Basic Design Considerations for Geothermal Heat Pump Systems

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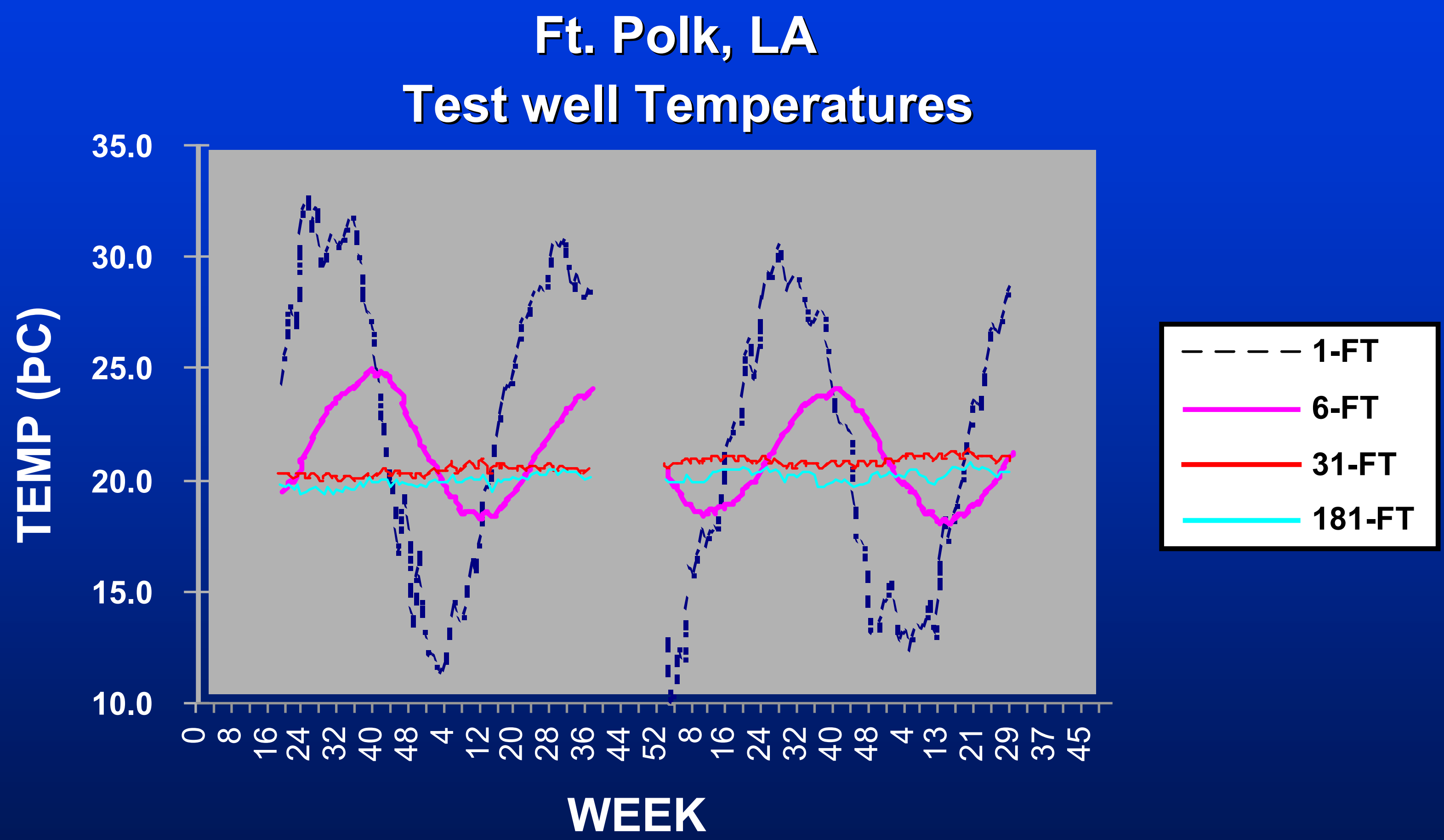
Outline for today

- Motivation for GSHP's
- Types of systems
  - Major system types
  - Summary of advantages and disadvantages
- Building heat loads and heat pump selection
- Design of ground-coupling
  - Design software
  - Other ground loop considerations
- Other system design issues
  - Pumps and piping
  - Ventilation air
  - Cost control
- How to stay out of trouble
- References

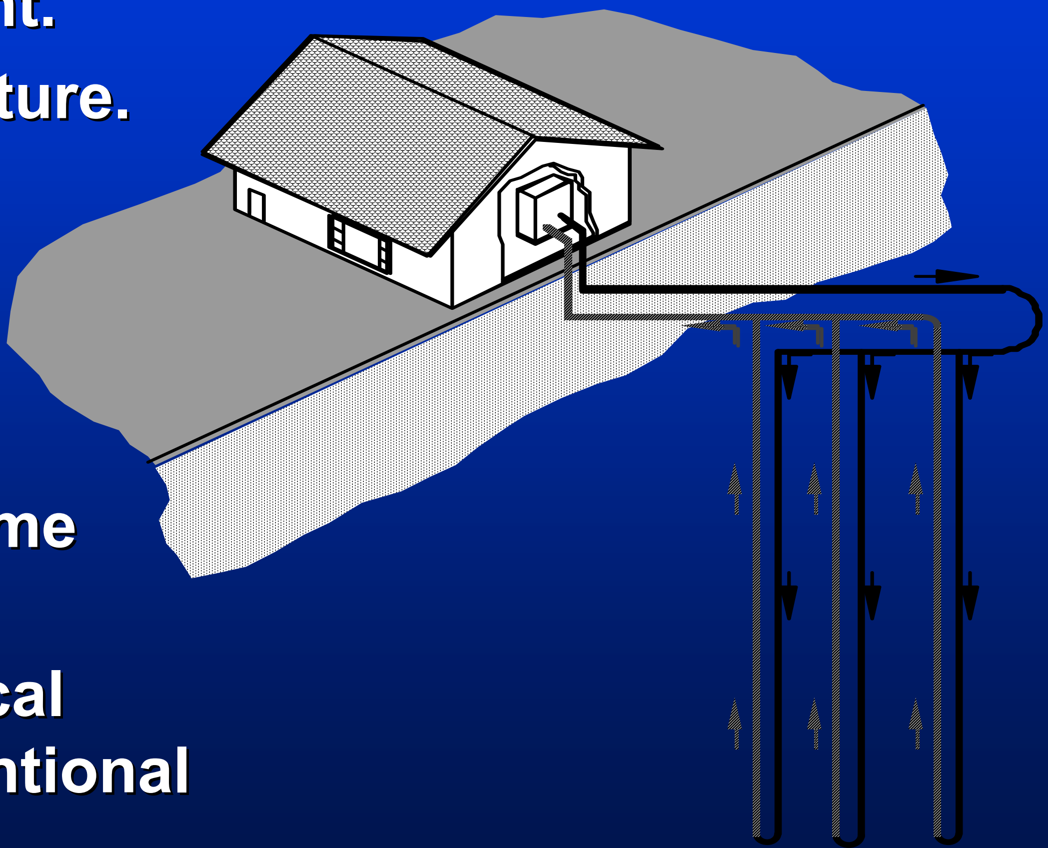
Why Use the Ground As a Heat Source/Sink?



