# Ground Coupled Heat Pumps

Discussion

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GREEN
Supporting Eco-Friendly Products

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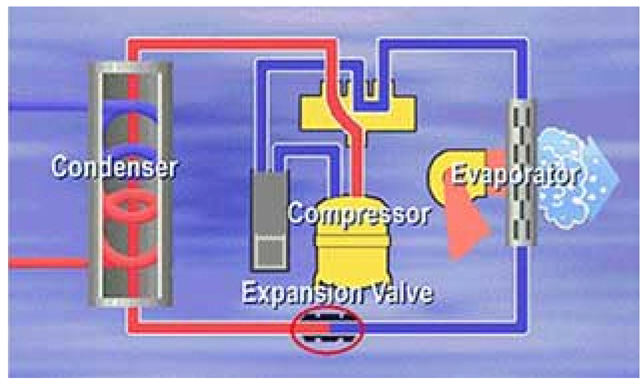
A 1971 graduate of the University of Wisconsin, Madison, he specialized in Mechanical Engineering with an emphasis on heat transfer. He designed both residential and commercial ground source heat pump systems since the early 1980's.

Ground Coupled Heat Pumps

Ground coupled heat pumps are an important way to heat and cool houses. Although it is considered by some to be a "greener" method than burning gas or oil, that depends on the use of the heat pump. If it is used in place of a furnace, it produces more carbon dioxide than a comparable high efficiency gas fired furnace. If the heat pump is used for radiant floor heating, it will produce less carbon dioxide than a comparable boiler. The heat pump moves the "carbon dioxide producing source" from the house to the power-plant.

The ground coupled heat pumps will save the homeowner money; since utilities are willing to subsidize heating with electricity with reduced electrical rates. On this basis, it makes economic sense for the homeowner to use a heat pump in lieu of a gas fired furnace.

A heat pump acts like a reversible refrigerator. It has an inside coil to transfer either heating or cooling to the home; an outside coil to absorb or reject heat to the outside; a compressor to boost low temperature refrigerant gas to a high temperature refrigerant liquid and an expansion valve to turn the refrigerant liquid back into a low temperature refrigerant gas. When the heat pump is in the cooling mode, the inside coil is cold and the outside coil is hot. In the heating mode, the inside coil is hot and the outside coil is cold.




As the refrigerant liquid becomes hotter or the refrigerant gas becomes colder, the efficiency of the heat pump is reduced. When a heat pump uses the outside air for its exchange media, the outside coil can experience 100 $^{O}$F temperatures in the cooling mode and -20$^{O}$F in the heating mode. These temperature extremes dramatically affect the efficiency of the heat pump. When the ground below frost level is used for the outside exchange media, the temperatures will range from 70 $^{O}$F temperatures in the cooling mode and 30$^{O}$F in the heating mode. This temperature range is much more in keeping with the refrigerant requirements for higher efficiency.

To talk about heat pump efficiencies, we need to introduce two terms. The first is Coefficient of Performance (COP) which is "output/input". Output is the capacity of the heat pump in btus per hour and the input is the electrical power used in btus per hour. The larger the number the better. Ground coupled heat pumps will have number ranging between 2 and 7. With a COP of 7, 1 btu input would transfer 7 btus to the output. The second term is Energy Efficiency Ratio (EER), which is also "output/input". The output is still the capacity of the heat pump in btus per hour and the input is the electrical power in watt per hour. Again, the larger the number, the better. Typical air conditioners have EERs in the 12 to 16 range. Ground coupled heat pumps have numbers ranging from 12 to 30 EER. With an EER of 30, one watt of power will transfer 30 btu of energy from the output.

COP is normally used to talk about the efficiency of the heating side of the heat pump and EER is used to talk about the efficiency of the cooling side of the heat pump. The minimum legal level for SEER is now set at 13. SEER is the EER computed over a full season of operation.

In Appendix 4, I have summarized a typical manufacturer's capacity Data for a Ground Coupled heat pump using R-410A refrigerant. In the heating mode, with inside water returning to the heat pump at 80$^{O}$F, the unit will operate with a COP between 6.4 and 4.0. This is highly efficient and produces less carbon dioxide than a comparable high efficiency furnace. A normal use with temperature of water would be a radiant floor with the heat pump. If we look at the row marked 120$^{O}$F Entering Water Temperature, we see the COPs ranging from 3.6 to 2.3. This is a level of operating needed to heat domestic hot water and to have air temperatures coming out of the air registers comparable to a furnace. At this level, twice as much carbon dioxide is produced than a furnace. However is still 2 to 3 times more efficient than straight electric resistance heating.

