Geothermal Heat Pump Systems

GeoExchange Technology

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Iowa Energy Center
Energy Resource Station

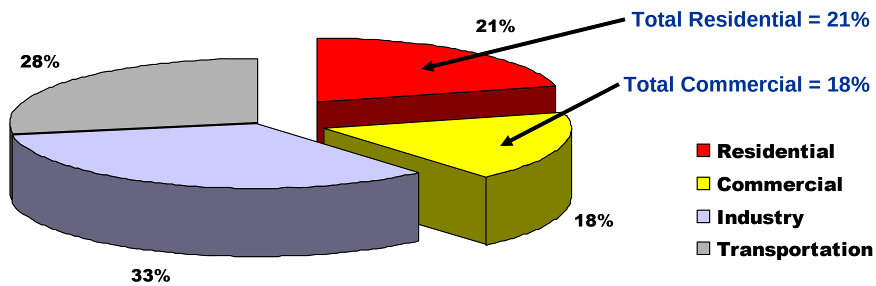
Geothermal Heat Pump Technology

- Introduction
- What is Geothermal Energy?
- Geothermal Heat Pump System Types
- Geothermal System Features
  - Pros and Cons
  - Applications
- Economics and the Bottom Line

Questions at Any Time……

Energy in Buildings

- Buildings Use 39% of the Nation's Primary Energy



Energy Efficiency – Building Blocks

- Step 1 – Reduce Energy Load
  - Site Orientation and Building Arrangement
  - Efficient and Effective Building Envelope
- Step 2 – Improve Efficiency of Systems and Equipment
  - HVAC Systems – Geothermal Systems
  - Efficient A/C units, Boilers, Motors, Light Fixtures
  - Lighting Systems – Daylighting
  - Computers and Office Equipment
- Step 3 – Effective Building Operations
  - Proper Control – Energy Management Systems
  - Commissioning
  - Operations and Maintenance – Training and Support
  - Leverage Utility Company Rate Schedules
- Step 4 – Alternative Energy Sources
  - Renewable Energy Options – Solar, Wind, Biomass

What Is Geothermal Energy?

- **Geothermal Energy is defined as "energy from the internal heat of the earth"**
  - **47% of the incoming radiation from the sun is absorbed by the earth**
  - **The remainder is absorbed by the atmosphere or reflected back into space**
- **Translated: Geo-Thermal means "Earth-Heat"**
- **"High Temperature" Geothermal Energy**
  - **Energy Source for Hot springs and geysers**
  - **Temperatures exceed 300°F**
  - **Converted to produce useable heat and electricity**

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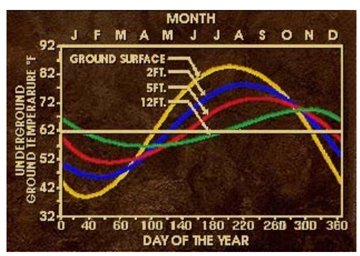
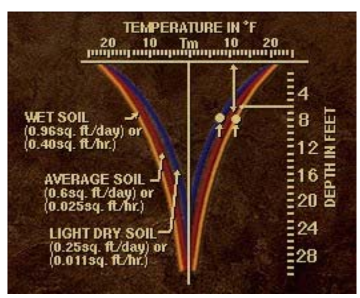
"Low Temperature" Geothermal Energy

- **Heat Energy contained near the surface of the Earth**
- **Shallow Earth temperatures fluctuate with seasonal outside air temperature**
- **Earth temperature becomes more stable with increasing depth**
- **Nearly constant Earth temperatures at depths below 16 feet**
- **Earth mean temperature approaches annual average outside air temperature**
- **Deep Earth temperatures start to increase at depths below 400 feet -- at about 1 °F per 100 feet**

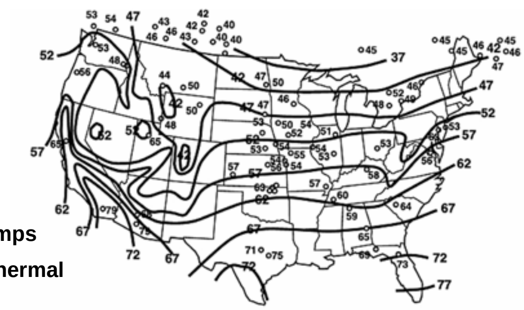




Low Temperature Geothermal Energy

- Geothermal Heat Pump Systems
  - Take advantage of "Low Temperature" Geothermal Energy
  - Constant Temperature Year Around – 47 to 50°F in Michigan
  - Apply a Water Source Heat Pump to "amplify" the heat energy

- AKA
  - Ground Source Heat Pumps
  - Earth Coupled Heat Pumps
  - GeoExchange Systems
  - Well/Ground Water Heat Pumps
  - v.s. High Temperature Geothermal



(a) Mean earth temperature, T_M (°F)

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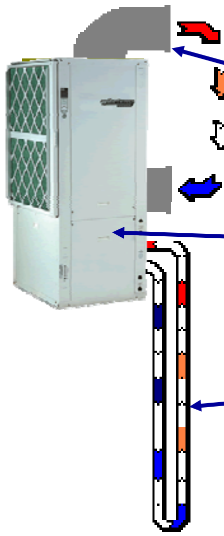
What are Heat Pumps?