Basic System Types

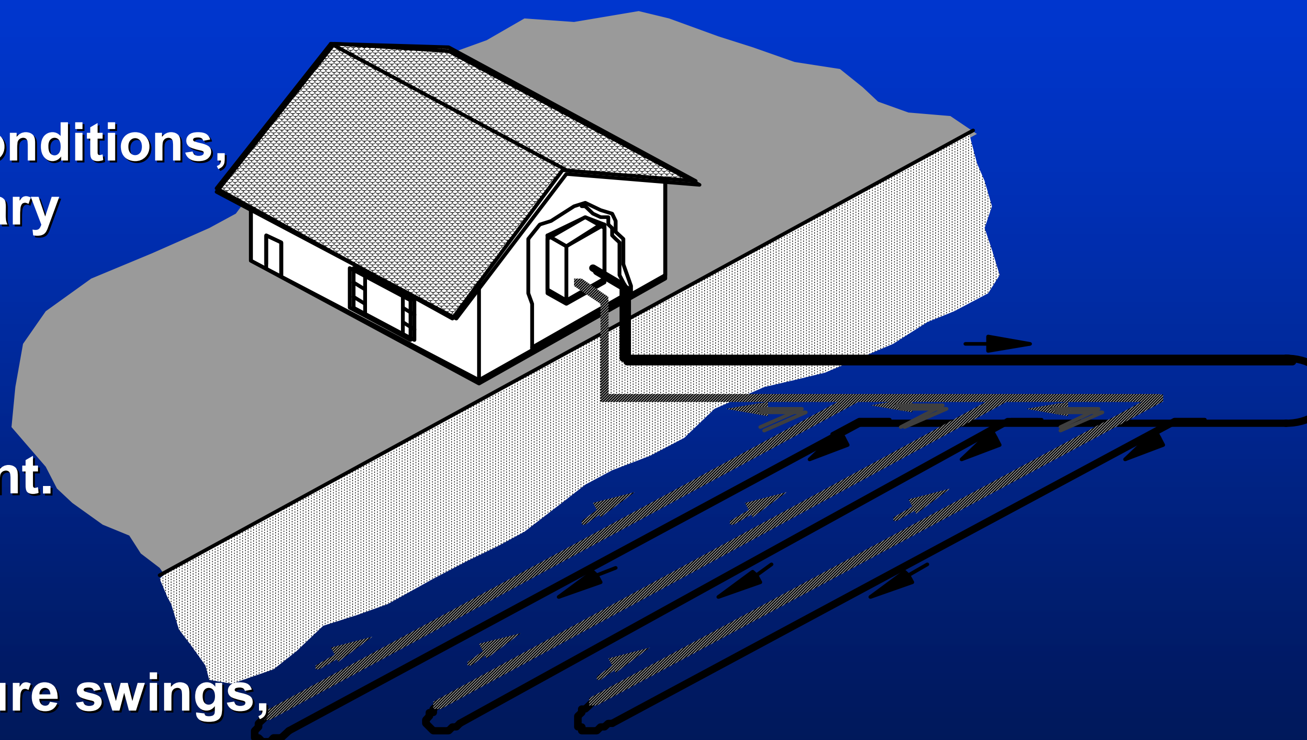
CLOSED LOOP
Vertical Ground Coupled

- Advantages
  - low land area requirement.
  - stable deep soil temperature.
  - adaptable to many sites.
- Disadvantages
  - high cost.
  - does not work well in some geological conditions.
  - needs experienced vertical loop installer, not conventional well driller.



CLOSED LOOP
Horizontal Ground Coupled

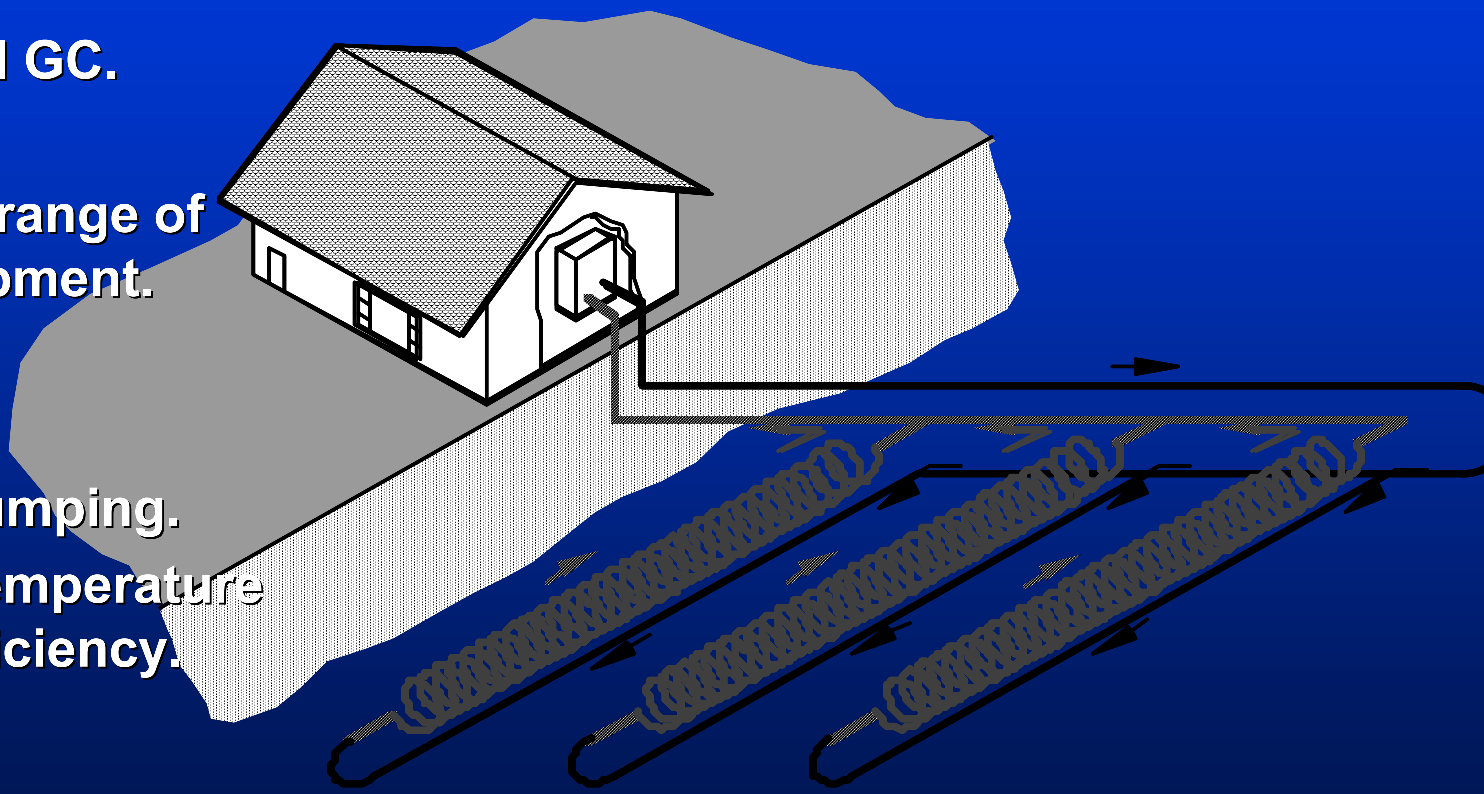
- Advantages
  - lower first cost.
  - less special skills.
  - less uncertainty in site conditions, but soil conditions can vary seasonally.