The various residential heat pump manufacturers all use standardized components. As such, although they claim great differences between themselves, you are purchasing the stability of the manufacturer and the expertise of the installing contractor. Because the current residential heat pump manufacturers are relatively small in comparison to

Trane, Carrier, or Lennox, the cost of equipment is higher than it will be if the major manufacturers finally start to produce lines of ground coupled heat pumps.

Every successful heating and cooling contractor can easily deal with the piping, ductwork and equipment installed within the house. Most do not have the expertise in fitting the ground loop onto the lot in the most economical manner. It is here where the knowledge of the local topography, the local soil conditions, and the local moisture content of the soil is required. One source of qualified contractors can be found at www.igshpa.okstate.edu (international ground source heat pump association).

Basically, there are three types of ground loops, each with several variations. Remember, that the purpose of the ground loop is to provide a low energy heat source that will be ½ to ¾ of the heat that will be used within the residence. The three types are: ground coupled buried pipe; direct source of water pumped from the ground and pipe suspended within a large mass of water. Over the next several pages, each of these systems will be discussed. Depending on each property, one will be a better choice than another.

**Ground coupled buried pipe**.

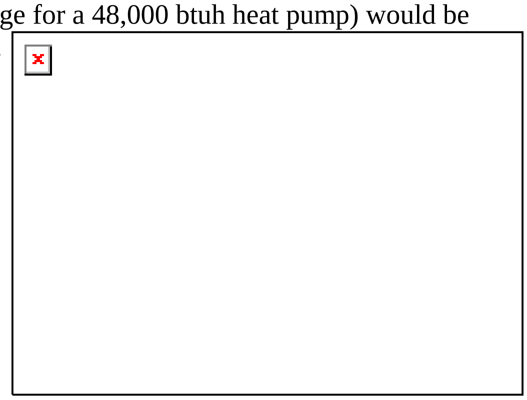
**General Conditions**:

1. Depending upon the soil and moisture conditions, ground coupled buried pipe systems need to be from 250 to 1,000 feet long per ton of heat pump. The quicker the soil can dry out and less the moisture in the soil, the longer the line length required. Clay-soil at the bottom of bluffs requires the least amount of pipe. Gravelly soils at the top of ridges require the greatest amount of pipe.
2. The system needs to be buried at least a foot below the normal frost line. Here in LaCrosse, that means that the pipe needs to be buried a minimum of four feet deep, although if may be much deeper in more open and drier soils.
3. The zone around the pipe that heat can be extracted from extends a maximum of 1 foot from the pipe. Piping installed closer together requires a greater length of installed piping.
4. The size of the piping, the gpm the pipe carries, and the pressure drop must be balanced against one another to minimize the pumping horsepower. Typically loop lengths are held to 400 feet of length and water velocities at 2 feet per second. The usual piping that is buried is ¾ inch black polyethylene based on its pricing and durability when buried in the ground.
5. Systems can not be located near wells, current septic systems nor the secondary septic fields.

**Types of systems:**

1. Single pipe in a trench.

The trench needs to be dug 2 ft wide and at least 4 feet deep and 200 feet long for each 400-foot loop of pipe. This amounts to 118 yards of soil that must be excavated per loop. An excavator can dig between 25 and 45 feet per hour, depending on the soil. The cost of digging and refilling the trenches will run be $2.50 to $3.50 per lineal foot. To trench in 1,600 feet of pipe (the average for a 48,000 btuh heat pump) would be $5,600. It will take between 40 and 65 hours to dig the system. This system is often used when existing trees need to be left in place in the heat transfer field.



Another method that is used is to bulldoze the area where the pipe will be located, then lay the pipe out in, and back fill with the dozer. For the same 1,600 lineal foot system, the cost of the excavation and filling runs about $1,500. This does require an area of 5,600 square feet to completely disturb.

