	63	61	63	69	76	83	88	90	88	83	76
	4	67	65	65	68	73	79	84	86	86	83	78
	6	70	68	67	68	72	76	80	83	84	83	80
	8	73	70	69	69	71	74	78	81	82	82	80
	10	75	72	71	70	71	73	76	79	80	81	80
	12	76	74	72	71	72	73	75	77	79	80	80

City: Lubbock

Temperature on 15th Day of												
	J	F	M	A	M	J	J	A	S	O	N	D
Air	AVG	39	43	50	60	69	78	80	78	71	61	42
	MAX	53	57	65	75	83	91	92	90	84	75	56
	MIN	24	28	35	46	55	64	68	66	59	47	27
Ground (x)	2	31	50	52	56	61	67	71	73	72	68	56
	4	55	53	53	55	59	64	68	70	70	68	60
	6	58	55	55	56	58	61	65	67	68	68	62
	8	60	58	56	56	58	60	63	65	67	67	63
	10	61	59	58	57	58	59	62	64	65	66	64
	12	62	61	59	58	58	59	61	62	64	65	64

City: San Antonio

Temperature on 15th Day of												
	J	F	M	A	M	J	J	A	S	O	N	D
Air												
AVG	52	55	62	69	75	82	84	84	79	71	60	54
MAX	62	66	73	80	85	92	94	95	89	82	71	64
MIN	41	44	51	59	65	72	74	73	69	60	50	43
Ground (s)												
2	61	60	62	67	73	80	85	87	86	81	74	67
4	66	63	63	66	71	76	81	84	84	81	77	71
6	69	66	65	66	69	73	78	81	82	81	78	74
8	72	69	67	67	69	72	75	78	80	80	78	75
10	73	71	69	69	69	71	74	76	78	78	78	76
12	74	72	71	70	70	71	73	74	76	77	77	76

PIPING HEAD LOSS (in feet per 100 ft of pipe)

A. Copper Pipe

NOMINAL PIPE SIZE	FLOW RATE GPM					
	2	4	6	8	10	15
3/4"	1.93	6.51	13.3	22	32	66.3
1"	.49	1.65	3.35	5.6	8.2	16.7
1 1/4"	.17	.57	1.16	1.91	2.84	5.78

B. PVC Pipe

NOMINAL PIPE SIZE & RATING	FLOW RATE GPM					
	2	4	6	8	10	15
3/4" 200 PSI	.62	2.0	4.2	7.0	10.1	22
1" 200 PSI	.2	.67	1.4	2.3	3.5	7
1 1/4" 160 PSI	.06	.2	.4	.65	1	2
1 1/2" 160 PSI	.033	.1	.21	.34	.54	1.1
2" 160 PSI	.01	.035	.075	.13	.19	.37
4" 160 PSI	-	-	-	-	.01	.018

C. SDR 11 Polyethylene Pipe

NOMINAL PIPE SIZE	FLOW RATE GPM					
	2	4	6	8	10	15
1 1/4"	.051	.18	.37	.62	.92	1.89
2"	-	.055	.12	.19	.28	.58
3"	-	-	-	.032	.051	.099
4"	-	-	-	-	-	.032

D. Volume of Water in Gallons per 100 feet of Pipe

NOMINAL PIPE SIZE	PIPE MATERIAL		
	COPPER	PVC	POLYETHYLENE
3/4"	2.52	3.53	-
1"	4.29	5.77	-
1 1/4"	6.53	9.58	-
1 1/2"	-	12.56	9.86
2"	-	19.62	15.4
3"	-	-	33.98
4"	-	70.4	56.16
5"	-	107.58	-