- Characterized by Medium used for Heat Source and Heat Sink
  - Air to Air or Air Source
  - Water to Air or Water Source
  - Water to Water
  - Ground Source or Geothermal

- Capable of Heating, Cooling and producing Hot Water
  - Capacity measured in *tons*
  - One *ton* of capacity = 12,000 BTU per hour (Cooling or Heating)
  - Typical new home is about 4 – 5 tons of heating capacity & 2 tons cooling
  - Typical Classroom is about 2 – 3 tons of heating or cooling capacity

Geothermal Heat Pump System

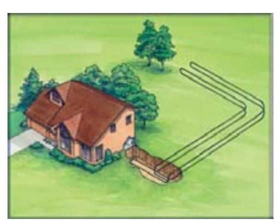


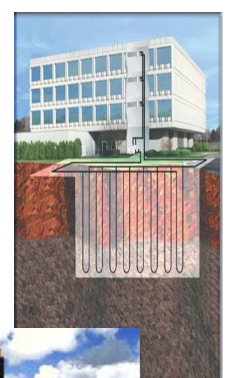
Three Basic Components:

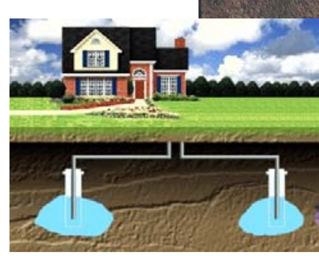
- **Heating/Cooling Delivery System**
  - Traditional Ductwork / Piping system to deliver heat throughout the building
- **Heat Pump**
  - Mechanical Unit that moves heat from the working fluid, concentrates it, and transfers the heat to the circulating air
- **Ground Heat Exchanger**
  - Underground piping system that uses a working fluid to absorb or reject heat from the ground

GeoExchange System Types

- **Closed Loop System**
  - **Buried HDPE Piping**
  - **Underground Heat Exchanger**
  - **Circulating Fluid contained**
  - **Exchanges only *Heat* with the Ground**
  - **Various Configurations**
- **Open System**
  - **Ground Water from Well**
  - **Exchanges *Heat and Water* with the Ground**
  - **Returns Water to the Ground**
- **Special Systems**
  - **City Water Interconnect Systems**
  - **Hybrid Systems**







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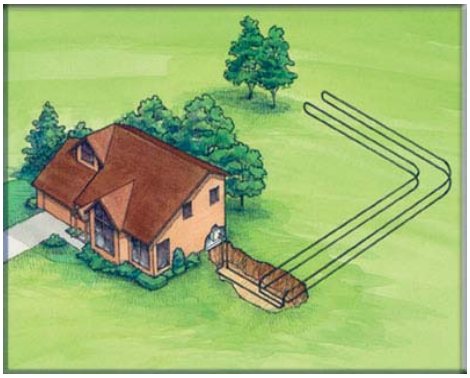
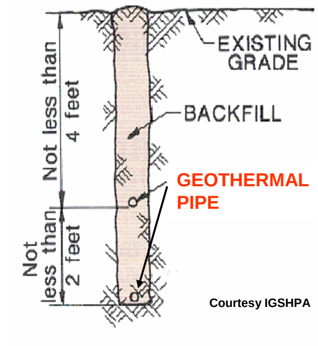
Horizontal Trench Loop

- Cost effective when land area is plentiful
- Needs 2500 square foot Land area per ton
- Trench depth – Six feet or more





Courtesy IGSHPA

- To Produce 1 ton of capacity:
  - Trench length – typically 300 feet
  - Pipe length – out & back = 600 feet

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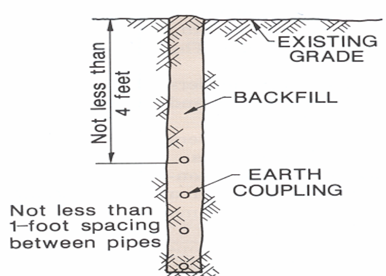
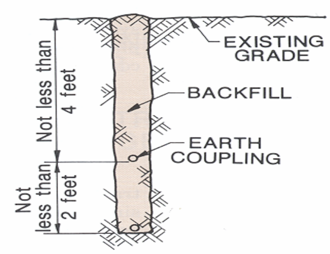
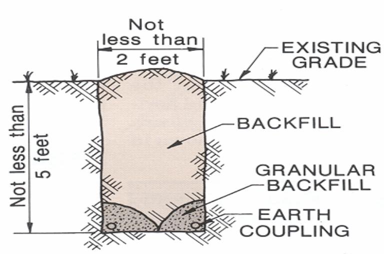
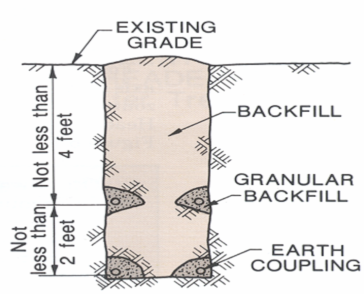