In this example of a standard 4 ton system, the water flow would be 11 gpm and the total pressure drop on the ground water side of the system would be about 15 psig. This would require a $^1/_3$ HP water circulating pump to run whenever the heat pump is running. This load is approximately ¼ KWH that needs to be added to the load of the compressor. It lowers the COP of the system roughly 8%.

2. Slinky-field piping

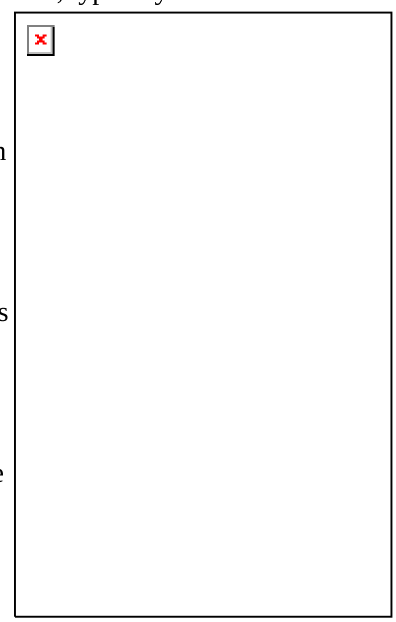
This is a system much like a single pipe system except that the coil of pipe is left in a coil and stretched out so that each loop overlaps approximately 50% with the previous loop. Because we are creating heat transfer zones that overlap each other, it is usually necessary to put in 50% more piping than would be used in a single pipe in a trench. Even so, for a system that will now have 2,400 feet of pipe, the disturbed area will only be 2,400 sq. ft., the cost of a bull dozer doing the work will still be about $1,500.

Slinky-field systems work best in areas that are more concerned with cooling than with heating since they can have greater temperature differentials within the soil to diffuse the heat away from the pipe faster.

Because slinky fields should have 50% more piping in them to compensate for the overlapping heat affected zones in the piping, a ½ HP circulator is needed to handle the increase water flow in our 4 ton example, this adds $^{1}/_{3}$ KWH to the compressor load and degrades the COP of the system about 10%.

3. Vertical borehole piping (down-hole heat exchanger).

This system uses vertically drilled wells that extend down 150 feet. The polyethylene tube is joined together with a U-bend and suspended with the well. The well is then grouted shut, typically with a betenoite clay.



Normally one well hole is used per ton of heat pump. For the example that we have been using, we would require four wells. The cost per well-hole is about $2,400 each. For 4 well holes, the cost would be $9,600. Because of the vertical depth that is used, the wells will normally pass through at least one level of subsurface water. In this part of Wisconsin, the water flows from north to south about 4 feet per day. This dramatically increases capacity of the borehole which is why it can use much less pipe than other systems. However, if the drilled well does not pass through any sub-surface water, then several more wells must be used and the system will need to use as much piping as a slinky system.

Vertical borehole piping is normally used on small lots, such as city lots. However wells that are in-line with other wells on the north-south axis will interfere with one another. The downstream wells will see colder water coming to them and they will have reduced capacity. In the LaCrosse area the well should be installed on an east-west axis 10 to 12 feet from each another.

The electrical horsepower necessary to run this system is comparable to the single pipe in a trench, so the COP is degraded about 8%. Because the recharge time of the ground is affected by the movement of the sub-surface water, this system normally runs with a higher overall COP than the other two systems.

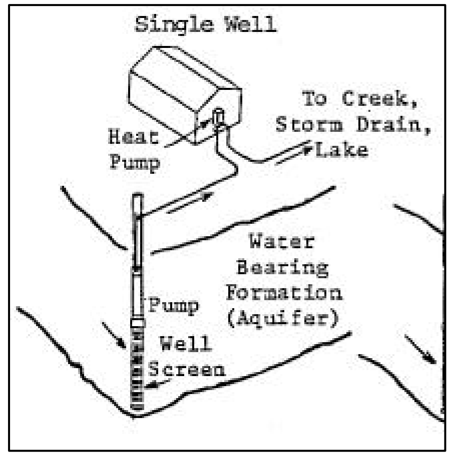
**Potential Problems:**

1. LaCrosse has 2,300 operating hours of heating and 292 operating hours of cooling (see Appendix 3). As winter temperatures drop below 25 degrees (more than 50% running time), the heat effected zone around the buried pipes does not have enough time to be reheated. When the ground drops below 32 degrees, the water in the ground freezes and acts as insulation. December, January and February have mean temperatures below 25 degrees (see Appendix 2). In many buried pipe systems, the ground starts to freeze around the pipe and the heat transfer rate declines at a progressively higher rate. Eventually, the heat pump becomes completely ineffective. Most manufacturers have system cut-offs that turn the compressors off whenever the fluid temperature from the ground loop drops to 30 degrees. In the LaCrosse area, it will take about three weeks for the ground to thaw enough raise the ground loop water temperature above the 30 degree mark.

