Ground Source Heat Pumps – The Fundamentals

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Ground Source Heat Pumps – The Fundamentals

- TOPICS:
  - Heat Pump Terminology
  - Basic Physics of Heat Pumps
  - Processes of Ground Source Heating and Cooling
  - What Happens to the Heat Underground
  - Measuring Efficiency
  - The Differences From Traditional Systems
  - What to Look For

Geothermal Heat Pump

- Ground Source Heat Pumps (Geothermal) are self-contained, and fit inside a cabinet that is about the same size as a conventional warm-air furnace.

Inside a Geothermal Heat Pump

- A high-efficiency blower draws air from the building across a large heat exchanger

- A refrigeration system extracts heat from (or rejects it to) water circulating through underground pipes.

How Do You Get Heat From Cold Water?

- There is some heat in every object (fluid) on earth.
- Cold water has a lot of heat in it, even though it feels cold to us.
- To extract heat from cold water, we pass it through a heat exchanger containing refrigerant that is colder than the water. Heat naturally flows to cold objects (the refrigerant) from warmer ones (the water).
- To make this low-grade heat useable for heating our buildings, geothermal heat pumps extract the heat at low temperature, then boost that heat to a temperature that is warmer than the air in our buildings. – It’s that simple!

Heat Pump Terms

- “Geothermal” really refers to hot water, or steam that can be extracted directly from the earth. It occurs in the western US, and other places. But the term is now commonly used when referring to heat pump systems that extract low-grade heat from the earth.

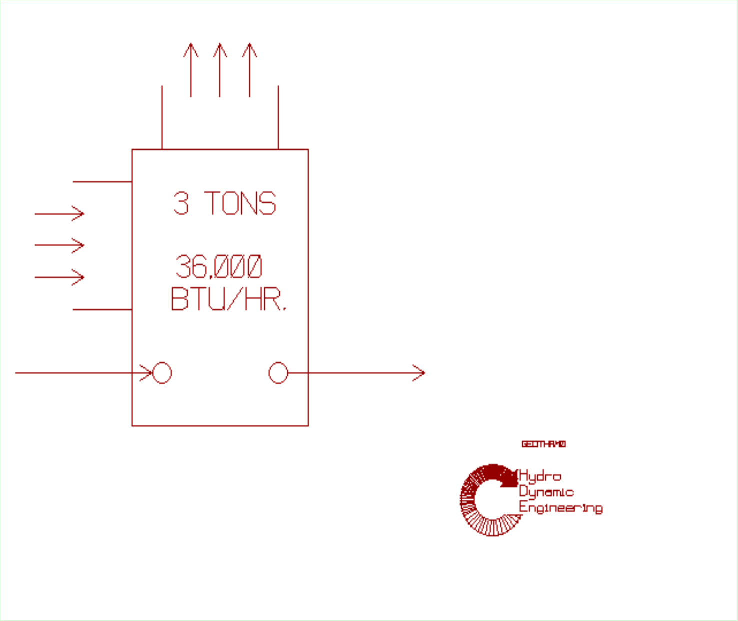
- Geoexchange, ground-source, and ground-coupled all refer to these same geothermal heat pump systems that we are looking at today.

Heat Pump Terms

- Four terms are commonly used, when describing heat pump capacity and efficiency.
- “BTU’s” and “Tons” describe heating and cooling capacities.
- “COP” and “EER” describe heating and cooling efficiencies.

BTU's vs. Tons

- BTU's per hour are units for measuring the heating capacities of heat pump systems.
- Tons are usually used to measure cooling capacities.
- Both describe units of heat, and each can be converted to the other.

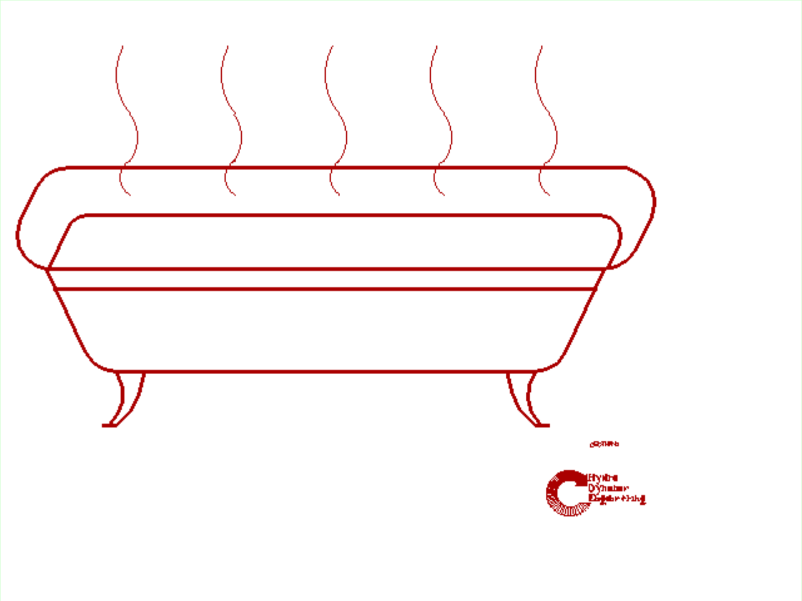


BTU = British Thermal Unit

- One BTU will raise the temperature of one pound of water by one degree Fahrenheit
- Brewing a pint of coffee (one pound of water) requires about 130 BTU's (180 deg. – 50 deg.)

British Thermal Unit

- A hot bath requires about 13,750 BTU’s.
- The math is simple: 30 gallons, weighing 8.33 pounds per gallon are warmed by 55 degrees.



British Thermal Unit

- Keeping an average home warm on a very cold night requires about 360,000 BTU's
- BTU = unit of heat
- BTU/hr = <u>Rate</u> of producing or removing heat

Measuring Heat Pump Capacity – BTU/hr

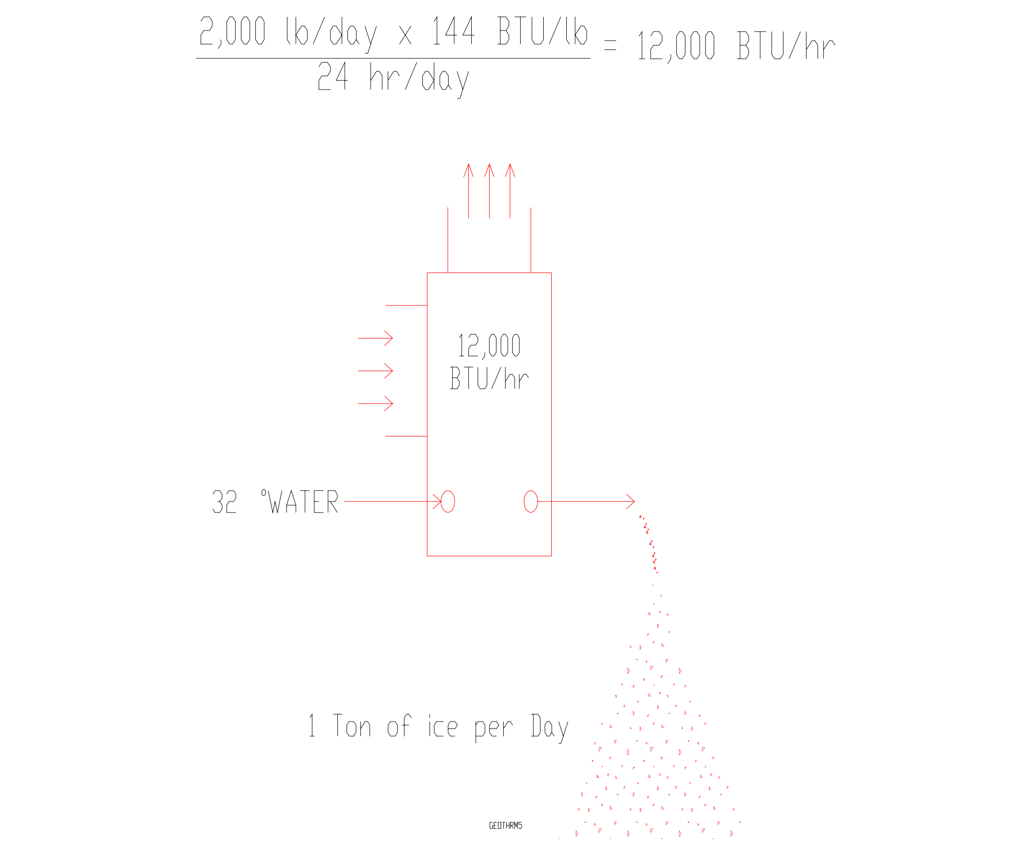
- A heat pump’s capacity is the rate at which it produces or removes heat. For heating, units are usually expressed as BTU/hr.
- For example, if a typical 36,000-BTU/hr heat pump runs constantly for ten hours, it will produce 360,000 BTU’s