Horizontal Trench Configurations





Courtesy IGSHPA

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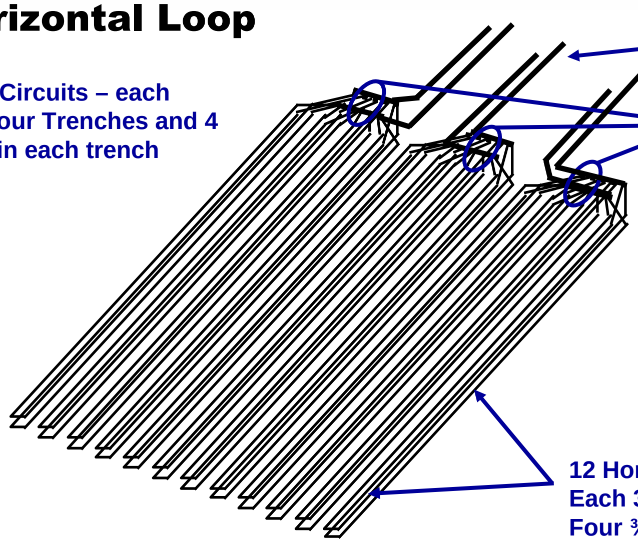
Horizontal Loop



Nominal 24 Ton Configuration

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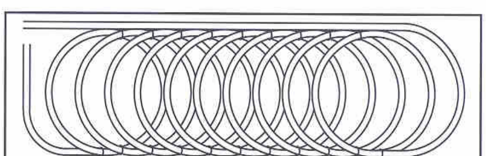
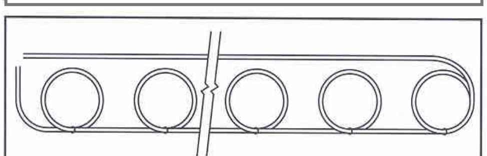
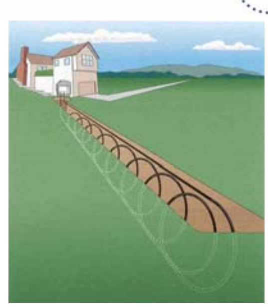
Slinky Loop



Slinky Coil – Overlap



Slinky Coil – Extended



- **To Produce 1 ton of capacity:**
  - Trench length – typically 125 feet
  - Pipe length – out & back = 700 feet

Courtesy IGSHPA

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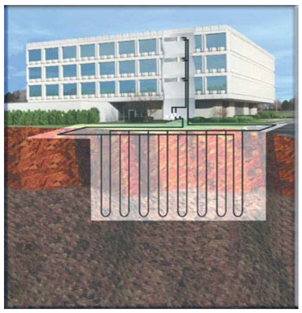
Vertical Bore Loop

- Keeps Space required to a minimum
- Needs 250 Square Feet Land area per ton
- Bore Depth – 100 to 300 feet
- Bore Diameter – about 4 to 5 inches
- Bore Spacing – 15 to 20 feet apart
- Nominal Capacity – One ton / 200 ft Bore Hole



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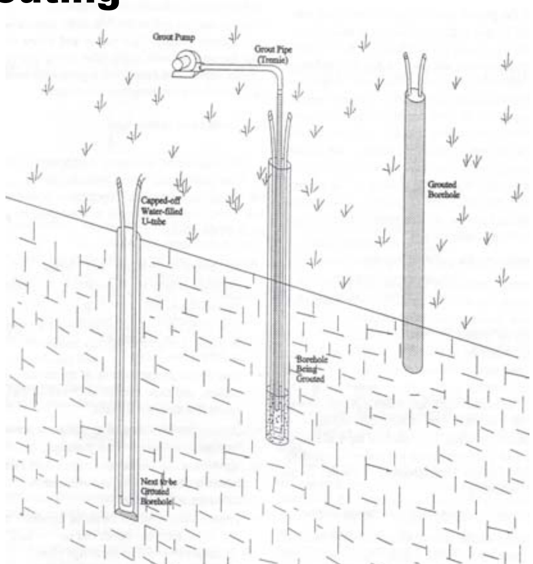
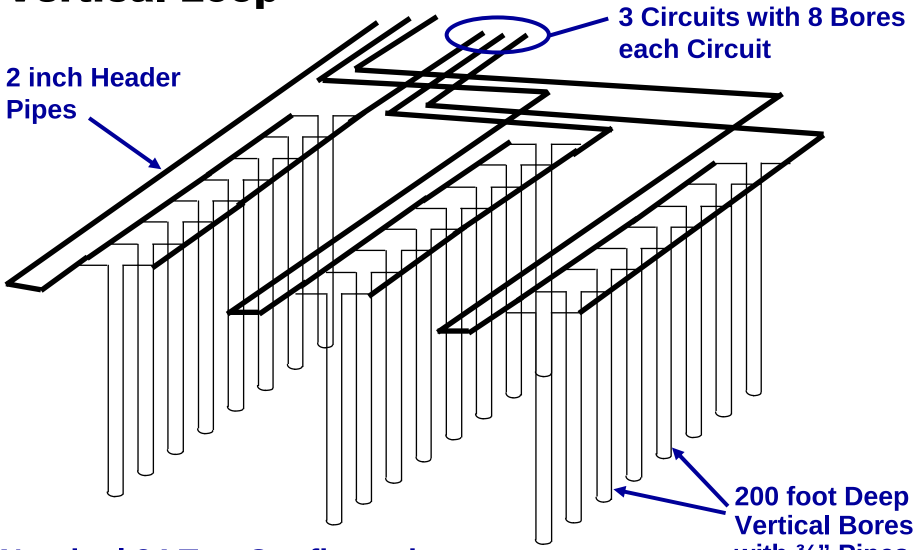
Vertical Bore Grouting