2. Supplemental heat must be provided to heat the house after the compressor shuts off. This adds to the total cost of the job and to the expense of running the system.
3. Heat pump systems need to be sized for the cooling load of the house to control the humidity during the summertime. On homes built prior to 1990 (less insulation, moisture and air barriers), supplemental heat will be required even when the heat pump is running. Thus, a majority of homes can not be retrofitted with this form of heating without incurring high operating expenses.

**Water from a well (pump and dump)**

**General Conditions:**




1. The depth to water; the availability of water; and the quantity of minerals are the prime concerns for this type of system.
2. Generally, in the LaCrosse area, there are aquifers of water 50 feet below the valley floor, again at 150 feet below the valley floor and a third at 250 feet below the valley floor.
The water 50 feet below the valley floor is considered surface water that can be contaminated with local pollutants. Its temperature will fluctuate up to 5 degrees between winter and summer.
The aquifer at 150 feet below the valley level is the one that is used by most people for drinking water. Its temperature remains constant. With the increase in population (an increase in water usage), this water is entraining more and more minerals, especially calcium carbonate and iron. Both of these minerals will come out of solution and decrease the heat transfer rate across the heat pump surface.
The third aquifer is too deep to be an economical source of water for a heat pump.
3. Homes located on top of the ridges will end up having to pump the water the additional height from the ridge-top to the valley-floor. This may make this system too expensive to run.
4. Farmers that have large number of animals that need water can extract 10 degrees of heat from the water before if goes to the animals and make this type of system nearly free.
5. Since the sub-surface water is nearly at a constant 55$^{O}$F, we can extract 15 degrees out of the water, in lieu of the 6.5 $^{O}$F. We need about 1¼ gpm per ton of connected heat pump load. If the water is pumped from 150 feet below the heat pump, this would require an extra ½ HP from the well pump that supplies the home. That's 309 watts of power that needs to be added to the compressor load to figure the true COP of the system. In practice, it degrades the COP about 8% but the COP of the system stays constant throughout the heating season, close to a 5 COP (every Btu input from electricity yields 5 btus of heating energy).
Putting the heat pump on top of a ridge-line would increase the depth to about 600 feet. The pump now needs to be 2 horsepower larger and 1,100 watts of power needs to be added to the compressor. This is will lower the COP from 5 to about 3.
6. Some method must be provided to dispose of the water that goes through the heat pump. The Wisconsin Department of Natural Resources does not allow water to be re-injected into the aquifer; it must be spilled on the surface. Except for extremely clayey soils, a pond 17 feet in diameter and 3 feet deep would be adequate to drain the water into the earth. This pond will not freeze solid in the wintertime because of the injection of water on a near continuous basis.

**Types of Systems**

1. Constant speed well pump. With this type of pump, the flow required for the domestic water and the heat pump determine the gallons per minute of the pump. The required head pressure is normally a function of the heat pump. For our example, we need 5 gpm of water (1¼ gpm/ton x 4 tons) plus the requirements for the house, 3 gpm per bathroom, 5 gpm for the kitchen. The flow rate needs to be a minimum of 13 gpm and maybe as high as 19 gpm. To get adequate flow through the ground coupled heat pump, a minimum of 40 psig is required. This would mean that the water pump control switch would need to be set for 40 psig to turn on and 60 psig to turn off.
Well pump manufacturers want their pumps to cycle on and off no more than 6 times per hour for pumps less than 5 hp and no more than 4 times per hour for pumps 5 hp and larger. The minimum size for the

compression tank would be 243 gallons. This would be a tank 30 inches in diameter and 7 feet high. (See Appendix 6 for explanation of compression tanks.)
2. Variable speed pump This type of pump has been available on the market only in the past several years. The pump will run between 30% and 125% of rated speed. A sensor is placed within the piping system and the pump speeds up or slows down to maintain the set pressure. Two advantages exist with this type of pump. First, the pump can save huge amounts of energy since energy consumption varies as the cube of the speed. Reduce the rpm by ½ and the energy consumed will be $^1/_8$ of the full rated energy. Second, the only compression tank that is needed is a 5 gallon tank to handle a single faucet being opened part way. The increased cost of the pump will be mostly offset by the reduced size of the compression tank.