Measuring Heat Pump Capacity - Ton

- In the cooling mode, heat pump capacity can be expressed in “Tons” of refrigeration capacity.
- A Ton of refrigeration is the cooling capacity which will freeze one Ton (2,000 pounds) of water in 24 hours <u>at 32 degrees F</u>.
- Looking at it another way, a one-Ton heat pump can provide as much cooling in 24 hours as a 2,000-pound block of ice.

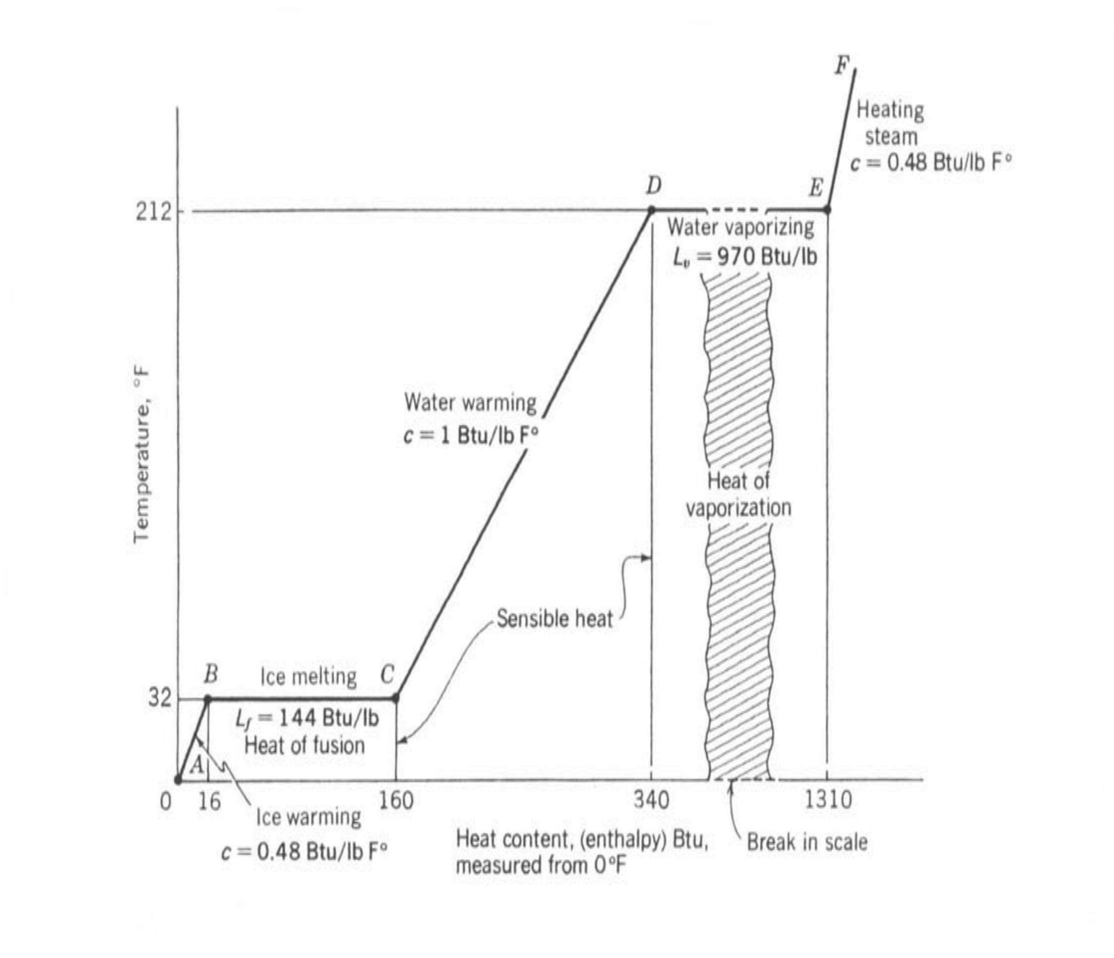
Converting "Tons" to "BTU/hr"

- One "Ton" of cooling capacity is equivalent to 12,000 BTU's per hour.
- Remember, a 12,000-BTU/hr. heat pump can freeze (or melt) one ton of ice in 24 hours.
- We use the terms interchangeably. A one-ton air conditioner cools the air at the rate of 12,000 BTU/hr.



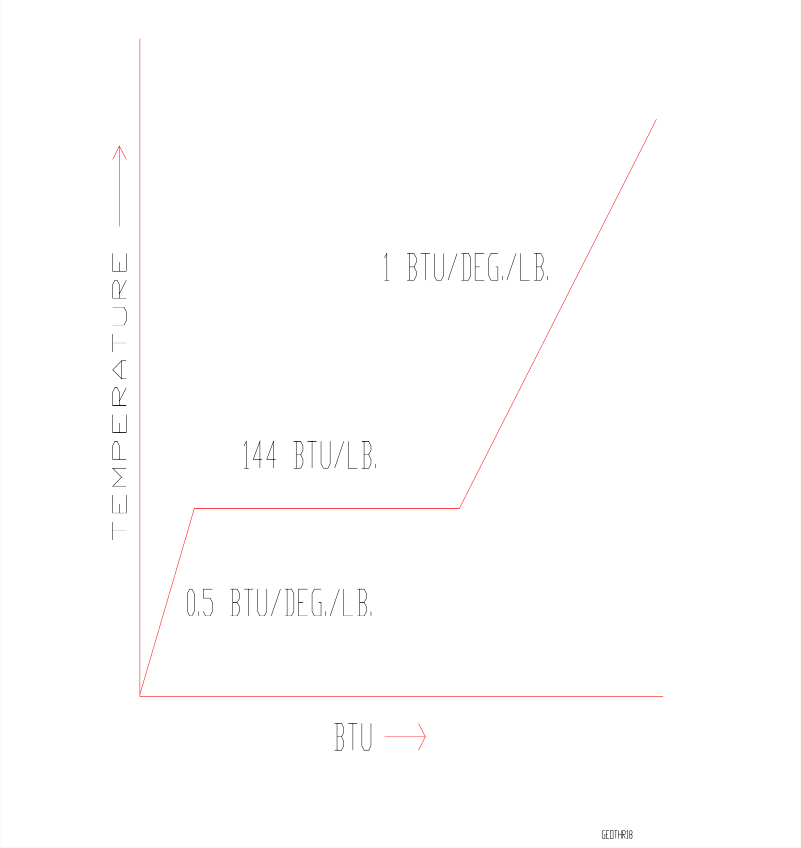
The Basic Physics
How Do Heat Pumps “Pump” Heat?

- First, look at water’s heat vs. phase diagram.
- Water, like other substances, absorbs a lot more heat when changing phases than when it is warmed within a phase.