- Grouting of Vertical Bore Holes Required
  - Seal Borehole to Protect Underground Aquifers
  - Maintain Thermal contact between pipe and ground
  - Allow movement of pipe
- Grout Types
  - Bentonite Based
  - Thermally Enhanced
  - Cement Based
- Pressure Grouting from the bottom up recommended



Courtesy ASHRAE GSHP Engineering Manual

Vertical Loop



Nominal 24 Ton Configuration

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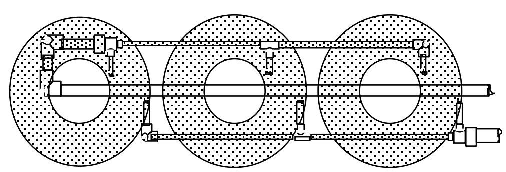
Horizontal Boring

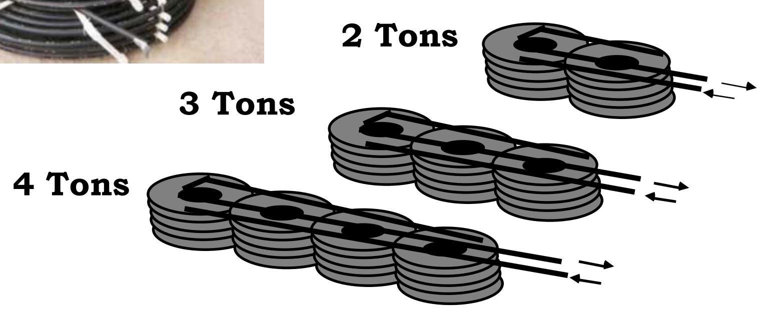
- Horizontal / Directional Boring Machine used
  - Horizontal length typically 200 feet for one ton of capacity
  - Bore depth controlled at 15 feet
  - Setup from one 'hub' location for multiple radial bores
  - Minimal disturbance to topsoil and landscaping

Pond Loop

- Most ***Cost Effective*** closed loop design
- Pond Depth – 12 – 15 ft minimum maintained depth
- Pipe Length – One 300 ft. coil per ton (minimum)
- Capacity – 10 to 20 tons/acre of pond

Pond Loop

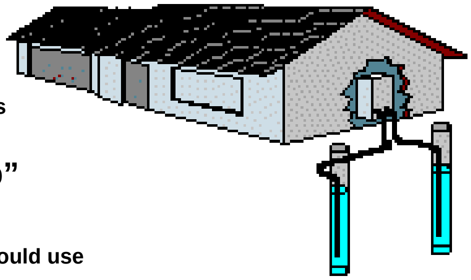




Pond Loop Installation

Open Loop

- Very Cost Effective, providing the following are verified:
  - Water Quality is High
  - Water Quantity is Sufficient
  - Meets Codes and Regulations
- AKA "Pump and Dump"
  - 1.5 to 2 GPM per ton required
  - At 30% run time a 4 ton unit could use 100,000 gallons per month
  - Typical Family of Four uses about 6,000 gallons per month for domestic purposes



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GeoExchange System Types

- Special Systems
  - Standing Water Well
    - Extraction and Rejection to the same well
    - Concentric Pipe – Return water on Outside Pipe
    - Bleed off water for temperature control
  - Interconnection to City Water Mains
    - Extract heat from water mains with heat exchanger
    - Return water to water mains downstream
- Hybrid Systems
  - Coldest days -- use auxiliary heat source
  - Hottest days -- supplement with cooling tower