- Disadvantages
  - high land area requirement.
  - limited potential for HX w/groundwater.
  - wider seasonal temperature swings, lower efficiency.

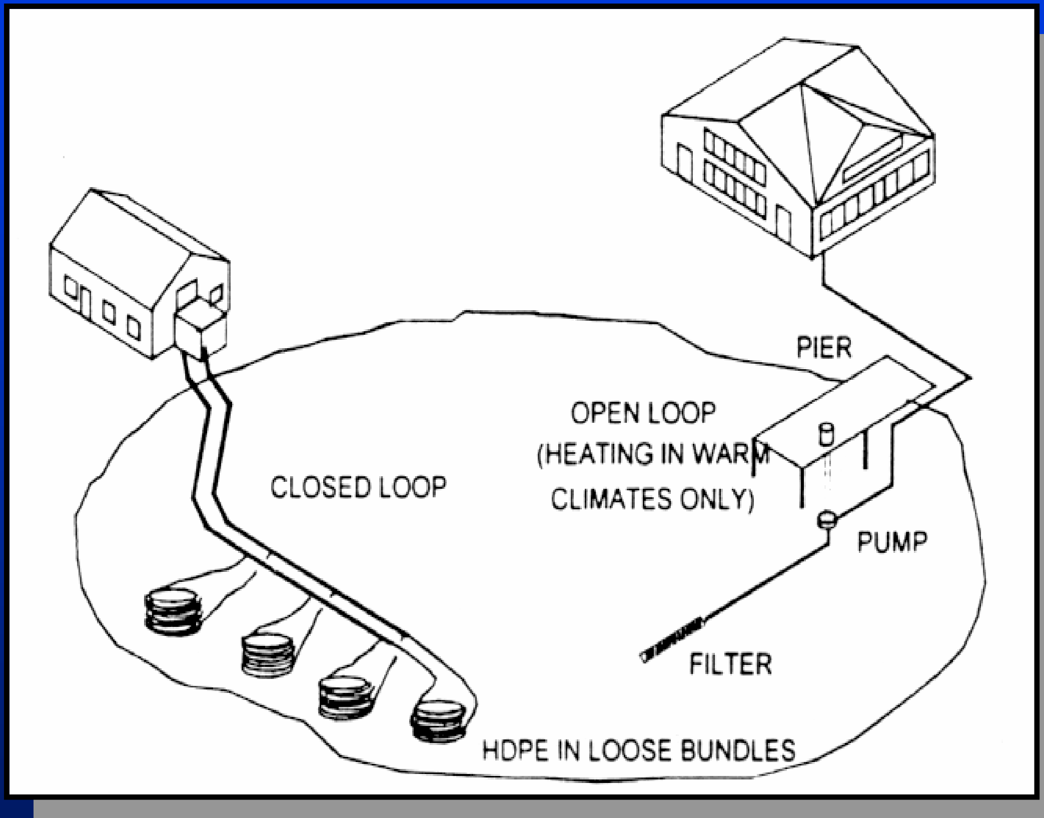
CLOSED LOOP
Slinky Ground Coupled

- Advantages
  - those of horizontal GC.
  - but less land area.
  - adaptable to wide range of construction equipment.
- Disadvantages
  - lots of pipe and pumping.
  - widest seasonal temperature swings, lowest efficiency.

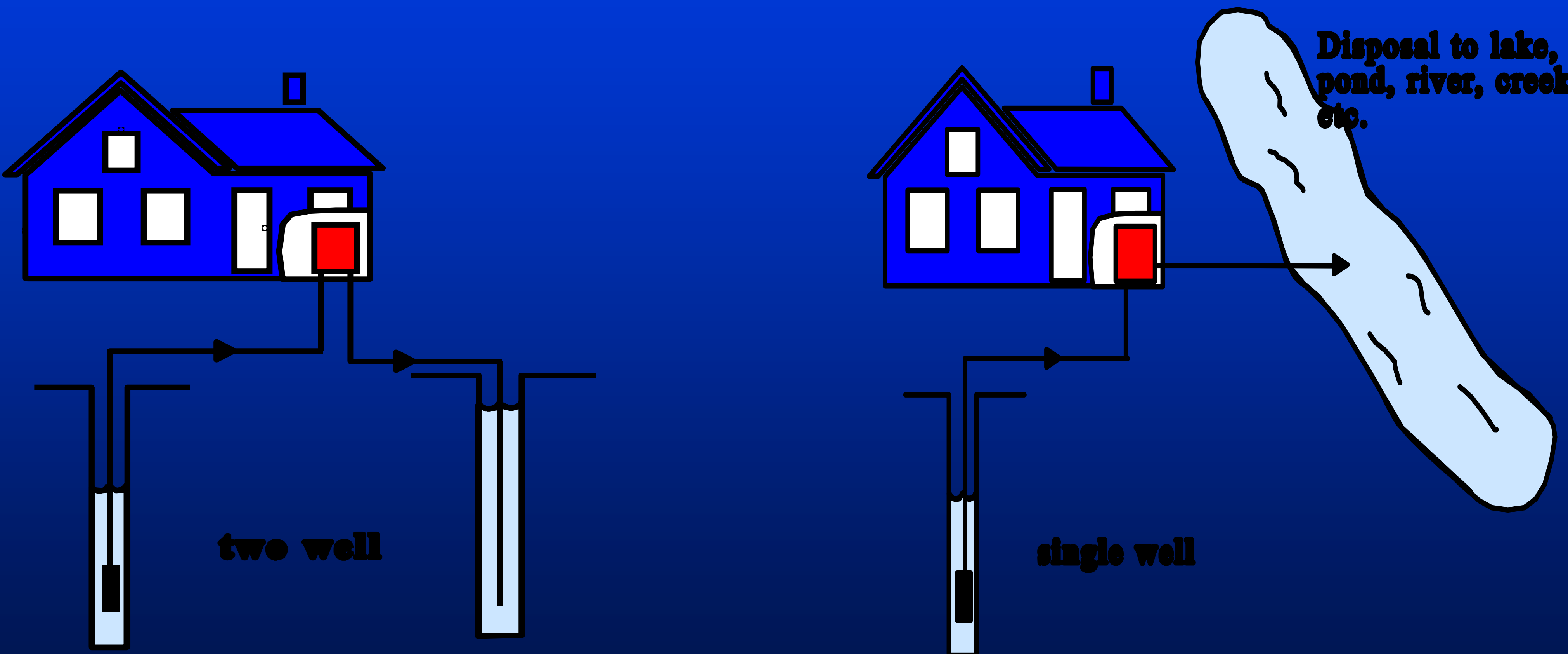


Surface Water Systems

- Advantages
  - Low first cost
  - Direct cooling may be possible
- Disadvantages
  - Fishermen
  - Wide seasonal temperature swings
  - Commercial-scale systems require significant water bodies