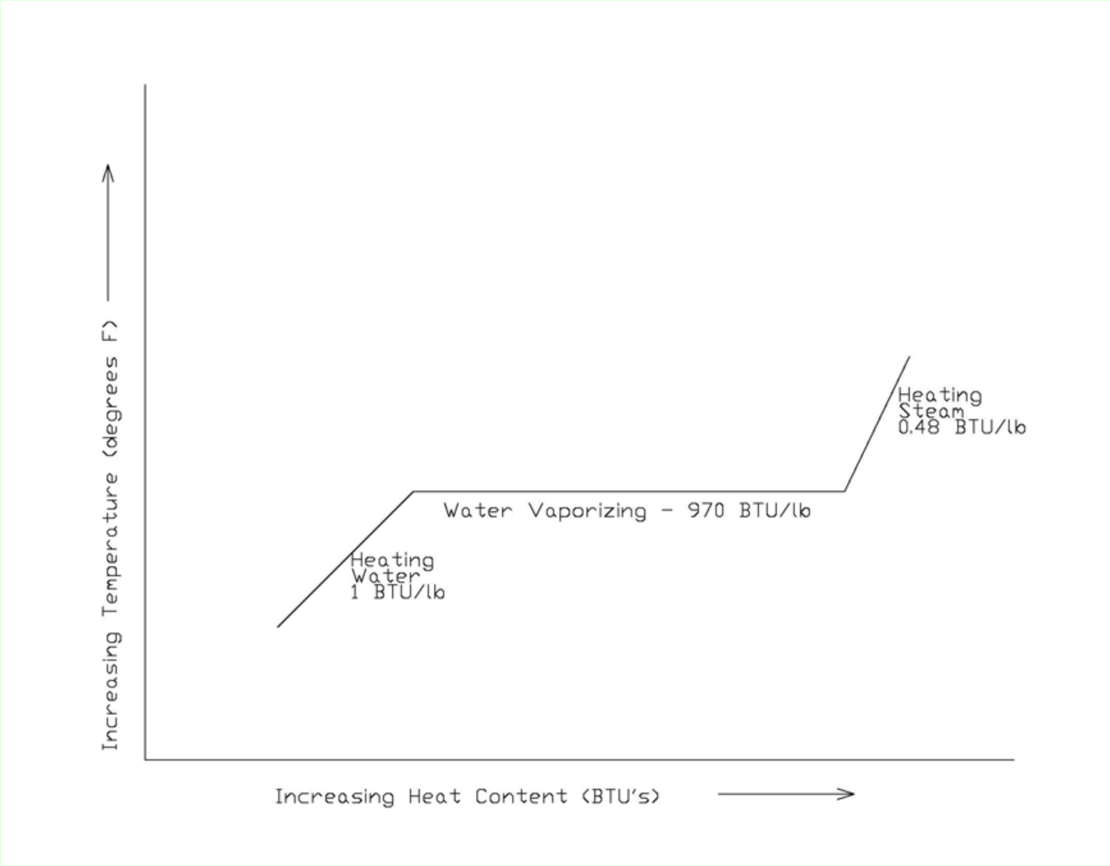
Water – Changing Phase to Ice

- It is relatively easy to warm a pound of water, and even easier to warm a pound of ice, but converting a pound of ice into a pound of water requires a lot of energy.
- Converting a pound of liquid to a pound of vapor requires even more energy. - -



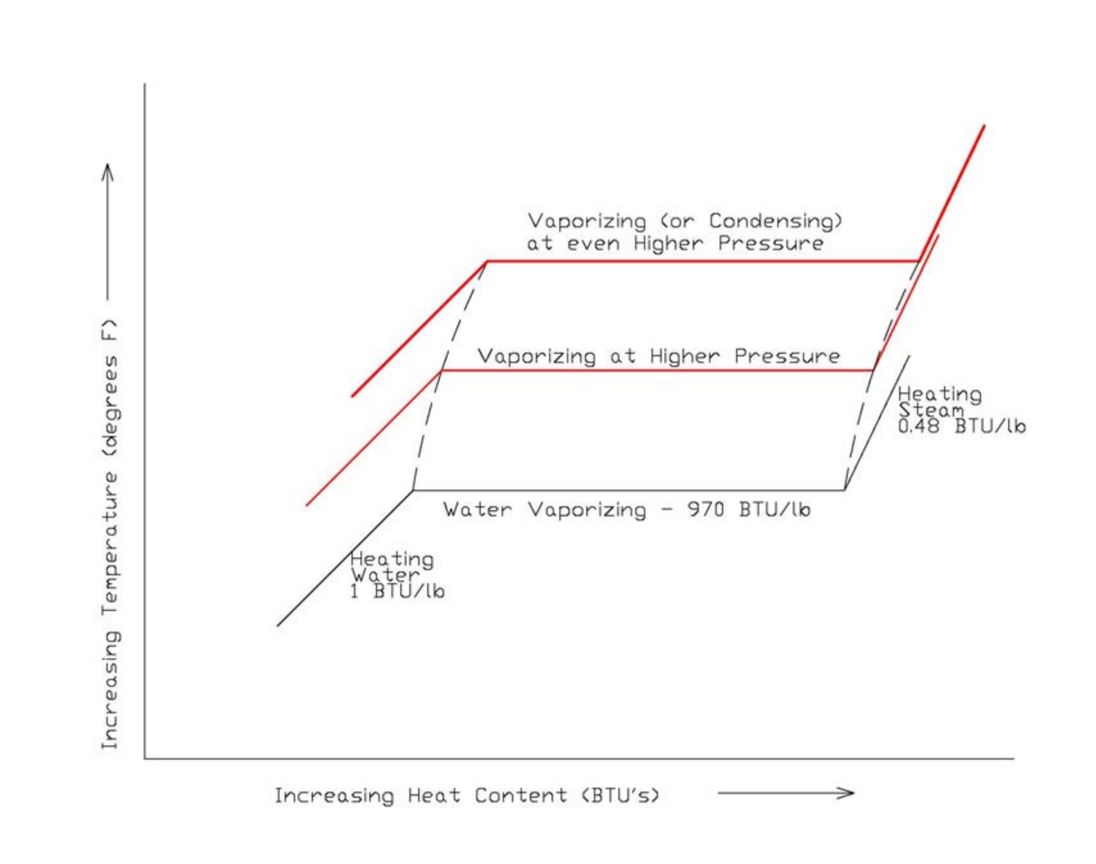
Water – Changing Phase to Steam

- Add 1 BTU of heat to a pound of liquid water, and its temp. rises by 1 degree F.
- But the pound of water absorbs 970 BTU as it evaporates at 212 deg.
- These are the numbers at atmospheric pressure.