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GeoExchange System Features

Energy

Pros and Cons

GeoExchange System Features

- Energy Pros
  - + GeoExchange Heating Contribution
    - 1 kW electricity plus 3 kW geothermal heat moved from the earth = 4 kW heat delivered
    - Heating COP of 3.5 to 4.9
  - + GeoExchange Cooling Contribution
    - Earth temperature sink cooler than air temperatures = reduced cooling compressor work
    - Cooling EER of 14 to 27 (on 2 speed units)
  - + Individual units allow zoning for off hour use
  - + Reduced site energy consumption: 30% - 50% less
  - + Lower energy costs: 20% - 30% less

GeoExchange System Features

- Energy Cons
  - − Economizer Free Cooling not normally available
  - − Ventilation/make up air energy handled separately

- Energy Considerations
  - = EER and COP include allowances for fan and pump energy
  - = Distinction between EER and SEER
  - = Minimize Circulating Pump energy
  - = Water to Water Heating Options

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Energy Considerations

- **Heat Pumps – Ground Source**
  - Heating Efficiency measured by COP (Coefficient of Performance)
  - Cooling Efficiency measured by EER (Energy Efficiency Ratio)
  - Efficiency measured at Specific Temperatures and Conditions

Efficiency Rating ARI / ASHRAE / ISO 13256 - 1	Closed Loop COP @ 32°F	Closed Loop EER @ 77°F	Open Loop COP @ 50°F	Open Loop EER @ 59°F
Best Available	4.9	27.0	5.5	31.1
High Efficiency	3.6 +	16.0 +	4.6 +	20.0 +
Low Efficiency	2.9	10.6	3.1	11.8

What are the Actual Entering Water Temperatures?

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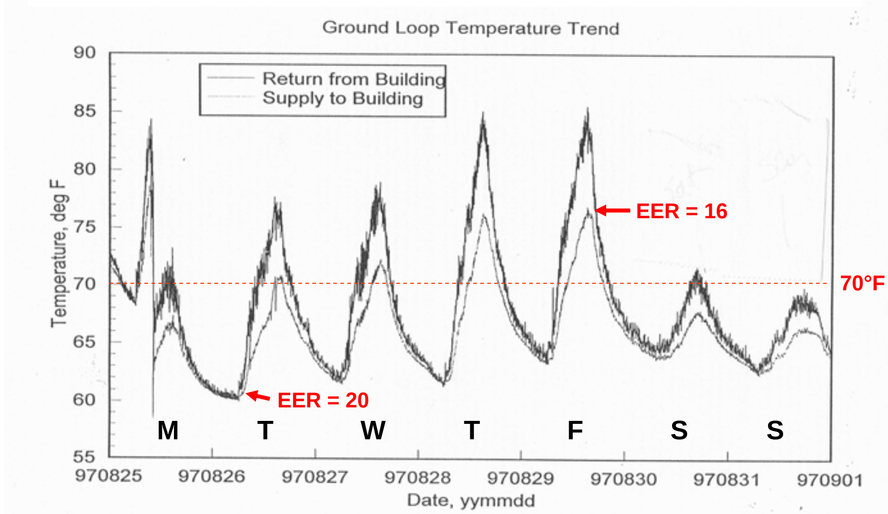
GeoExchange System EWT – Summer



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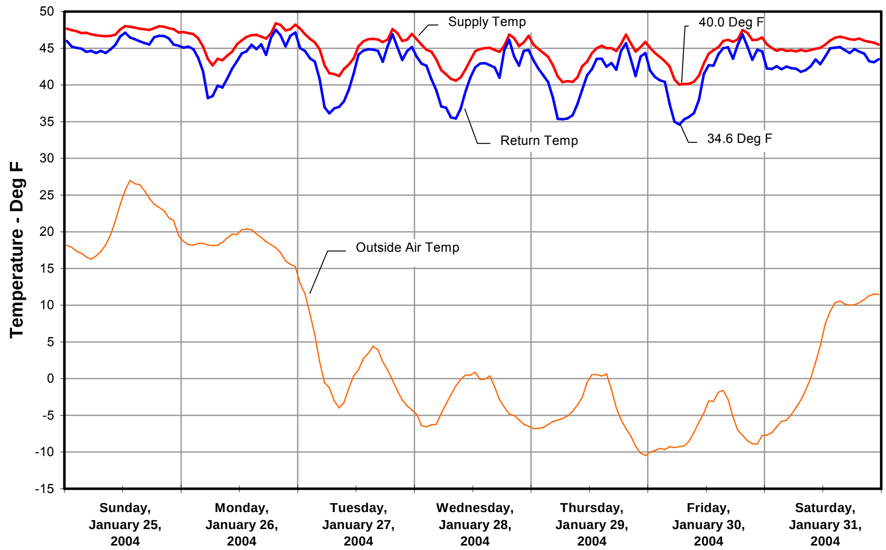
GeoExchange System EWT – Winter



