This is only a test – if it had been a real slide there would have been bulleted text replete with profound statements, and zoomy animations

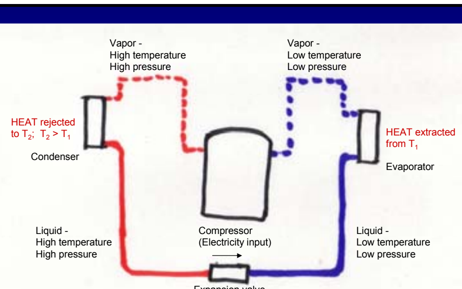
When Does Using a Ground Source Heat Pump Make Sense?

Today's presentation will cover:

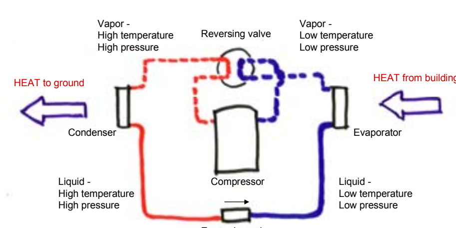
- What is a heat pump and how do they work?
- What is a ground source heat pump (GSHP)?
- How can ground connections be made?
- What applications make sense for GSHPs?
- What aspects need careful attention?
- Some buildings that use GSHPs

Some Fundamentals

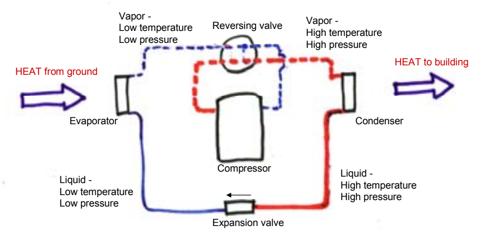
- When a vapor condenses, it gives up heat to the surface it condenses on
- When a liquid boils, it takes heat from the surface it boils on
- When the pressure of a vapor is increased, its temperature increases
- When the pressure of a liquid is decreased, its temperature decreases (and it may boil)
- Heat moves from hot to cold – if you want it to go from cold to hot, you need to put energy into the system



The Refrigeration Cycle



Ground Source Heat Pump Cooling Cycle



Ground Source Heat Pump Heating Cycle

COP and EER

- Coefficient of Performance (COP) is defined as the ratio between the energy delivered to the building (heating) divided by the energy input to the system. A good GSHP will have a COP of 3 to 4 or more. Higher is better.
- Energy Efficiency Ratio (EER) is defined as the ratio between the energy removed from the building in BTU/hour divided by the energy input to the system in Watts. A good GSHP will have an EER of 16 to over 25. Higher is better. Cooling COP can be calculated by dividing EER by 3.413.
- GSHPs have different rated COPs and EERs at different source and sink temperatures.
- System COP and EER is always lower than GSHP COP and EER, due to the energy going into pumps and blowers.

Air Source Heat Pumps vs. GSHPs

- Heat pump efficiency *decreases* as the temperature difference between the source (evaporator side) and sink condenser side) *increases*
- Air source heat pumps use the air as the source for heating energy and the sink for cooling energy (the latter is the same for a residential air conditioner.)
- COPs drop dramatically at temperatures below freezing, as do capacities
- GSHPs use the much more stable temperature of the earth as a source and sink, giving higher efficiencies for both heating and cooling

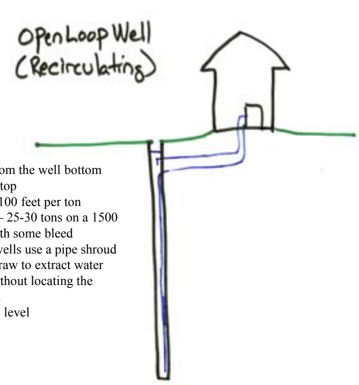
Air or Water?