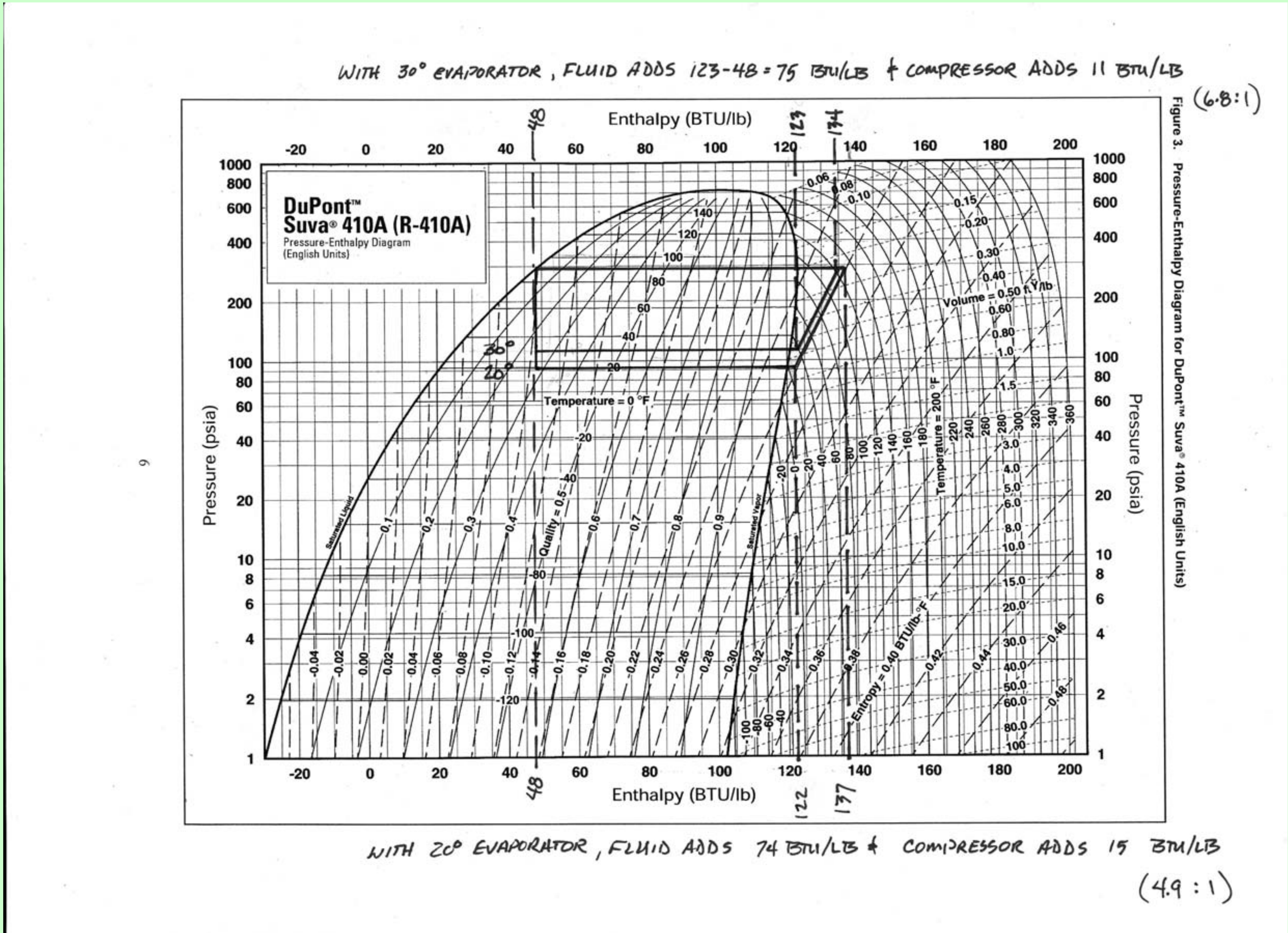


Changing Phase to Steam at Higher Pressures

- Raise the pressure, and the properties remain similar, except that the phase change occurs at increasingly higher temperature.
- Heat pumps use “refrigerants” that shift phase at convenient temperatures and pressures.

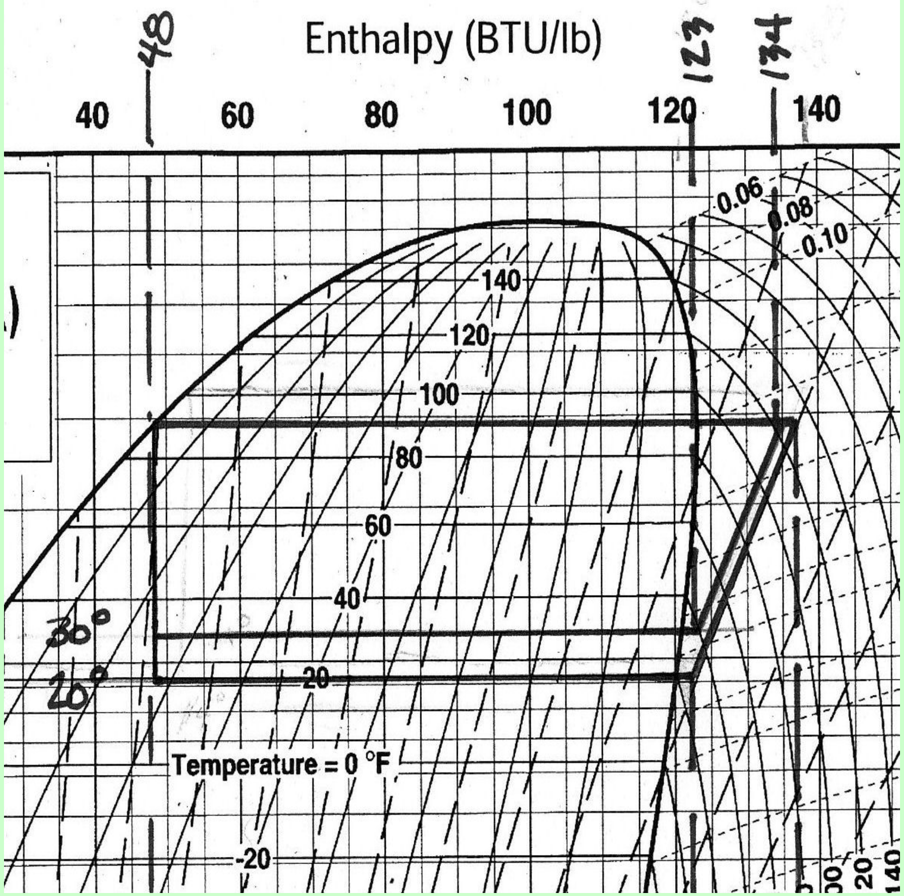


Refrigerants – Pressure vs. Heat Content



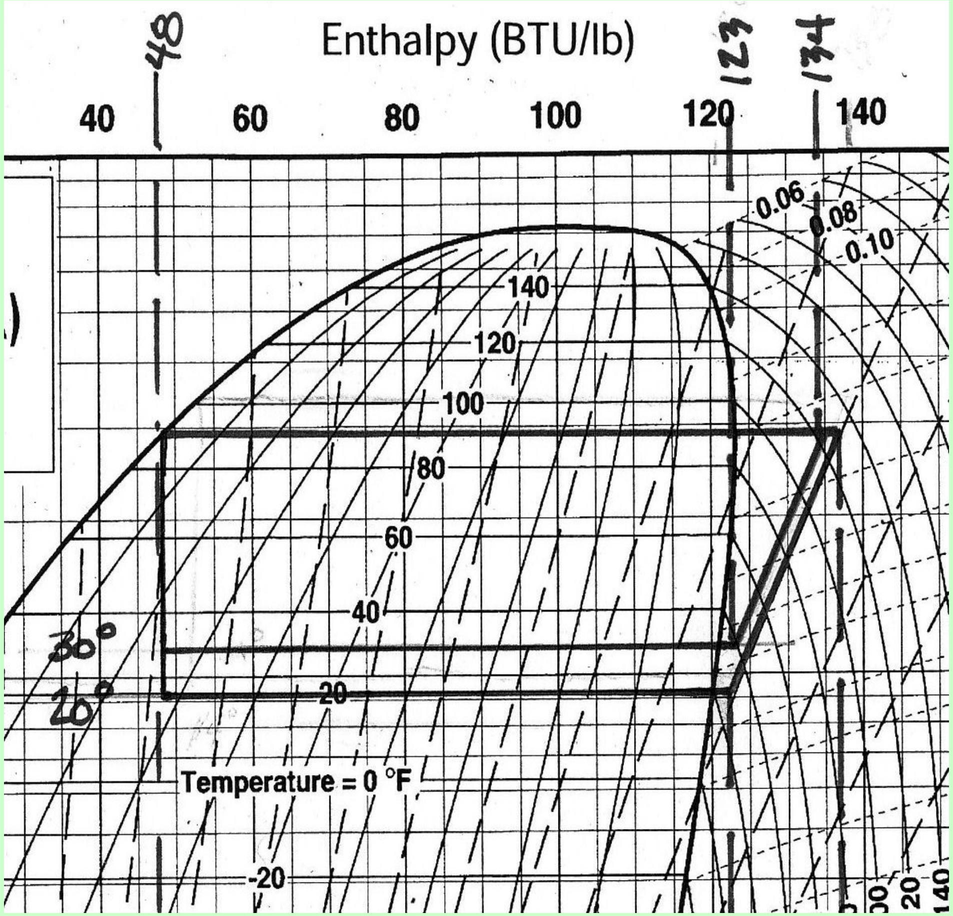
Refrigerants – Pressure vs. Heat Content