**Potential Problems**

1. The depth to water precludes using this type of system on high ridges. It is best suited when the ground water table is less than 100 feet underground.
2. A pond needs to be created to allow the water to drain back into the earth. During the spring and fall, it will be mostly dry and could be a breeding ground for mosquitoes.
3. The suspended minerals in the well water may plug the ponds drainage over time and a new pond may have to be created.

## Pipe loop suspended in a large volume of water

**General Conditions**

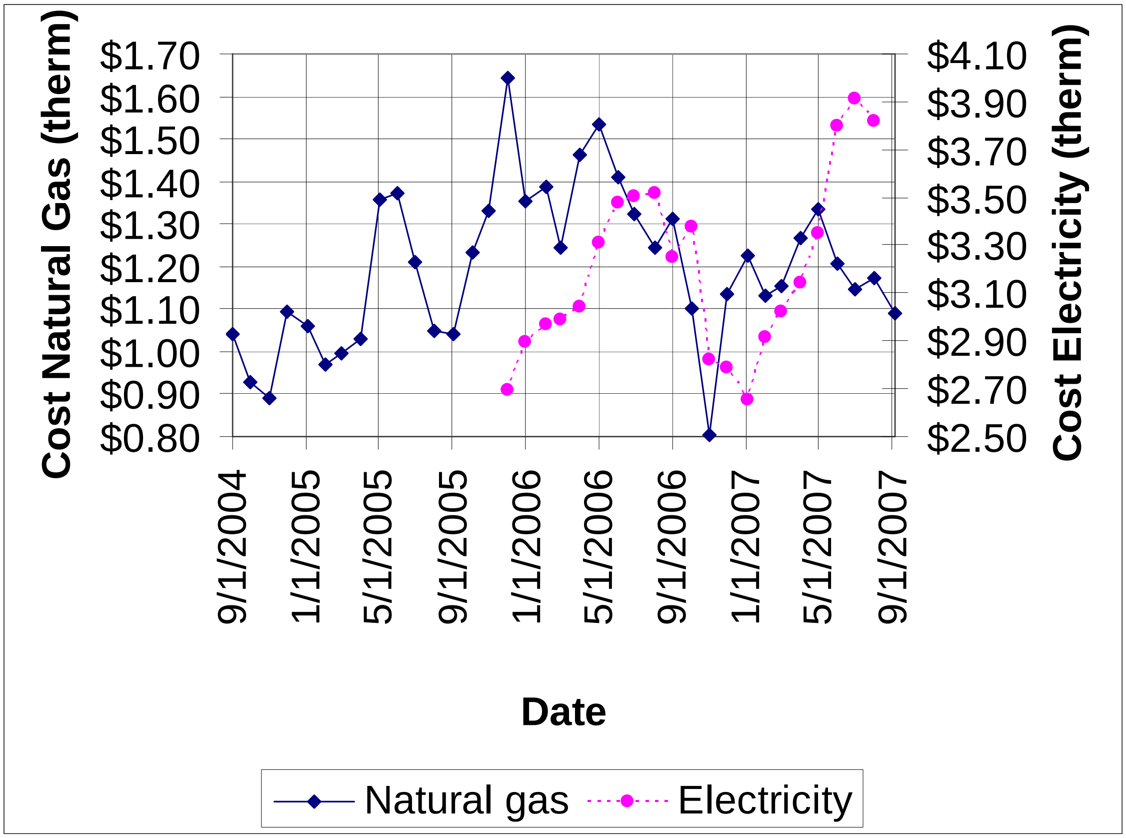
1. A residential size heat pump load can be supported by a pond that is ½ acre in size and 8 feet deep. This would be a pond 99 feet in diameter. It would hold 1,300,000 gallons of water and would take 10,800,000 btus to change the bulk water temperature 1 degree. It could handle our example house for the entire year while changing the water temperature only 9 $^{O}$F. This assumes that there is no recharge into the pond during the entire time of heat extraction. Factoring back in heat recharge from the earth and the sun, the bulk water temperature would be lowered only an additional 2-3 degrees during the heating season.
2. Water is densest at 39 $^{O}$F, the bottom of a pond that is more than 8 feet deep will seldom freeze. As the water around the coil drops below 39 $^{O}$F, the water will start to rise, allowing the pond to turn over.