- The building-side heat exchanger (alternately condenser or evaporator) can be made such that the heat pump makes cool and warm air or chilled and hot water
- Because GSHPs drop in efficiency and capacity as the output temperature increases, GSHPs deliver air at lower temperatures than do combustion-based furnaces – leaving air temperatures in the 90F range are common
- In hydronic GSHPs, leaving water temperature shouldn't much exceed ~120F
- Capacity is rated in tons – one ton is 12,000 BTU/hour or ~3.5 kW

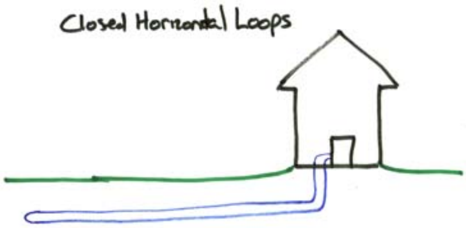
Ground Coupling

GSHPs can couple to the temperature of the earth in several ways. In almost all cases, the earth-side heat exchanger has a liquid pumped through it.

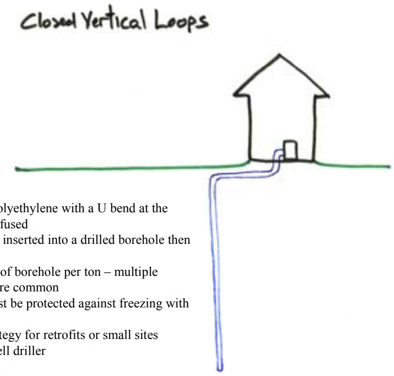
- Open loop well (could also be surface water, ocean?)
- Closed loop buried horizontal piping loop
- Closed loop vertical piping loop
- Closed loop submerged in surface water
- Direct expansion buried piping loop



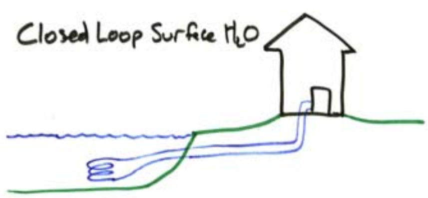
- Water is drawn from the well bottom and returned at the top
- Domestic wells ~100 feet per ton
- Larger buildings – 25-30 tons on a 1500 foot deep well – with some bleed capability – these wells use a pipe shroud in the well like a straw to extract water from the bottom without locating the pump at the bottom
- Need a high static level
- 2.3 – 3 gpm/ton



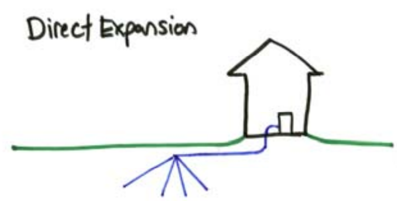
- Loops are polyethylene piping with fused joints – no buried fittings
- Multiple loops in a trench is common, e.g., a three loop trench
- ~900 feet of piping per ton is common
- Trench depth 5-6 feet
- Fluid must be protected against freezing with antifreeze
- No specialized installation equipment (i.e., a backhoe works)



- Loop is polyethylene with a U bend at the bottom, all fused
- Loops are inserted into a drilled borehole then grouted
- ~200 feet of borehole per ton – multiple boreholes are common
- Fluid must be protected against freezing with antifreeze
- Good strategy for retrofits or small sites
- Need a well driller



- Coils of pipe are submerged in a body of water with sufficient depth (> 6 feet) and area
- Least expensive to install
- 500 feet of coil per ton



- Instead of a pumped loop in plastic pipe, DX systems bury copper tubing containing the actual refrigerant, which boils or condenses as required by the GSHP
- This type of system should use less energy than pumped systems
- Copper in acid soils must be protected with a small current to avoid corrosion
- Care must be taken during installation to not kink or crush the copper tubing

Rated vs. Actual Capacity

- GSHP output depends on loop water temperature
  30F = 25,600 BTU/hour
  40F = 28,100
  50F = 31,900
- To a lesser extent, GSHP output depends on the flow rate of fluid through the heat exchanger