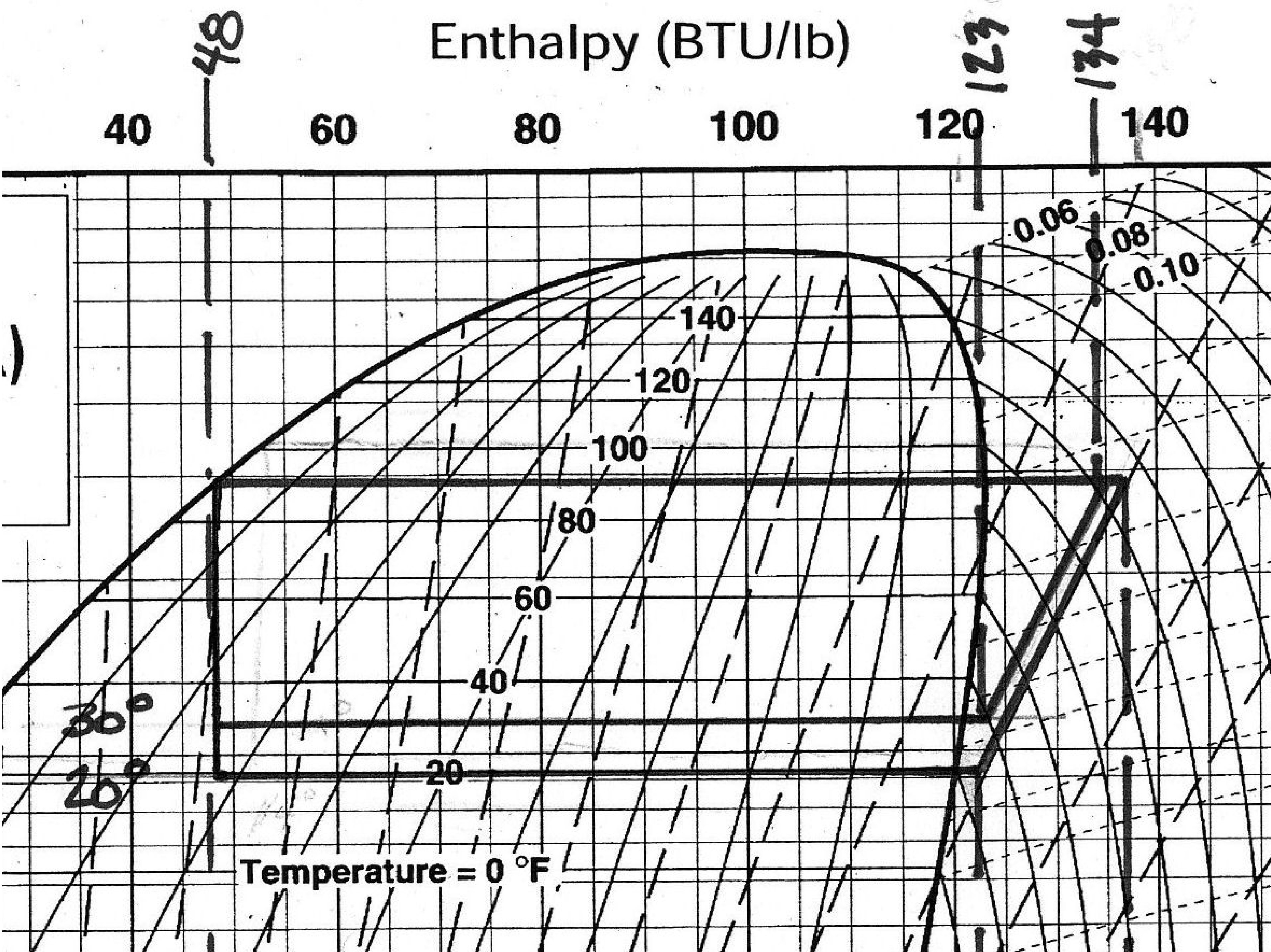
- At 120 psi, Refrigerant 410-A changes state from liquid to vapor at about 30 deg. F.
- At 300 psi, it changes state at about 90 deg. F.
- These are convenient temperatures and pressures for absorbing heat from ground water, and for releasing heat to our homes.



How Do Heat Pumps "Pump" Heat?

- In a typical heating cycle, most of the heat is added to the refrigerant in the cold "evaporator" when it changes state from liquid to vapor.
- The compressor adds some heat, but its primary job is to raise the pressure so heat can be released in the warm "condenser".



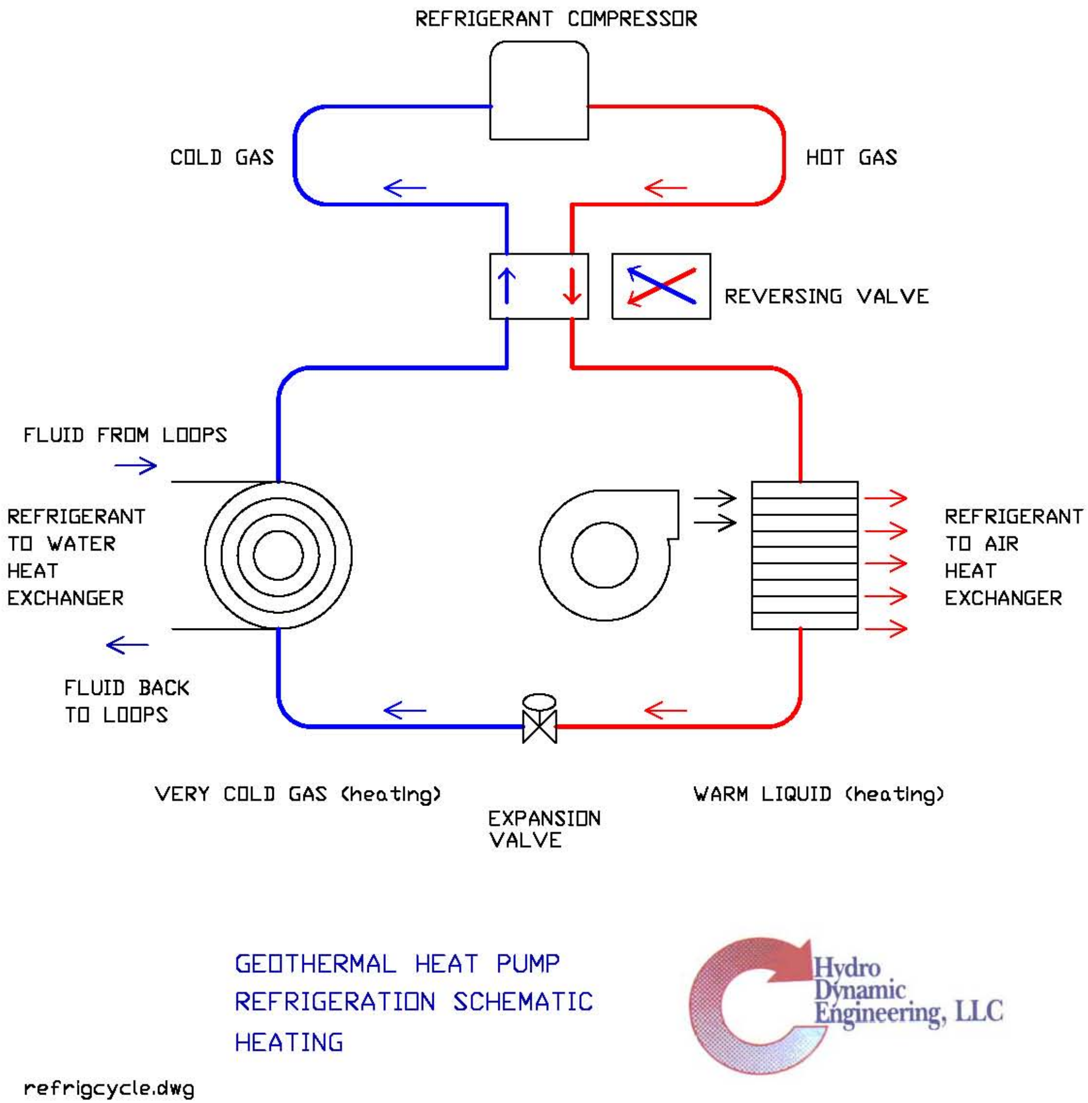


Enthalpy (BTU/lb)
48
123
134
40
60
80
100
120
140
0.06
0.08
0.10
140
120
100
80
60
40
20
30°
20°
Temperature = 0 °F

Review the Process:

- Low pressure liquid refrigerant evaporates at about 30 deg. F, within a water heat exchanger, and absorbs heat from the water (or antifreeze solution).
- The cool refrigerant vapor is then compressed, typically from 120 psi to 300 psi. The heat of compression warms the gas to about 90 deg. F.
- The warm vapor gives its heat to the house in an air heat exchanger, as the vapor condenses to a liquid.
- The refrigerant passes through an expansion valve, where the pressure is reduced back to 120 psi.