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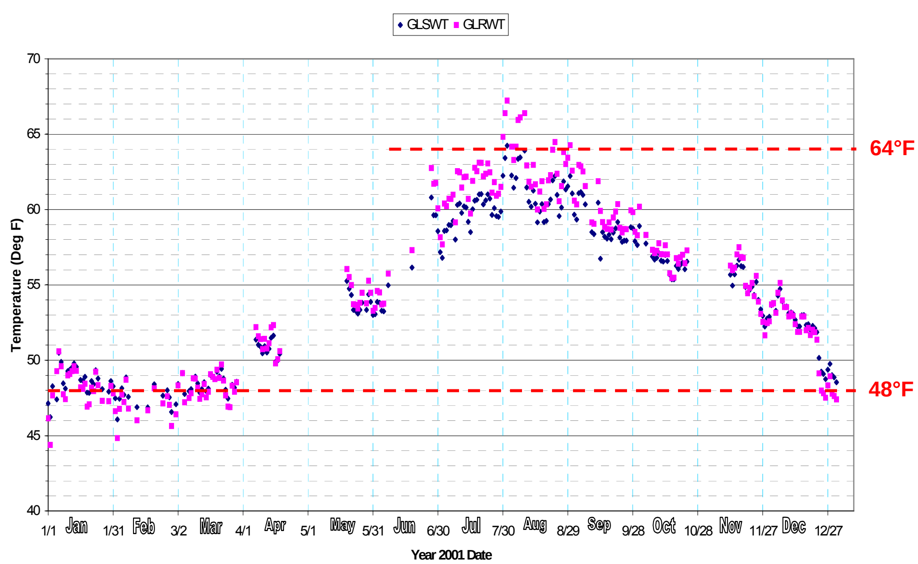
GeoExchange System EWT -- Annual



Energy Considerations

- **Circulating Pump Energy**
  - **Pumping Energy Can Be Significant due to 24 / 7 Load Factor**
  - **Minimizing Pump Head effective**
  - **Many Geothermal Systems have excess Pumping Energy**
  - **Circulating Pump Monitored Energy Use:**
    - Represents 8 % of the HVAC Metered Peak Demand
    - Consumes 36 % of the Total Building HVAC Energy
    - Responsible for 18 % of the Total Building Energy Costs

- **Evaluate Pumping Options**
  - **Decentralized Loop Distribution**
  - **Two stage parallel pumping**
  - **Variable Flow pumping w/VFD's**

Energy Considerations

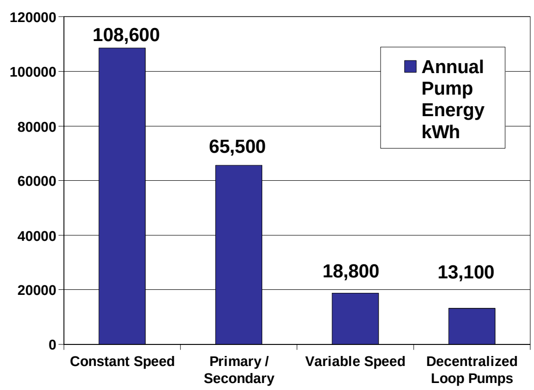
- **ASHRAE Technical Paper**
  - ***"Energy Use of Pumping Options for Ground Source Heat Pumps"***

    An ASHRAE Technical Paper by Stephen Kavanaugh, PhD. and Sally McInerny, Ph.D.,P.E.

Evaluated Energy Consumption of 4 Pumping Systems

- **Constant Speed**
- **Primary / Secondary**
- **Variable Speed Drive**
- **Decentralized Pumping**

Majority of Savings due to the ability to cycle off pumps during unoccupied hours and lower pump head requirements



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Energy Considerations

- **Pump Energy Report Card**

  By Stephen Kavanaugh, PhD

Pump Power per 100 tons	Grade
5 or Less	A – Excellent
5 to 7.5	B – Good
7.5 to 10	C – Mediocre
10 to 15	D – Poor
15 or More	F – Bad

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Operation and Maintenance

Pros and Cons

GeoExchange System Features

- Operation and Maintenance Pros
  - + Unitary equipment – failure of one unit
  - + Simple, not complex – Reduces Service Contracts
  - + Avoids Boiler, Condensing Units or Cooling Towers
  - + Elaborate Control Systems not required
  - + No annual Boiler Teardown and Inspections

GeoExchange System Features

- Maintenance and Operations Cons
  - − Quantity of units to maintain
  - − Air filters and drain pans (unitary)
  - − Heat pump locations accessible
- Maintenance Considerations
  - = Refrigerant 22 vs 410A
  - = Equipment/compressor service life of 19 years
  - = Looping piping service life of 50 + years

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Environmental

Pros and Cons

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GeoExchange System Features

- Environmental Pros
  - + More comfortable indoor environment
    - > Each unit operates independently, allowing either heating or cooling to occur as required
    - > Individual Room Control of Heating or Cooling
  - + No Make-Up Water for Boiler / Cooling Tower
  - + No Chemical Treatment / Hazardous Materials
  - + Eliminate Carbon Monoxide (CO) Potential
  - + No Vandalism or Security Concerns
  - + Minimal floor area required
  - + Less energy means less natural resources and less pollution

GeoExchange System Features

- Environmental Cons
  - Noise inside building

- Environmental Considerations
  - Selection of Circulating Fluids
  - Temporary disturbance of landscaping
  - Design for proper indoor air quality

Where does a GeoExchange System Apply?