OPEN LOOP
Ground Water



Open loop ground water system

- Advantages
  - Lowest first cost, especially for large loads
  - Stable source temperature, high efficiency
  - Some direct cooling possible
  - Oldest, most commonplace
- Disadvantages
  - Environmental requirements
  - Site specific
  - Poor water quality can cause difficulties

Summary of Ground-Source vs Conventional Systems

- GSHP Advantages
  - Ideal zone control
  - Simple, highly reliable controls and equipment
  - Low operating cost
  - Low maintenance
  - Less floor area requirements
  - No on site fuel
  - <u>Green</u> technology
  - Heat recovery hot water heating possible
- GSHP Disadvantages
  - Higher first costs compared to some systems
  - Experienced designers and design guidance limited
  - Installation infrastructure regionally inadequate

Building Loads and Heat Pump Selection

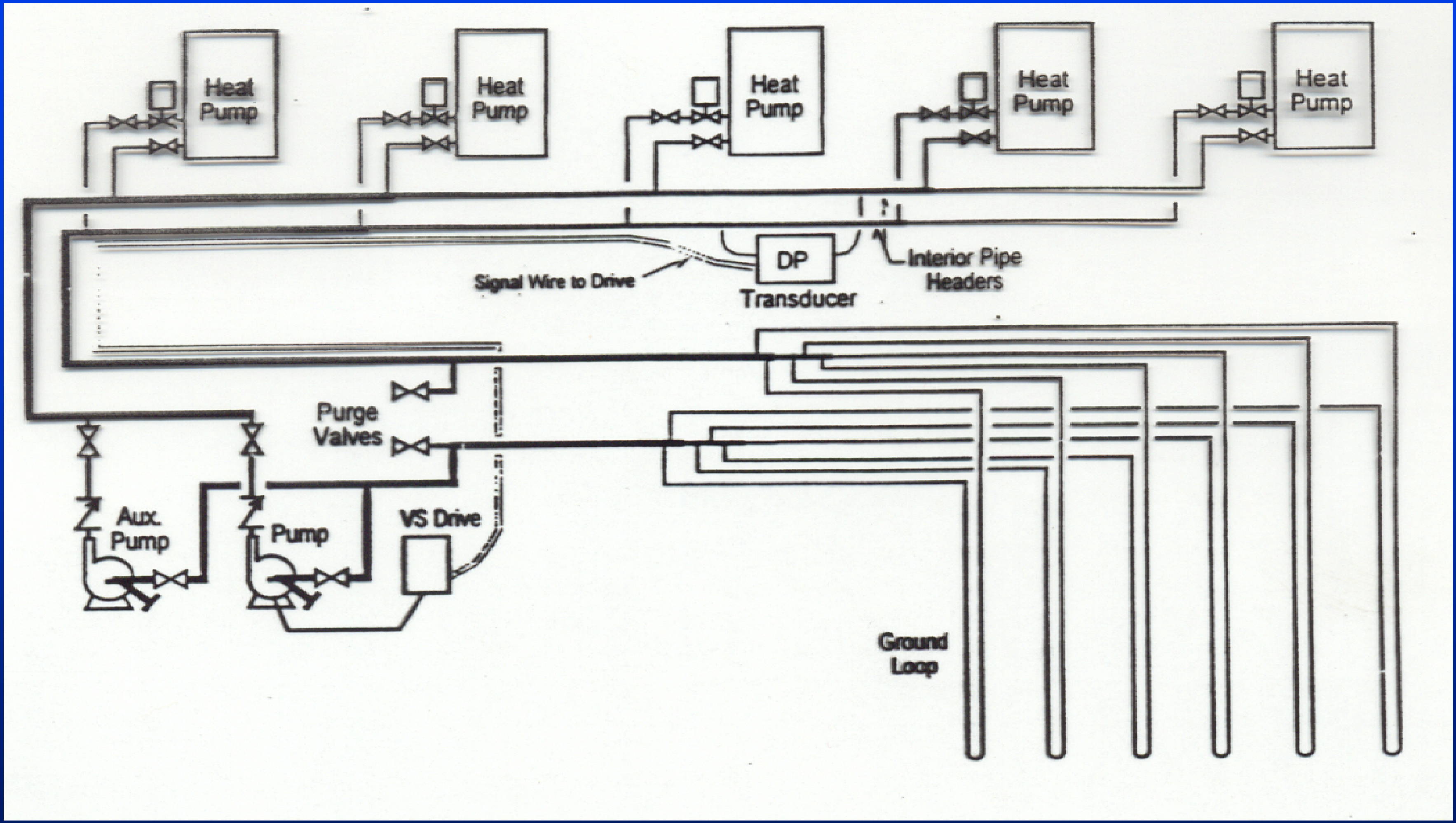
Building Loads and Heat Pump Selection

- A wide variety of heat pump configurations and sizes are available
- No more than one zone per heat pump is usually best
- Bigger equipment is normally not better
  - Smaller units usually have higher efficiencies
  - Larger units have little cost advantage. Often ducting costs will offset any advantage

Building Loads and Heat Pump Selection

- Three principal options for configuration of ground-coupling:
  - Common circulating loop, best for compact floor plans
  - Separate ground-coupling for each heat pump, best for some retrofit situations and spread-out buildings like schools
  - Some combination of these two approaches

Central System



- Do not worry that flow in loops goes laminar at low flow.
- VSD may be justified even for small pumps.