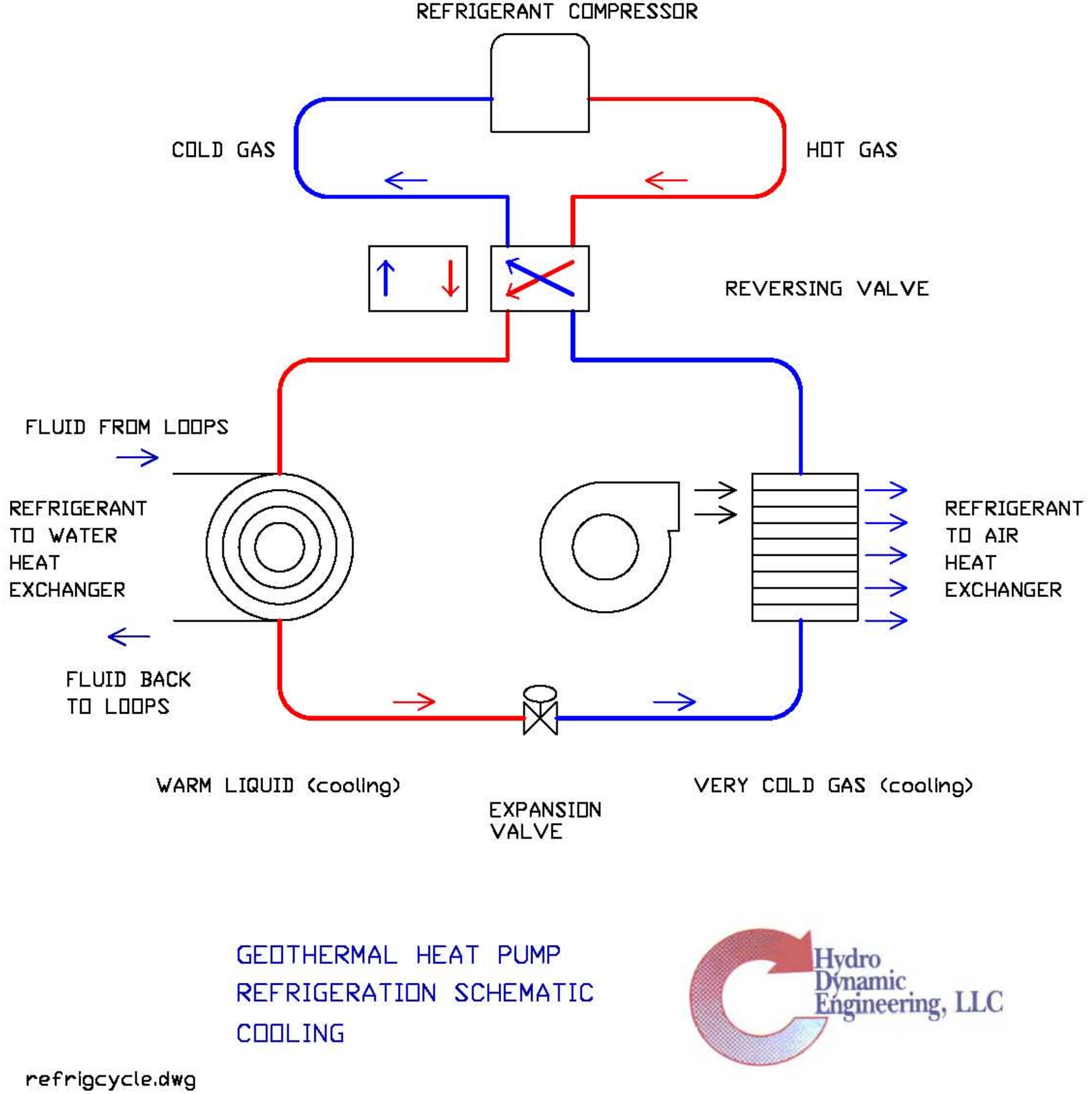
The Heat Pump – Heating Process



The cycle is reversed for cooling

- The compressed, warm vapor goes to the water heat exchanger first, where it releases heat to the water and condenses to a liquid.
- The refrigerant pressure is reduced at the expansion valve, as for heating.
- The refrigerant now vaporizes in the air heat exchanger, absorbing heat from the air in the living space.

The Heat Pump – Cooling Process



Hydro Dynamic Engineering, LLC

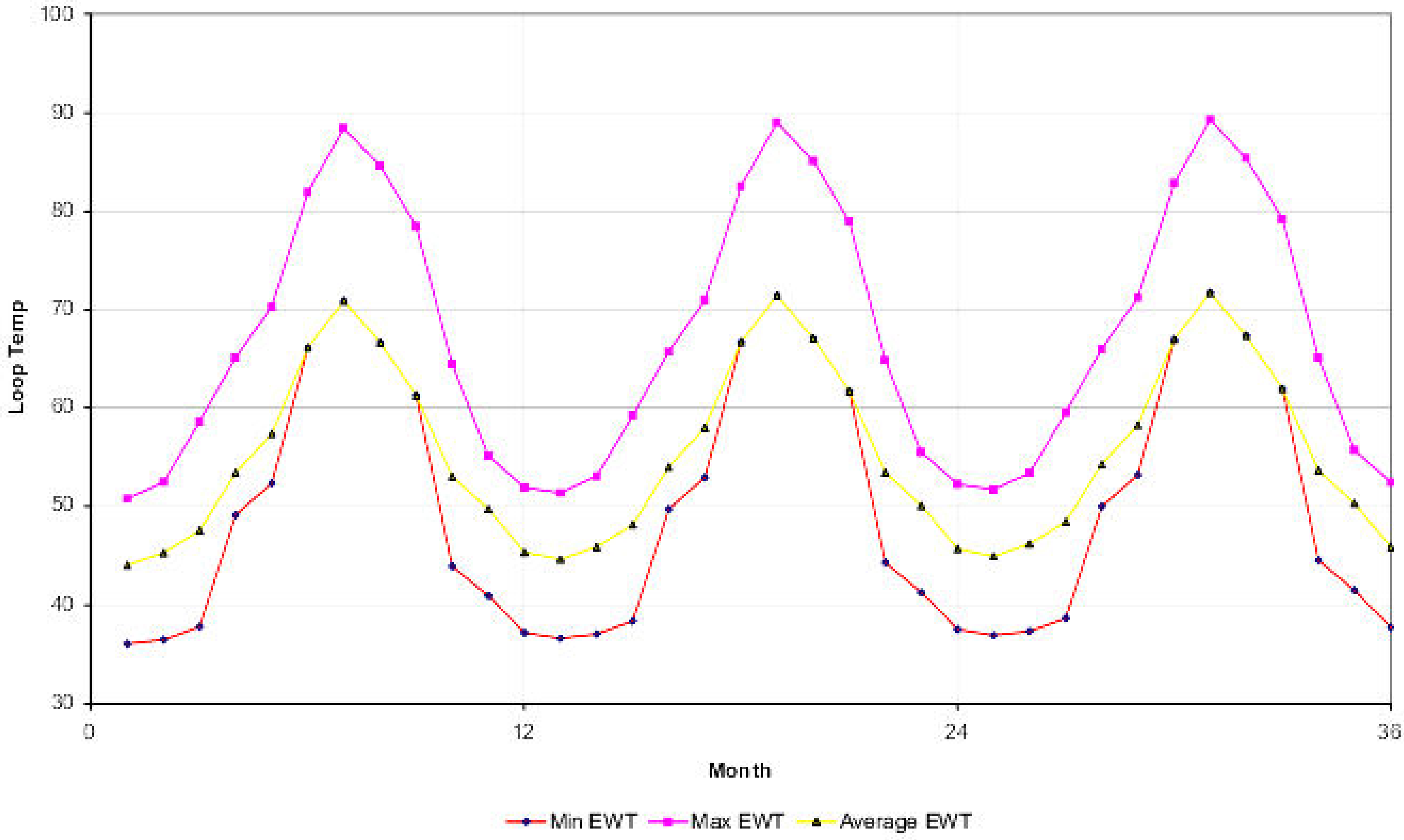
What Happens to the Heat Underground

- Most of the heat, removed from the ground by the heat pumps during the winter, is replaced by natural heat flow underground. Some heat is also replaced during the summer, when the heat pumps run in the air conditioning mode.