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GeoExchange Applications

- New Construction
  - Integrate GeoExchange into design
  - Optimize system efficiency and costs
- Retrofit Construction
  - Air condition existing non A/C building
  - Replace Unit Ventilators or Fan Coil Units
  - Minimum disturbance for Historical Preservation

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GeoExchange Applications

- Building Type
  - Good application:
    - Single-story – finger plan
    - Balanced envelope / interior thermal loads
  - Weak application:
    - New well insulated multi-story “box” with high internal loads
  - Residential
    - Excellent application

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GeoExchange Applications

- **Schools are Good Candidates for GeoExchange Systems**
  - ✓ Retrofit older systems
  - ✓ Air conditioning upgrade
  - ✓ School building layout normally good for balanced heating/cooling loads
  - ✓ Typical classroom good economic size for heat pump
  - ✓ Open field area available for Geothermal Heat Exchanger
  - ✓ System advantages attractive to schools
  - ✓ Schools will be around to enjoy the life cycle cost benefits

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GeoExchange Applications

- **Domestic Water Heating Applications**
  - **Desuperheater kit to heat domestic water – Standard Option**
    - Cooling Season = Free water heating
    - Heating Season = High COP water heating
  - **Water to water heat pumps preheat Domestic Water at a COP of 3.0 – 5.0**
- **Water to Water Heat Pump Applications**
  - **Hydronic systems**
  - **Radiant floor systems**
  - **Heating water/chilled water source for Outside Air/ Ventilation Air with conventional air handling systems**
  - **Swimming Pool water heating**

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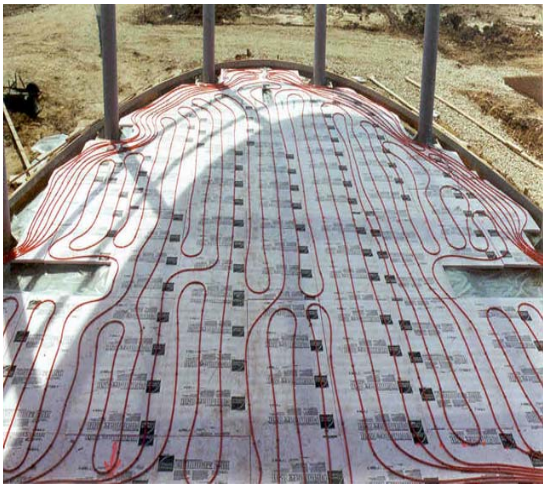
Radiant Floor Heating Application

- Radiant Floor
  - Circulate heated water through piping circuits embedded in floor slab
  - Warm Floor radiates heat to the walls, ceiling and other objects
  - Water to Water Heat Pumps provide water at an effective temperature



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Geothermal System Economics

$ First Costs

\+ Energy Costs

\+ Maintenance Costs

= Bottom Line

What is the Cost Experience?

First Cost Basics

- Building and HVAC System Criteria drive Costs
  - Building Type, Occupancy and Use
  - Thermal Zones and Ventilation Requirements
  - HVAC Equipment Space Allocation
  - Central System vs Distributed / Unitary System
- Generally, the Geothermal system cost inside the building is less than or equal to conventional system
- Incremental cost of a Geothermal Heat Exchanger vs
  - Boiler and Heating Water Pumping systems
  - Chiller / Cooling Tower and related Pumping systems
  - Condensing Units / Rooftop Units
- First Cost is greatly influenced by Effective Design

First Cost Considerations

- Manage the Installed Cost
  - Reduce the total Heating / Cooling Load
    - Efficient Building Envelope
    - Outside Air Loads: CO_2 / DCV and Energy Recovery Units
    - Recognize System Load Diversity
  - Field Test for actual Soil Thermal Conductivity
  - Organize and Minimize Geothermal System Piping
  - Control the Control System Costs
  - Experience based evaluation of System Design

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First Cost Considerations

- Recognize All System Related Cost Savings
  - Boiler Stacks and Roof Penetrations
  - Boiler Room Combustion Air
  - Chemical Treatment, Make Up Water and related equipment
  - Structural Cost for Cooling Tower or Equipment Support
  - Screen Walls and Fences for Vision, Vandalism, Security
  - Machine Room (Refrigerant) Ventilation
  - Natural Gas Service Entrance
  - Reduced Mechanical Equipment Floor area