Alternatives to central system

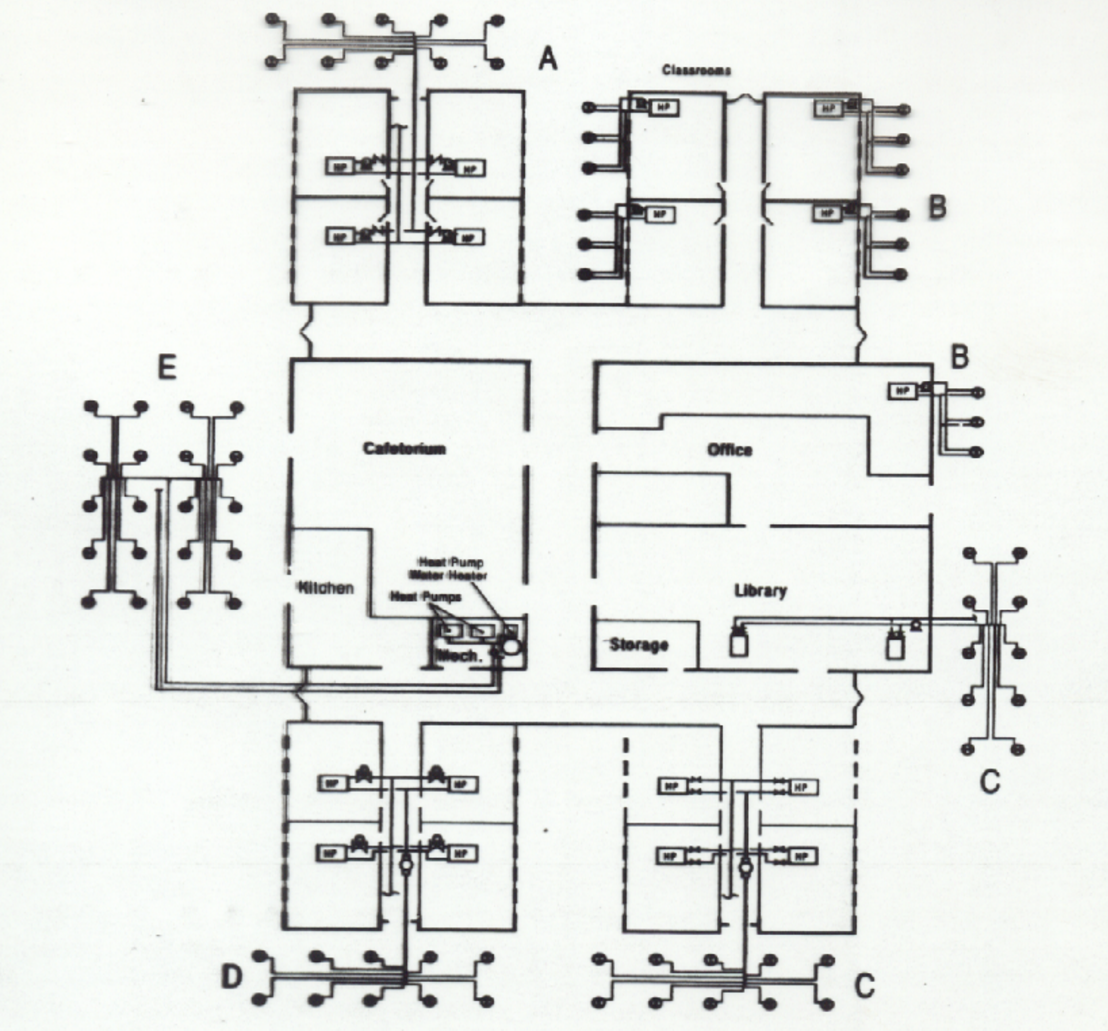


Figure 1.3 Alternatives to central loop ground-coupled heat pumps.
- **A:** One local loop, multiple heat pumps with pump and check valve on each unit
- **B:** Multiple individual loops, heat pumps, and circulator pumps
- **C:** Multiple units with one local pump that operates when one or more units is on
- **D:** Multiple units with two-way valves, one local loop, and VS pump
- **E:** Heat pumps and water heater on same loop to balance local load

Alternatives to central system

Each unit has its own pump ⇒

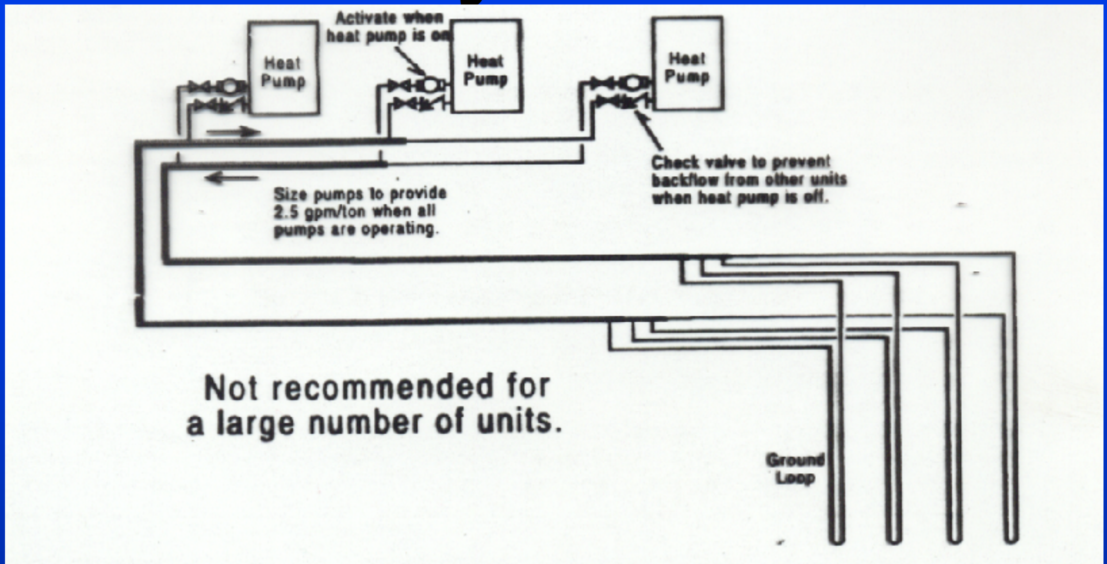


Figure 5.12 Small building (or area) flow control with dedicated circulators.

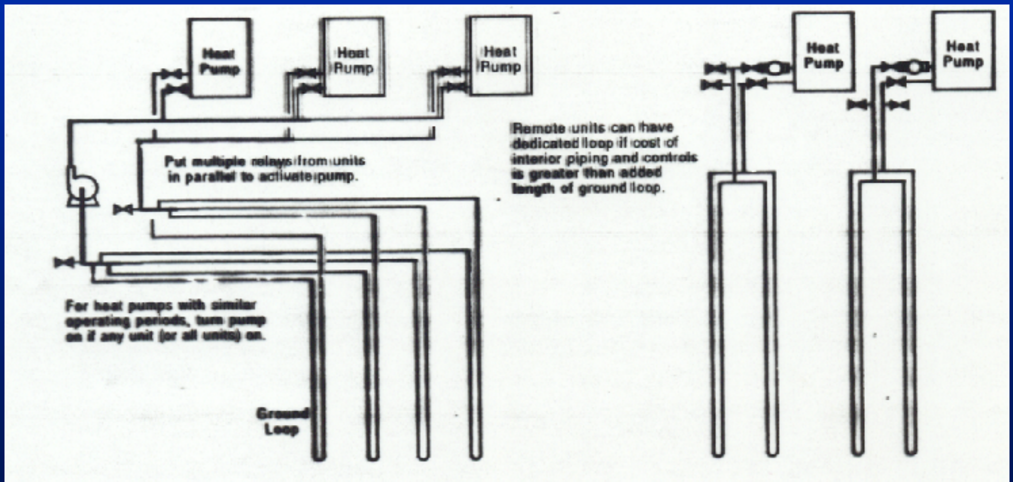


Figure 5.13 Two simple methods of pump control.