Performance Data — Ultra Classic Model 036 - Full Load

Model 036 Full Load
Rated Air Flow 1200 CFM

EWT °F	GPM	WPD†		COOLING - EAT 80/67 °F						HEATING - EAT 70°F					
		PSI	FT	TC	SC	kW	HR	EER	HWC	HC	kW	HE	LAT	COP	HWC
20	4.0	1.2	2.8	Operation Not Recommended											
	6.0	2.2	5.0												
	8.0	3.5	8.0							22.4	2.20	14.9	87.3	2.99	2.2
30	4.0	1.2	2.7							24.4	2.27	16.9	88.8	3.55	2.3
	6.0	2.1	4.8							25.6	2.31	17.9	89.7	3.64	2.5
	8.0	3.4	7.8							26.3	2.33	18.5	90.3	3.66	2.7
40	4.0	1.1	2.6	39.9	29.0	1.82	45.5	21.9	2.4	28.1	2.38	21.5	91.7	4.14	2.7
	6.0	2.0	4.7	40.9	29.4	1.68	46.0	24.3	2.3	29.5	2.42	22.1	92.8	4.13	2.9
	8.0	3.2	7.5	41.4	29.6	1.61	46.2	25.8	2.2	30.3	2.44	22.8	93.4	4.15	3.1
50	4.0	1.1	2.5	38.7	28.5	2.03	44.9	19.1	2.8	31.8	2.48	25.2	94.5	4.50	3.1
	6.0	1.9	4.5	39.6	28.8	1.88	45.4	21.1	2.6	33.5	2.53	25.7	95.9	4.50	3.3
	8.0	3.1	7.2	40.1	29.0	1.80	45.6	22.2	2.5	34.5	2.55	26.3	96.6	4.50	3.5
60	4.0	1.1	2.4	37.3	27.9	2.24	44.2	16.7	3.1	35.7	2.58	28.9	97.6	4.87	3.5
	6.0	1.9	4.4	38.3	28.3	2.09	44.7	18.3	2.9	37.7	2.64	29.5	99.1	4.88	3.7
	8.0	3.0	7.0	38.8	28.5	2.02	44.9	19.2	2.8	38.9	2.67	30.1	100.0	4.87	3.9
70	4.0	1.0	2.3	36.0	27.4	2.46	43.5	14.6	3.4	39.8	2.69	32.7	100.7	5.24	3.9
	6.0	1.8	4.2	36.9	27.8	2.31	44.0	16.0	3.1	42.1	2.75	33.1	102.5	5.20	4.1
	8.0	2.9	6.7	37.4	28.0	2.24	44.2	16.7	3.1	43.4	2.78	33.9	103.5	5.25	4.3
80	4.0	1.0	2.3	34.6	26.7	2.68	42.8	12.9	3.7	44.0	2.80	36.5	103.9	5.55	4.2
	6.0	1.8	4.1	35.5	27.1	2.53	43.3	14.0	3.5	46.6	2.86	36.9	106.0	5.53	4.4
	8.0	2.8	6.6	35.9	27.4	2.46	43.5	14.6	3.4	48.2	2.90	37.7	107.2	5.57	4.7
90	4.0	0.9	2.2	33.1	26.2	2.91	42.0	11.4	4.0	48.4	2.91	38.4	107.3	4.87	4.2
	6.0	1.7	3.9	34.0	26.5	2.76	42.6	12.3	3.8	51.5	2.99	41.2	109.7	5.04	4.4
	8.0	2.7	6.3	34.5	26.7	2.69	42.8	12.8	3.7	53.2	3.04	42.8	111.0	5.12	4.7
100	4.0	0.9	2.1	31.7	25.6	3.15	41.4	10.1	4.3	Operation Not Recommended					
	6.0	1.7	3.8	32.6	26.0	3.01	41.8	10.8	4.1						
	8.0	2.7	6.2	32.9	26.1	2.94	42.0	11.2	4.0						
110	4.0	0.9	2.1	30.1	25.0	3.39	40.6	8.9	4.6						
	6.0	1.6	3.7	31.0	25.4	3.25	41.0	9.5	4.4						
	8.0	2.6	6.0	31.4	25.5	3.19	41.3	9.9	4.3						

Good reasons for choosing GSHP

- The annual cooling load is larger than the heating load
- Only low temperature loads in the building (warm vs. hot)
- Occupants with a high sensitivity to fuels and combustion
- Desire for a building with no combustion sources
- Lack of a good location for cooling lead rejection to the air
- Source of renewable electricity on site (or purchased offsite)
- Fuel cost stability vs. fossil fuels

Equivalent costs:
Electricity at $0.12/kWh, GSHP at COP = 3
Oil at $1.35/gallon, AFUE = 83%
LPG at $0.97/gallon, AFUE = 90%