**Potential Problems**

1. Although this is a very efficient method for heat transfer, most ponds ½ acre in size and larger are public waterways and controlled by the Department of Natural Resources. Since they are very concerned in maintaining the environment in a "stasis" condition; the Department is very cool to changing the water temperature in lakes and rivers. Approval would be very difficult at best.

Appendix 1
(History of Natural Gas and Electric pricing)

Midwest Natural Gas (residential rate)
Vernon Electric Coop (residential rate)



Appendix 2
Average LaCrosse Temperatures 1948-1992

| Hours of Daily Mean Temp (1948-1992) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
| 94 | 90 | | | | | 1 | | 1 | 3 | | | | | 4 |
| 89 | 85 | | | | | 1 | 8 | 22 | 14 | 1 | | | | 47 |
| 84 | 80 | | | | | 14 | 42 | 94 | 62 | 22 | 1 | | | 236 |
| 79 | 75 | | | | 5 | 42 | 108 | 195 | 155 | 35 | 1 | | | 540 |
| 74 | 70 | | | | 12 | 90 | 174 | 234 | 208 | 78 | 14 | | | 809 |
| 69 | 65 | | | 2 | 23 | 105 | 186 | 147 | 175 | 120 | 42 | 1 | | 801 |
| 64 | 60 | | | 4 | 55 | 144 | 138 | 47 | 103 | 174 | 90 | 4 | | 759 |
| 59 | 55 | | | 12 | 79 | 144 | 51 | 3 | 21 | 152 | 105 | 18 | 1 | 586 |
| 54 | 50 | | 1 | 20 | 114 | 122 | 13 | 1 | 2 | 92 | 144 | 41 | 1 | 552 |
| 49 | 45 | 1 | 5 | 53 | 143 | 55 | 1 | | 1 | 35 | 144 | 73 | 5 | 516 |
| 44 | 40 | 4 | 14 | 81 | 135 | 20 | | | | 12 | 122 | 103 | 16 | 506 |
| 39 | 35 | 30 | 59 | 128 | 94 | 5 | | | | | 55 | 153 | 52 | 576 |
| 34 | 30 | 77 | 105 | 162 | 44 | 1 | | | | | 20 | 132 | 132 | 673 |
| 29 | 25 | 101 | 105 | 113 | 12 | | | | | | 5 | 99 | 137 | 572 |
| 24 | 20 | 102 | 85 | 71 | 2 | | | | | | | 45 | 114 | 418 |
| 19 | 15 | 98 | 93 | 49 | 1 | | | | | | | 35 | 86 | 362 |
| 14 | 10 | 72 | 70 | 33 | | | | | | | | 9 | 71 | 256 |
| 9 | 5 | 82 | 56 | 12 | | | | | | | | 6 | 49 | 204 |
| 4 | 0 | 80 | 46 | 1 | | | | | | | | 1 | 48 | 176 |
| -1 | -5 | 50 | 17 | 1 | | | | | | | | | 19 | 87 |
| -6 | -10 | 31 | 14 | 1 | | | | | | | | | 8 | 54 |
| -11 | -15 | 13 | 2 | | | | | | | | | | 2 | 18 |
| -16 | -20 | 4 | 1 | | | | | | | | | | 1 | 6 |
| -21 | -25 | | | | | | | | | | | | 1 | 1 |
| Mean | | 15 | 21 | 32 | 48 | 60 | 69 | 73 | 71 | 62 | 51 | 35 | 21 | 47 |