Ground-Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings

⇐ A single pump comes on if any unit is on, or each unit is totally independent.

Building Loads and Heat Pump Selection
The New Standard: ARI/ISO 13256-1

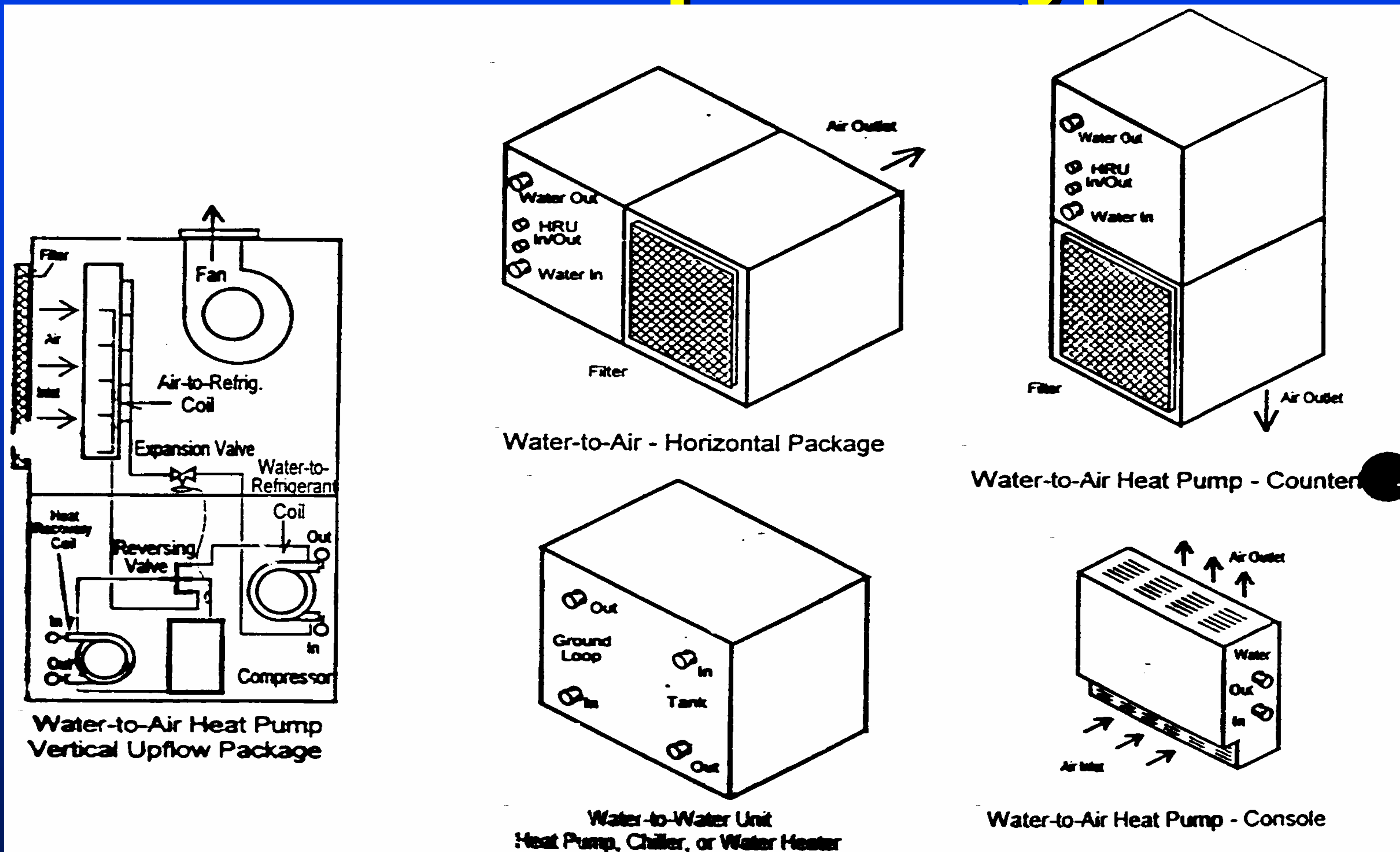
Table 1
Comparison of ARI and ISO Rating Test Conditions

RATING TESTS	Water-Loop Heat Pumps		Ground-Water Heat Pumps			Ground-Loop Heat Pumps	
	ARI/ISO	ARI 320	ARI/ISO	ARI 325 Hi	ARI 325 Lo	ARI/ISO	ARI 330
Standard Cooling:							
- air dry bulb, °F	80.6	80	80.6	80	80	80.6	80
- air wet bulb, °F	66.2	67	66.2	67	67	66.2	67
- air flow rate, Cfm	per mfr	per mfr	per mfr	per mfr	per mfr	per mfr	per mfr
- liquid full load, °F	86.0	85	59.0	70	50	77.0	77
- liquid part load, °F	86.0	75	59.0	70	50	68.0	70
- liquid flow rate, Gpm	per mfr	10°F rise	per mfr	per mfr	per mfr	per mfr	per mfr
Standard Heating:							
- air dry bulb, °F	68.0	70	68.0	70	70	68.0	70
- air wet bulb, °F	59.0	60	59.0	60	60	59.0	60
- air flow rate, Cfm	per mfr	std clg	per mfr	std clg	std clg	per mfr	std clg
- liquid full load, °F	68.0	70	50.0	70	50	32.0	32
- liquid part load, °F	68.0	75	50.0	70	50	41.0	41
- liquid flow rate, Gpm	per mfr	std clg	per mfr	per mfr	per mfr	per mfr	std clg
External Static:							
- air, in H20	0	0.1-0.3	0	0.1-0.3	0.1-0.3	0	0.1-0.3
- liquid, ft H20	0	na	0	50	50	0	17

Energy Star minimum performance

System Type	Cooling EER	Heating COP
Closed Loop	14.1	3.3
Open Loop	16.2	3.6

Heat Pump Unit Types



Building Loads and Heat Pump Selection

- Final thoughts on heat pump selection:
  - Recommended minimum *Energy Star* EERs/COPs
  - Maximum head losses in the water coil of the heat pump should not exceed 45 kPa (15 ft of water) when the flow rate is at 0.19 L/s (3 gpm) per nominal ton of cooling capacity.
  - Watch out for multispeed unit ratings
  - Use high-efficiency units:
    - less heat discharge in cooling mode
    - much better at "off-design" conditions

Design of
vertical ground-coupling

Design of the ground-coupling

- Sizing of the ground-coupling for a heat pump is different than sizing conventional equipment.
  - The capacity of the ground to absorb or provide heat is a transient heat transfer problem.
  - The thermal state of the ground is determined by prior heat addition/extractions rates and durations.
  - While significant imbalance of heat extraction/heat rejection can be tolerated, the long term impacts must be considered.
  - The ground can not be assumed infinite and the interaction of adjacent borehole heat exchangers is very important for commercial scale systems.
- Bottom line is that we need to know the load duration information as well as peak load and we need a design tool that appropriately considers all these factors as well as accuracy models the heat transfer in the ground.