Some caveats…

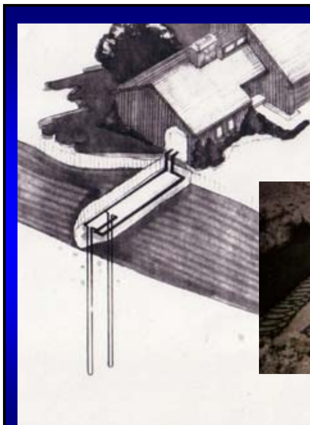
- Undersizing is bad – because the balance of the load is usually made up with electric resistance
- Oversizing is bad – unlike fossil fuel appliances, cost is proportional to size
- Most GSHPs don’t make DHW on demand – so the balance is made with electric resistance
- Output temperatures are low in air systems, this means ducts will be larger and that proper diffuser location is more important
- Output temperatures are low in hydronic systems, so heating delivery needs to be low temperature such as radiant, and DHW design needs good engineering
- Beware special utility rate offering for GSHPs, they can change
- Poor engineering of the loops and pumping required can lead to significant reductions in system efficiency

Rated vs. Actual COP

Here’s the ARI/ISO/ASHRAE rating for heating of the UC036:
Loop temperature = 32F; COP = 3.7
Loop temperature = 50F; COP = 4.3

Here’s my calculation including *optimized* pump power:
Loop temperature = 32F; COP = 3.0 (245W pump)
Loop temperature = 50F; COP = 3.5 (338W pump)

NB: both could be worse with *typical* pump selections – COPs of ~2.7 and 3.1, respectively



Examples of ground coupling

Water-to-air

Water-to-water

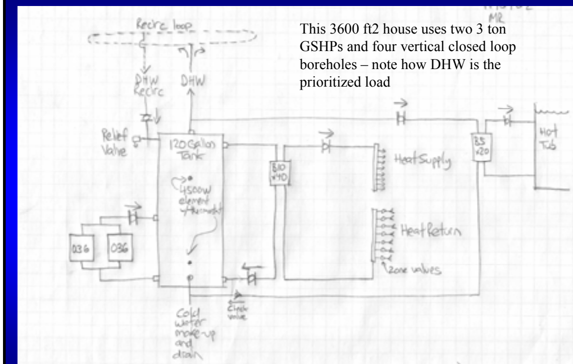
Cost

- In residential systems, a fully set-up GSHP in the 3-5 ton range will cost about $ 1750-2000 per ton installed
- Horizontal loop for a 3 ton system recently quoted at about $8,000
- Drilling and casing costs for a well between 1400-1500 feet was recently $27,000 – this does not include the pump and shroud installation

Case 1 – Mazar House

This 3600 ft2 home on Martha's Vineyard was designed to be a zero annual net energy home, using a grid-tied Bergey 10 kW wind turbine. Heat, DHW, and hot tub heating are provided by two 3 ton water-to-water heat pumps coupled to four closed loop vertical boreholes. Heat is via hydronic radiant floor.

South Mountain Company



This 3600 ft2 house uses two 3 ton GSHPs and four vertical closed loop boreholes – note how DHW is the prioritized load

Modeled Annual Energy Use

Heating	6,732 kWh
DHW	1,849 kWh
Lights	1,303 kWh
Appliances	7,241 kWh
Total	17,125 kWh/year

Expected wind turbine output on this site is approximately 17,000 kWh/year.

Case 2 – Woods Hole Research Center

This 19,300 ft2 gut rehab/addition was designed to be a zero annual net energy project, using 26.4 kW of PV and a future 100 kW wind turbine. Five water-to-water heat pumps couple to the earth via a 1200 ft deep recirculating well.

William McDonough & Partners Architects

In the 12 months from Oct 2003 through September 2004, energy use was 89,669 kWh. The solar electric system produced 30,469 kWh, or 34% of the total energy used.

Case 3 – NRG Systems

This 45,600 ft2 commercial building in Hinesburg uses five water-to-water GSHPs coupled to the fire pond for cooling, including some radiant slab floors

William Maclay Architects

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Case 4 – Tuck Mall Residence Hall

New 70,000 sf residence hall at Dartmouth College will use two 30 ton GSHPs coupled to two 1450 foot deep recirculating wells. Distribution system is radiant tubing structurally integrated into a topping slab over concrete plank.

Atkin Olshin Lawson-Bell Architects

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