Appendix 3

Hours of required heating and cooling to maintain room temperatures

| Avg. Temp | Hrs above or below set point | % of full load | Total hours of run time |
|---|---|---|---|
| 92 | 827.4 | 100% | 4.46 |
| 87 | 822.9 | 75% | 34.92 |
| 82 | 776.4 | 50% | 117.97 |
| 77 | 540.4 | 25% | 135.11 |
| 72 | 1,610.3 | | |
| 67 | | | |
| 62 | 759.2 | 11% | 79.91 |
| 57 | 1,345.1 | 16% | 92.52 |
| 52 | 1,897.3 | 21% | 116.25 |
| 47 | 2,413.6 | 26% | 135.87 |
| 42 | 2,920.1 | 32% | 159.95 |
| 37 | 3,496.2 | 37% | 212.27 |
| 32 | 4,169.6 | 42% | 283.51 |
| 27 | 4,741.7 | 47% | 270.99 |
| 22 | 5,159.6 | 53% | 219.95 |
| 17 | 5,521.9 | 58% | 209.78 |
| 12 | 5,778.2 | 63% | 161.89 |
| 7 | 5,982.6 | 68% | 139.84 |
| 2 | 6,158.5 | 74% | 129.57 |
| -3 | 6,245.2 | 79% | 68.48 |
| -8 | 6,298.8 | 84% | 45.09 |
| -13 | 6,316.4 | 89% | 15.78 |
| -18 | 6,322.3 | 95% | 5.57 |
| -23 | 6,323.0 | 100% | 0.74 |

| | |
|---|---|
| winter hours needing heat | 2,347.96 |
| summer hours needing cooling | 292.46 |

Appendix 4
Typical Manufacturer's Capacity Data

| Heat Pump | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mfg | WFI | | | | | | | | | |
| | Fort Wayne, Indiana | | | | | | | | | |
| Model | EW042,H/R R410-A refrigerant | | | | | | | | | |
| HEATING MODE | | | | | | | | | | |
| Load Side Conditions | | | Ground Source Conditions | | | | | | | |
| | | | flow rate 11 gpm | | | | | | | |
| Entering Water Temp | Leaving Water Temp | Water Flow (GPM) | Minimum ground Temp | Leaving loop temp | Entering loop temp | Heat Extracted (x1000 btuh) | Compressor Power (KWH) | Total Heat Delivered (x 1000 btuh) | COP | |
| 80 | 93 | 11 | 75 | 70 | 61 | 62.2 | 3.3 | 73.6 | 6.4 | late summer |
| | 91 | | 55 | 50 | 43 | 47.9 | 3.3 | 59.1 | 5.3 | early fall |
| | 88 | | 35 | 30 | 25 | 33.5 | 3.3 | 44.7 | 4.0 | Mid winter |
| 100 | 113 | 11 | 75 | 70 | 62 | 56.2 | 4.2 | 70.6 | 4.9 | late summer |
| | 110 | | 55 | 50 | 44 | 42.8 | 4.2 | 57.1 | 4.0 | early fall |
| | 108 | | 35 | 30 | 26 | 29.5 | 4.2 | 43.7 | 3.1 | Mid winter |
| 120 | 132 | 11 | 75 | 70 | 63 | 47.5 | 5.3 | 65.7 | 3.6 | late summer |
| | 130 | | 55 | 50 | 45 | 35.9 | 5.3 | 53.9 | 3.0 | early fall |
| | 128 | | 35 | 30 | 27 | 24.2 | 5.3 | 42.2 | 2.3 | Mid winter |
| COOLING MODE | | | | | | | | | | |
| Load Side Conditions | | | Ground Source Conditions | | | | | | | |
| | | | flow rate 11 gpm | | | | | | | |
| Entering Water Temp | Leaving Water Temp | Water Flow (GPM) | Minimum ground Temp | Leaving loop temp | Entering loop temp | Heat Extracted (x1000 btuh) | Compressor Power (KWH) | Total Heat Delivered (x 1000 btuh) | EER | |
| 50 | 41 | 11 | 45 | 50 | 60 | 49.1 | 2.3 | 56.7 | 21.6 | late spring |
| | 42 | | 75 | 90 | 90 | 42.8 | 3.4 | 54.4 | 12.6 | late summer |