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First Cost Considerations

- Utility Company Incentives
  - $ 0 to $ 600 per ton
  - Custom Incentive Programs
  - Alternate Rate Schedules
  - Check with the Local Utility before Design
- Financing Options
  - Energy Savings or Performance Contracting
  - Utility Company Financing
- Tax Incentives
  - Up to $1.80 per SF for 50% better than Energy Standard
  - Up to $300 Tax Credit for Residential Geothermal Heat Pumps

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First Costs – GeoExchange Bore Field

- Unit Cost Summary – 14 Buildings

Gross Bore Field Cost	Range	Average
Cost per Square Foot:	$ 1.88 – $ 4.55	$ 3.27 / SqFt
Cost per Ton:	$ 715 – $ 2,817	$ 1,719 / Ton
Cost per Bore:	$ 775 – $ 3,032	$ 1,537 / Bore
Cost per Foot of Bore:	$ 4.43 – $ 12.50	$ 7.83 / BoreFt

- These are project reported construction costs
  - The costs are not qualified for scope or normalized for conditions
  - Costs do not include Credits for Boilers, Chillers, Cooling Towers
  - Costs do not include Utility Company Incentives
  - Additional Project Cost Information appreciated

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First Cost Examples

- West Liberty High School
  - New High School 78,000 GSF with 280 tons cooling capacity
  - Horizontal Bore Installation Alternate bid
  - 112 Horizontal Bores at 500 feet long
  - Horizontal Bores stacked two high
  - $363,000 for Horizontal Bore Field piped to Building
  - $3232 per bore / $6.46 per bore foot
  - Vertical Bore arrangement bid at $160,000 more (44% increase)

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Energy Costs

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Energy Costs

- All Electric / Electric Heat Rate Schedule
  - Significant Factor for Energy Costs
  - Identify the applicable Rate Schedule
  - Electric Costs of 4 ¢/KWH electric heat vs. 8 ¢/KWH for winter use
  - Some Rates may be applied to the total building electrical use
  - Net Heating Energy Costs of $4/MMBTU vs. $12/MMBTU
- Electrical Demand
  - Typical Reduction in Electrical Demand
  - Demand Limiting / Load Shedding Opportunities
  - Demand may be a significant factor in total electric costs

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Energy Costs

- **Case Studies – Three Ankeny Elementary Schools**
  - **Actual Site Energy Reduction:** **46% to 54% BTU/SF-Yr**
  - **Actual Energy Cost Reduction:** **6% to 14% $/SF-Yr**
    Non Air Conditioned to Air Conditioned
  - **Energy Cost Avoidance:** **20% to 34% $/SF-Yr**

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Operation and

Maintenance Costs

Maintenance Costs

- **ASHRAE Technical Paper**
  - ***"Comparing Maintenance Costs of Geothermal Heat Pump Systems with Other HVAC Systems: Preventive Maintenance Actions and Total Maintenance Costs"***
    A Technical Paper prepared for ASHRAE by Michaela A. Martin, Melissa G. Madgett, and Patrick J. Hughes, P.E.
  - **Project focus – Lincoln Public School District, Lincoln, NE**
    - **20 School buildings and 4 HVAC System types were evaluated**
    - **Maintenance Costs summarized by:**
      - > **Preventive Maintenance Costs per SF per Year**
      - > **Repair, Service, and Corrective Action Costs per SF per Year**
      - > **Total Maintenance Costs per SF per Year**

Maintenance Costs

- **Lincoln Schools, Lincoln Nebraska**

TABLE 5b
Summary of Annual Preventive Maintenance Costs, Repair, Annual Service, and Corrective Action Costs, and Total Annual Maintenance Costs per Square Foot (I-P Units)

	Average PM Costs, Repair, Service, and Corrective Action Costs, and Total Maintenance Costs			
School	Preventive Maintenance Costs per Year per ft^2 (¢/yr·ft^2)	Repair, Service, and Corrective Action Costs per Year per ft^2 (¢/yr·ft^2)	Total Maintenance Costs per Year per ft^2 (¢/yr·ft^2)	Total Maintenance Costs per Year per Cooling ft^2 (¢/yr·cool ft^2)
Geothermal Heat Pumps (vertical bore)	7.14	2.13	9.27	9.27
Air-Cooled Chiller and Gas-Fired Hot Water Boiler	5.87	2.88	8.75	10.43
Water-Cooled Chiller and Gas-Fired Steam Boiler	9.82	3.73	13.54	18.68
Water-Cooled Chiller and Gas-Fired Hot Water Boiler	12.65	6.07	18.71	20.71

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Economic Performance

- Bottom Line
  - Most Energy Efficient Heating & Cooling System Available
  - Comfortable with a High Degree of Owner Satisfaction
  - Reduces Energy Cost by 20% to 35%
  - Adds 2 – 4% to the Total Cost of New Construction
  - Incentives, Credits and Alternate Financing may be Available
  - Typical 5 to 10 year payback
  - Generally best Life Cycle Costs

- Each Commercial Facility is Unique

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Thank You……..

Discussion ! ! ! !

Questions ????

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