Design of the ground-coupling

Equations for Loop Length

$$L_c = \frac{q_a R_{ga} + (C_{fc} \times q_{lc})(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p}$$

$$L_h = \frac{q_a R_{ga} + (C_{fh} \times q_{lh})(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p}$$

L_c	required bore length for heating - ft
L_h	required bore length for heating - ft
q_a	net annual average heat transfer to the ground - Btu/hr
q_{lc}	design block load for cooling - Btu/hr
q_{lh}	design block load for heating - Btu/hr
R_{ga}	effective ground thermal resistance, annual - h ft oF/Btu
R_{gm}	effective ground thermal resistance, monthly - h ft oF/Btu
R_{gd}	effective ground thermal resistance, daily - h ft oF/Btu
R_b	thermal resistance of bore - h ft oF/Btu
C_{fh}	heat pump performance correction factor, heating
C_{fc}	heat pump performance correction factor, cooling
PLF_m	part load factor, monthly pulse
F_{sc}	short-circuit heat loss factor
t_g	undisturbed ground temperature - oF
t_{wi}	heat pump fluid inlet temperature - oF
t_{wo}	heat pump fluid outlet temperature - oF
t_p	temperature penalty for adjacent bore interference - oF

Vertical Ground-Loop Design

- **Design software essential for commercial- scale systems. Sources:**
  - **GchpCalc Version 4.1, Energy Information Services, www.geokiss.com, $300**
  - **GLHEPRO V.3.0, International Ground Source Heat Pump Association (IGSHPA), www.igshpa.okstate.edu, $525**
  - **GS2000 Version 2.0, Caneta Research Inc., www.canetaenergy.com, to be distributed free in future by NRC Canada.**

Vertical Ground-Loop Design

- Oak Ridge National Laboratory has compared the results of these (and other) design programs against detailed simulation models and field data from operating systems. The results have shown that GCHPCalc is accurate and in most cases out performs the other programs. The results of the Oak Ridge studies can be found at:

  - Thornton, J. W., McDowell, T. P. and Hughes, P. J. (1997). Comparison of practical vertical ground heat exchanger sizing methods to a Fort Polk data/model benchmark. *Proceeding of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE),* 103(2), ASHRAE, Atlanta, GA.

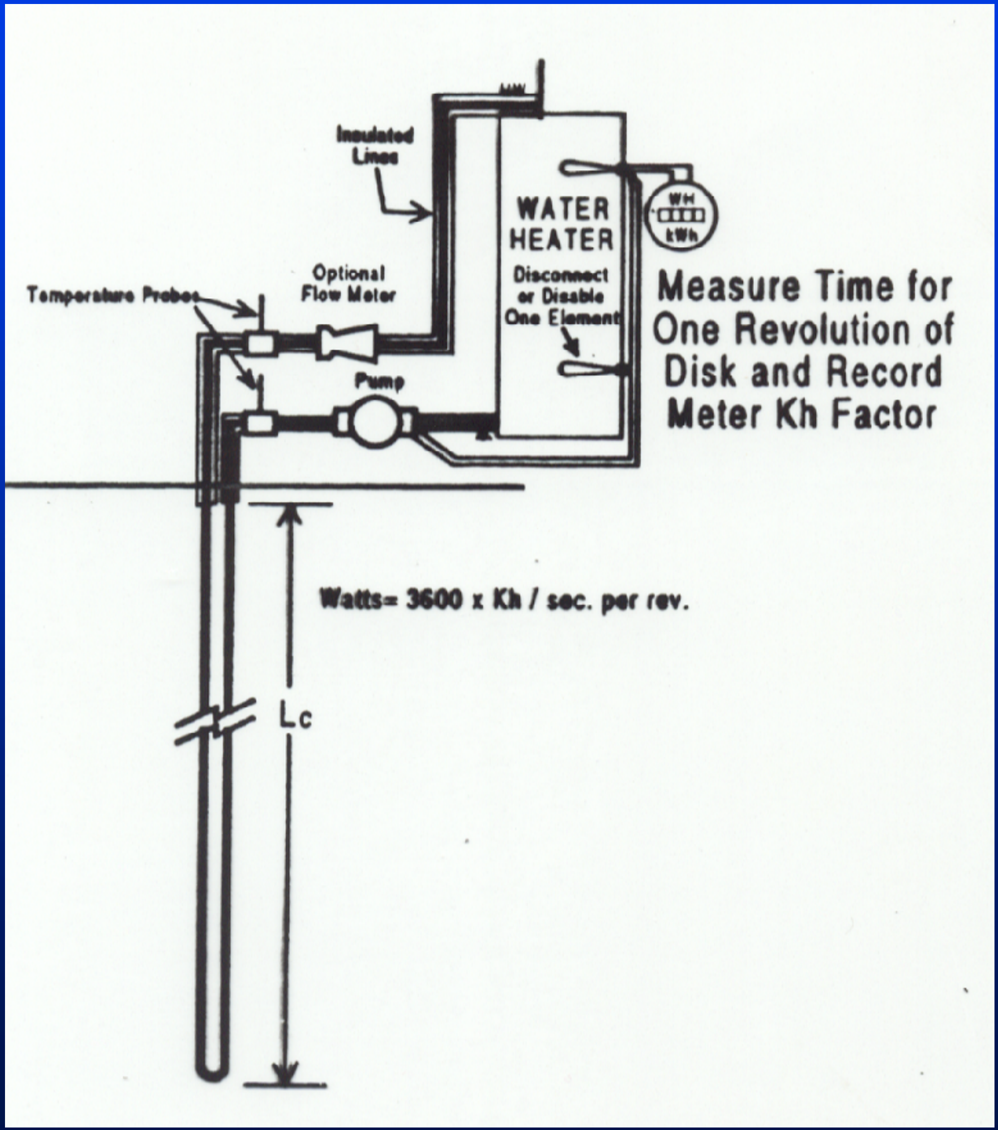
  - Shonder, J. A., Baxter, V., Thornton, J., and Hughes, P.. (1999a). “A New comparison of vertical ground heat exchanger sizing methods for residential applications.” Proceeding of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), 105(2), ASHRAE, Atlanta, GA.

  - Shonder, J. A., Baxter, V., Hughes, P., and Thornton, J.   (2000a). “A comparison of vertical ground heat exchanger design software for commercial applications.” *Proceeding of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers* (ASHRAE), 106(1), ASHRAE, Atlanta, GA.