Appendix 5
Pounds of Carbon dioxide produced per 1,000 btus of heating

| | | | | |
|---|---|---|---|---|
| Western Powder River Basin Coal | 9,000 | btu/# | A | equation |
| Pure carbon | 14,093 | btu/# | B | |
| 1 kw | 3,413 | btu | C | |
| energy conversion in power plant | 40% | | D | |
| energy transmission losses | 10% | | E | |
| combined efficiency | 36% | | F | D*(1-E) |
| btus required to produce 1 kw | 9,481 | | G | C/F |
| # carbon required for 1kw | 0.673 | | H | G/B |
| # carbon dioxide produced for 1 kw | 2.468 | | I | H*(44/12) |
| # carbon dioxide for 1,000 btus | 0.723 | | J | I*(1000/C) |

| | | | | | |
|---|---|---|---|---|---|
| Heat Pump COP | 2 | 3 | 4 | 6 | K' |
| # carbon dioxide per 1000 btus | 0.362 | 0.241 | 0.181 | 0.121 | J/k' |

| | | | | |
|---|---|---|---|---|
| Natural gas | 1,000 | btu/ft$^3$ | a | |
| | 23,800 | btu/# | b | |
| high efficiency furnace | 93% | | c | |
| # of natural gas for 1,000 btus | 0.0452 | | d | (a/c)/b |
| # carbon dioxide / # natural gas | 2.750 | | e | (28/12)*(12/16) |
| #carbon dioxide per 1,000 btu output | 0.124 | | | d*e |

Appendix 6
Sizing well tank compression tank

| | | | |
|---|---|---|---|
| flow rate (gpm) | 13 | A | equation |
| Acceptance factor $(psia_{initial}/psia_{fill)}) - (psia_{initial}/psia_{final})$ | | | |
| psia initial | 55 | B | |
| psia fill | 55 | C | |
| psia final | 75 | D | |
| | 0.27 | E | (B/C)-(B/D) |
| minimum gallon for 5 minute off cycle | 65 | F | A x 5 |
| minimum tank size (gallons) | 243.8 | | F/E |

To prevent short cycling of pumps, a method of water storage is required that can both store a volume of water as well as maintain pressure. The hydro-pneumatic tank, also known as a compression tank or an expansion tank is what is used. It is based on the concept that water is not compressible and that air is compressible. Boyle's law for gases states:

***pressure x volume = constant.***

As water enters the tank decreasing the volume of air, the pressure of the air increases and matches the pressure of the water.

When working with the pressure, we measure in "absolute" pressure which is the gauge pressure plus the atmospheric pressure.

Atmospheric pressure is the barametric pressure reported by the weather department. For LaCrosse, a usual barometric reading is 29.8 inches of mercury. The conversion factor to psia is .4912 psi/ in. Hg. So the usual barometric pressure in LaCrosse is 14.63 psia.

So filling a tank with water from atmospheric pressure to 40 $psi_{g(auge)}$ will decrease the volume by (1- $Pressure_{initial}/Pressure_{final}$ ): 1-(14.63/(40+14.63))= 1- (14.63/54.63) = 73.22%. Similarly, if we fill the tank to 60 $psi_{g(auge)}$ , the volume decrease would be 1-(14.63/(60+14.63))= 1-(14.63/74.63) = 80.4%
If we want to cycle the pump so the pump turns on at 40 psi and off at 60 psi, we can just subtract the two percentage changes to find out how much water we can store as usable water in the tank 80.4-73.22 = 0.072 or 7.2% of the total volume. A standard 100 gallon tank will provide only 7.2 gallons of storage from 60 to 40 psi.

One of the methods manufacturers have devised is a pre-pressurized tank with diaphragm between the water side and air side of the tank. Using the example above, but pre-pressurized to 40 psi, the formula would be:

1-((40+14.63)/(60+14.63) = 1-(54.63/74.63) = 1- .732 = 26.8%

A pre-pressurized 100 gallon tank would provide 26.8 gallons of storage from 60 to 40 psi.

Sources:

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ASHRAE Handbook 1999 HVAC Applications
HVAC Systems Design Handbook, Third Edition, Roger Haines, Lewis Wilson, McGraw Hill, 1998
Encyclopedia of Energy, McGraw Hill, 1976
NOAA website, Historical data LaCrosse Wisconsin
WFI website, Heat pump data sheet ERW042
Ground-coupling with water source heat pumps, Steve Kavanaugh , University of Alabama , Tuscaloosa

Some websites with useful information:

www.consumerenergycenter.org/home/heating_cooling/geothermal.html
www.geoexchange.org
www.igshpa.okstate.edu
www.geoheat.oit.edu
www.alliantenergygeothermal.com

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