What Happens to the Heat Underground

- Several software applications are available, which calculate the ground loop temperature for closed loop systems. These temperature calculations require:
  - The design (peak) heating and cooling loads
  - Annual weather data for the site
  - The design layout for geoexchange loops
  - Heat conductance and heat storage capacities of the soil (bedrock)

Geothermal Loop Temperature Range
(186 ft borehole per ton)



home.xls

Designing The Water Supply Side

- Each BTU removed from a pound of water lowers its temperature by one degree Fahrenheit.
- Each gallon of water weighs 8.33 pounds.
- Removing 8.33 BTU's from a gallon of water lowers its temperature by one degree Fahrenheit.

Designing The Water Supply Side

- The three-ton heat pump, which delivers 33,300 Btu/hr to the house, needs to extract 25,500 Btu/hr from the water.
- If the design-temperature drop, for water passing through the heat exchanger, is 6 degrees F, then the heat pump needs:
  - 25,500 Btu/hr / (8.33 Btu/gal · deg x 6 deg) = 510 gal/hr
  - or 8.5 gal/minute
- If the heat pump runs for 8 hours in one day, it will need 4,080 gallons of water pumped through it that day.

Designing the Water Supply Side

- 25,500 Btu/hr are extracted from the water, but 33,300 Btu/hr are delivered to the house.
- The additional 7,800 Btu/hr, comes from the electricity purchased to run the heat pump. This is the heat generated in motor windings within the blower and compressor.
- An important point - no heat is wasted.

Measuring Heating Efficiency - COP

- In the heating mode, efficiency is expressed as Coefficient of Performance, or COP.
- COP = Total heating capacity in BTU/hr, divided by the electric power input in BTU/hr.
- Example: 33,300 / 7,800 = 4.27 COP
- By minimizing power input, the COP is maximized.
- That means minimizing compressor, fan and circulator running watts.

Measuring Cooling Efficiency - EER

- In the cooling mode, efficiency is expressed as Energy Efficiency Ratio = EER.
- EER = Total cooling capacity, in BTU/hr, divided by the electric power input in watts.
- Example: 39,700 / 1,670 = 23.8 EER.
- The same rules for maximizing efficiency by minimizing running watts hold true here too.

Differences From Traditional Systems

- Heat pumps do not burn fossil fuel. There is no air emission.
- ¾ of the heat comes from the earth, and is renewable.
- The antifreeze used in closed loop systems is propylene glycol, the non-toxic type used in recreational vehicles.
- The water used by open loop systems is returned to the earth unchanged, except for heat.

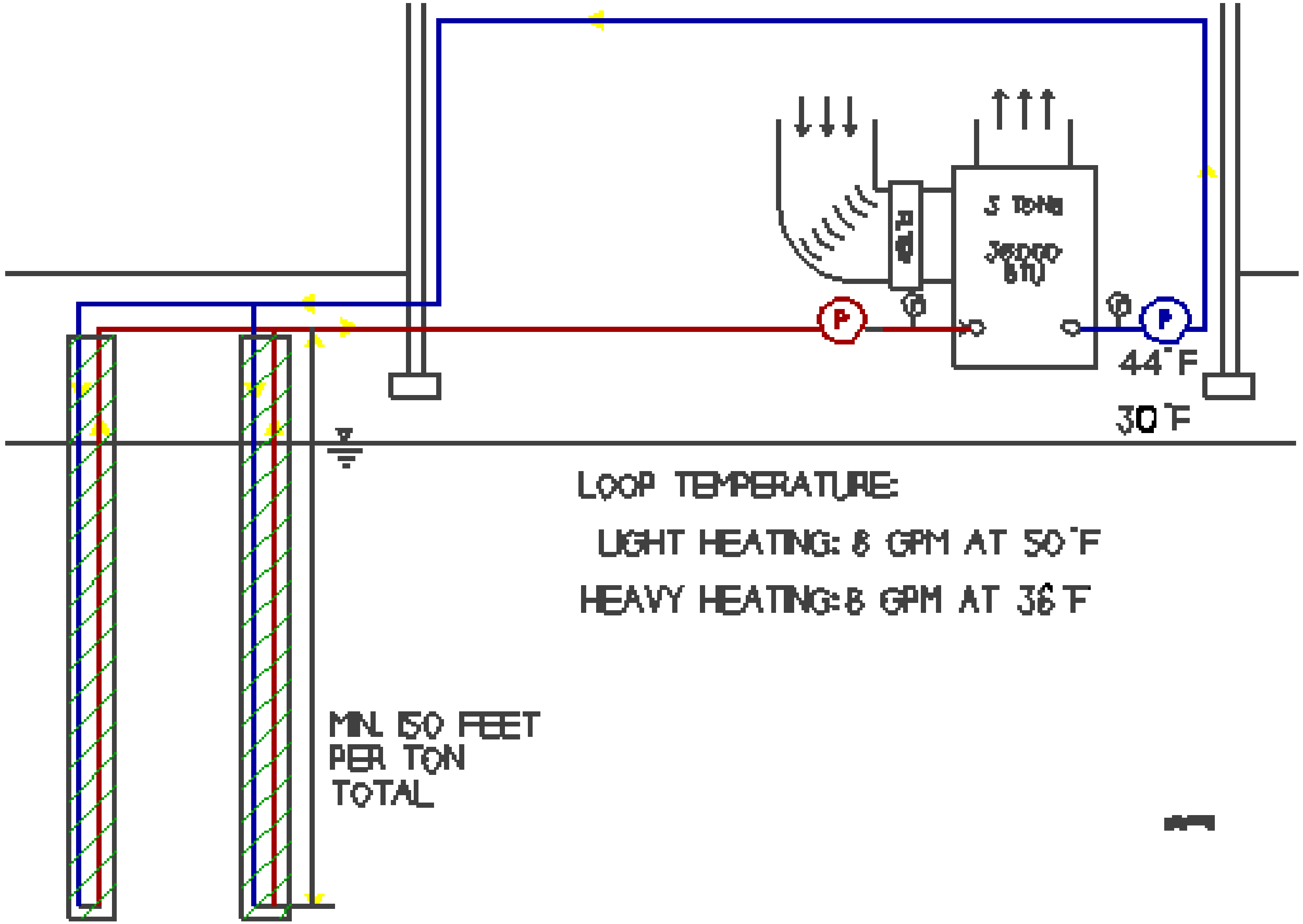
Differences From Traditional Systems

- A good Air-Source Air Conditioner runs at a SEER rating of 13. Compare geothermal equipment that runs at EER ratings near 20.
- The difference is not because of magic. Geothermal systems reject heat to a 50-degree earth, while air-source equipment rejects heat to 80 or 90 degree air.