Other Ground-Loop Considerations –Thermal tests

- **Through site characterization, including test boring is advisable, especially where little is known about the geological conditions *at the job site*.**
- **For larger projects, say 100 tons or more, in-situ thermal properties tests will probably be justified.**
- **Recommendations for thermal properties testing requirements and methods can be Found in Chapter 32 of the 2003 ASHRAE HVAC Applications Handbook.**

Other Ground-Loop Considerations –Thermal tests



Other Ground-Loop Considerations - Antifreeze

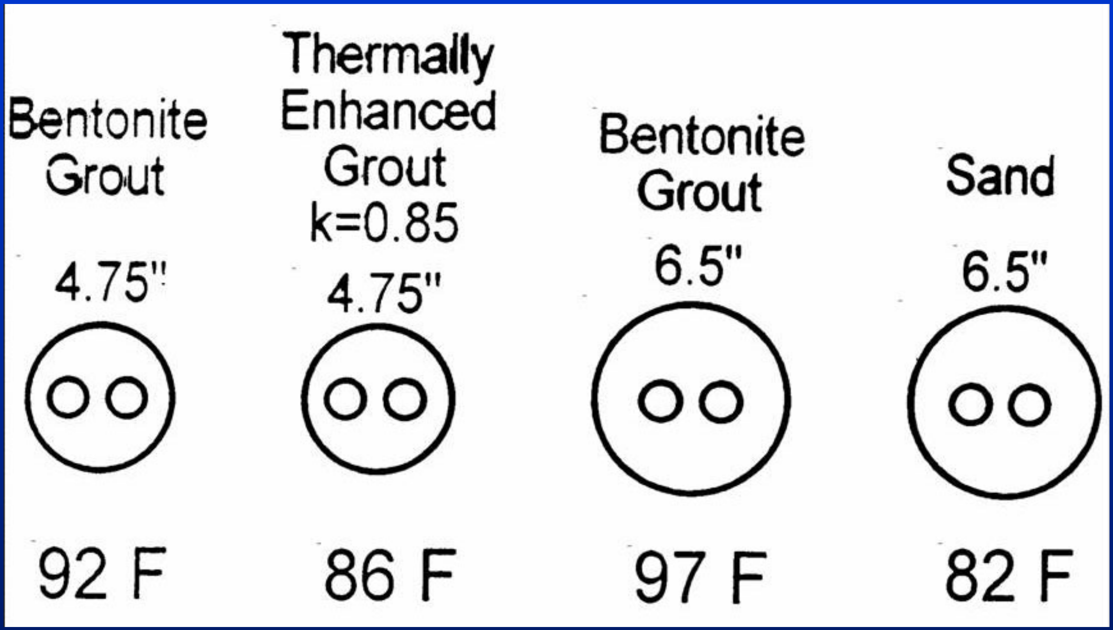
- Antifreeze is seldom necessary in vertical ground-coupled systems.
- When it is necessary, use the minimum amount for protection.
- A number of antifreeze compounds are available, each with desirable and undesirable properties. Propylene glycol is often the best all around choice, consult Chapter 32 of the 2003 ASHRAE HVAC Applications Handbook for a discussion of the various antifreeze compounds used and their individual attributes.

Other Ground-Loop Considerations -Grout

- Grout is often required by the regulatory authorities to protect ground water from surface contamination, or prevent cross contamination of aquifers.
- Unfortunately the thermal conductivity of the popular bentonite based grouts is very low when compared to most geologic formations.
- Hence, grouting of the borehole with conventional bentonite grout is analogous to insulating your heat exchanger.
- Thermally enhanced grouts have been developed to address this issue.

Other Ground-Loop Considerations -Grout

A set of tests conducted by Spilker (1998) showed the dramatic effects that grout can have on the average circulating water temperature after just 48 hours of continuous heat rejection:



Details of the tests can be found at : Spilker, E. H. (1998). "Ground-coupled heat pump loop design using thermal conductivity testing and the effect of different backfill materials on vertical bore length." *Proceedings of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE),* Atlanta, Georgia.

Other Ground-Loop Considerations -Grout

The Three Rules of Grouting:

I. Reduce borehole to minimum size necessary to reduce grout volume and preserve the geological formation.

II. Grout only that portion of borehole required by regulation (use clean sand in remainder if allowed).

III. If significant portions of the borehole (say more than 25%) will be grouted, use thermally enhanced grout, especially if the formation has high thermal conductivity.

Other Ground-Loop Considerations – regulatory requirements

- Regulatory requirements vary widely by state.
- Studies have been completed of the various state requirement's, however they continue to evolve so check with the state and/or other local authorities before proceeding with design.

Piping and Pumps

Piping and Pumps

- General recommendations:
  - Size piping based on accepted design guides (references given at end of presentation)
  - Avoid use of antifreeze, use low concentration
  - Variable-speed pumping w/ two-way valves on HPs
  - Use high-efficiency motor and operate pump near its sweet spot
  - Select heat pumps and valves with low ΔP
  - Pump no more water than necessary, 2.5 to 3 gpm per ton of peak block load for vertical ground-coupled systems.

Ventilation Air

- Various solutions are available depending on climate and type of installation:
  - For classrooms and hotel-type installations in moderate climates, console units may be best
  - For larger units, preconditioned air can be ducted to each unit
  - Sensible heat recovery is probably worthwhile in heating-dominated climates
  - Water source heat pumps normally have high latent capacity, but preconditioning may still be advisable in humid climates

Cost Control

- Some possible cost control measures:
  - Use hybrid systems in cooling dominated climates
  - Avoid costly sophisticated control systems, GSHPs inherently provide excellent zone control
  - Use accepted design guides and consult experienced designers
  - Encourage bids from contractors outside local area if inadequate local infrastructure exists

Disclaimers and warnings

- I can't cover all the details in a one hour presentation so if you plan to design a GSHP systems here are some steps that will help you successfully do so:
  - Take a short-course on design of these systems, sources I can recommend are:
    - ASHRAE Short courses (not comprehensive, a starting point only, offered intermittently at ASHRAE meetings)
    - University of Wisconsin (next offered on 12-14 September 2005)
    - GchpCalc courses (offered occasionally via Energy Information Services)
  - Obtain a copy of one of the recommended design software programs and training on how to use it. Do not size ground-coupling based on rules-of-thumb, manufacturers recommendations, etc.
  - Obtain copies of the accepted design guides *and use them*, see list at end of presentation. If you have questions consult an experienced designer.
  - Do not make the systems overly complicated by adding unnecessary backup, redundancy, controls, etc.

References

- Recommended design references:
  - *2003 ASHRAE Handbook, HVAC applications*. Chapter 32 – Geothermal Energy. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA.
  - ASHRAE. (1997). *Ground source heat pumps—design of geothermal systems for commercial and institutional buildings*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA.
- Recommended survey article:
  - Phetteplace, Gary (2002) Ground-source heat pumps. In: *Renewable energy: trends and prospects*. (S.K. Majumdar, E.W. Miller, and A.I. Panah, Eds.). Pennsylvania Academy of Science, Chapter 14, p. 231-244. ISBN 0-945809-17-4