Differences From Traditional Systems

- Search the internet for sources that calculate the comparative operating costs for various heating and cooling systems.
- Try:
  - www.warmair.net/html/fuel_cost_comparisons.htm
  - http://hearth.com/econtent/index.php/articles/fuel_cost_comparison_calculator/
    - For heat pump, use electric heat at 427% (for COP = 4.27)
- Google “Fuel Cost Comparison Sites”

Piping Example – Vertical Closed Loop Heating



What to Look For
Vertical Closed Loop

- In southern New England, we usually design for 150 feet of borehole per ton of heat pump capacity.
- Boreholes should be kept at least 15 feet apart.
- Each borehole is filled with clay grout after the loops are installed. Casings are cut off below surface to allow lateral connections to be made.
- Loops are filled with a solution of propylene glycol and water. (usually 20%)
- Lateral runs into the house should be buried at least four feet below surface.

What to Look For – Closed Loop Systems

- Clay grout is non-setting, so it is possible that the clay will migrate. Keep the loop wells separated from the potable well, especially where the bedrock is highly fractured.
- Well casings are cut off below grade, or removed entirely, so a good grouting job is important. A mound of chip-sized bentonite should also be placed over the top of each well.

Operating Costs

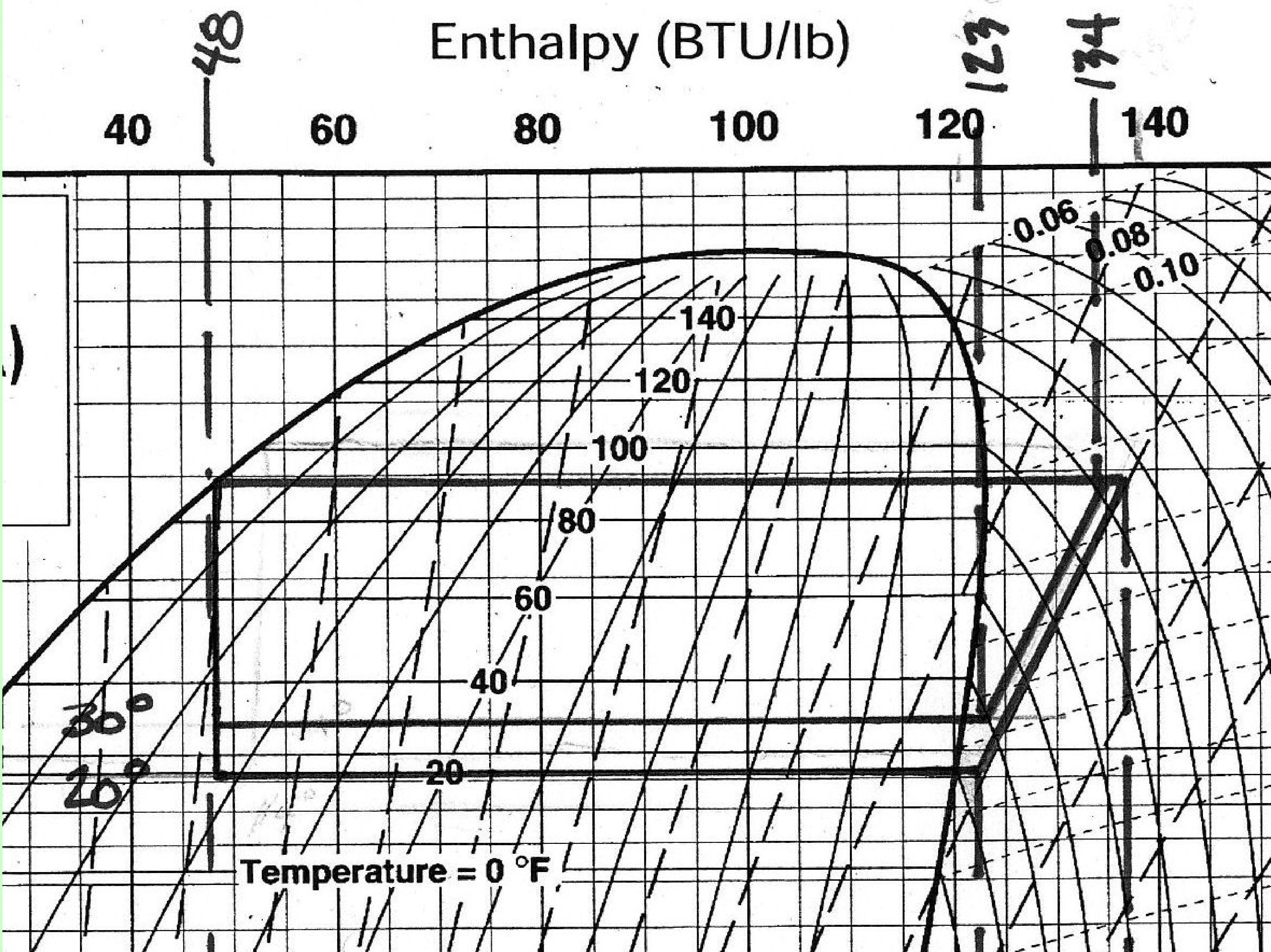
- Operating cost for heating and cooling a 3,200 square foot house, with a closed loop vertical system, at current electric prices, should average about $1,800.00 per year.
- Average monthly heating costs can vary from $36.00 / month to $316.00 / month.

Compare Operating Costs

- Closed-Loop Geothermal heat pump, at 17 cents / KWH, costs about $1,800.00 per year to heat and cool the 3,200 sq. ft. house.
- Straight electric heat, at 17 cents / KWH, would cost over $6,070.00 per year for the same house.
- Fuel oil at $3.00 / gallon, burned in an 80%-efficient furnace, with a 12-SEER air conditioner, could cost over $3,750.00 per year.

Importance of Good Design

- One of the most important factors, in designing a geothermal system, is to give the evaporator as much heat as you can. This means plenty of borehole and flow-rate in a closed-loop system.
- If you skimp on water or loops, the evaporator runs cold, the condenser will also be cooler, and the heat pump will need to run longer to warm the house.
- Similarly, if you skimp on duct sizes, the condenser runs hot, and the compressor consumes more electricity than needs to.



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20
30°
20°
Temperature = 0 °F

Importance of Good Design

- The geothermal system designer (installer) needs to design the air ducts and geoexchange loops conservatively, for economical operation of the system.
- On a typical heating day our 3-ton heat pump system might cost $3.62 to operate for the day.
- If the ducts are undersized, capacity <u>and</u> efficiency are compromised, and the same machine might cost $4.11/day.
- Similarly, if the geoexchange loops are undersized, operating cost might be $4.00/day.
- If both are under-designed, operating cost might be $4.54.

New Incentives

- The Connecticut Clean Energy Fund has money available from the American Recovery and Reinvestment Act.
- Retrofit customers must participate in their Utility’s audit/upgrade program and show evidence of their building’s energy efficiency.
- New Construction homes must be Energy Star rated.
- All recommended upgrades must be made before installing the geothermal system.
- Residential retrofits are eligible for $2,000/ton, and new construction installations are eligible for $1,200/ton.
- Check at www.ctcleanergy.com/geothermal for more information.

Other Incentives

- Connecticut Light & Power and United Illuminating are offering rebates of $500.00 per ton of heat pump capacity, for new heat pump installations. (Up to $1,500.00 per site)
- The heat pumps must be Energy Star rated.
- The operating performance, as installed, must be within 15% of the factory ARI rating.
- The IRS allows a 30% tax credit for the installation cost of a geothermal heat pump system. (no performance test req.)
- Homeowners and businesses should check with their accountants before committing to buying geothermal.

More Information - Websites

- www.fhp-mfg.com
- www.climatemaster.com
- www.waterfurnace.com
- www.geocomfort.com
- www.noblecompany.com/burst.html
- www.geothermal.okstate.edu
- www.geo4va.vt.edu
- www.cl-p.com

Information on Regulations

- In Connecticut, check at: http://www.ct.gov/dep for information on "General Permits" In June 2007 - Pump and Discharge systems under 250,000 gpd need not file, but must meter flow and keep daily records. No DEP regulations for closed loop systems.

- New Connecticut Well Drilling Regulations are being developed. They will provide for smaller separating distances to septic system and underground drains for closed loop wells than for water supply wells (open loop systems), because the closed loop wells are filled with clay grout.


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8-well manifold

Installing loops


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