Fundamentals of Thermal Heating
for Geo-active & -inactive Regions

Edward F Wahl, PhD, PE

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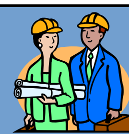


Agenda Item One
Key Definitions
for Thermal Heating for Geo-active & Geo-inactive Regions

Definitions are important and necessary. With a clear understanding Professional Engineers or Other Decision Makers can make the best decision.
Without a clear understanding of the words, sometimes incorrectly understood by tradespeople, professionals cannot make appropriate decisions.

Table 1. Definitions and Synonyms of Basic Geological Terminology (active)

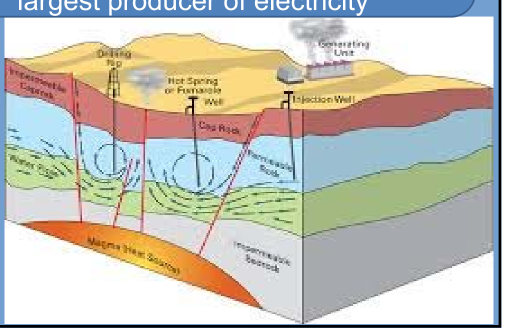
Name	Field of science or other note	Meaning
Tectonics	geology generally	geological structural features as a whole
Tectonics	geology particularly to planet	the structure of the **crust** of a planet and especially the formation of folds and faults in it
Tectonics	Geology, particularly to Earth's crust	the structure of the Earth's crustal surface & how it changes over time
geo-	from Greek word	earth or of the earth
thermal	basic word definition	heat
Geothermal next slide	geo- plus thermal	of, relating to, or using the natural heat produced inside the earth
Climate, climatic	basic geology definition	conditions at surface of earth
Geothermal energy	current common terminology	pockets of hot water or steam near the Earth's surface accessed at reasonable cost. 1 to 2 miles below surface

Table 1. Definitions and Synonyms of Basic Geological Terminology (inactive)

Name	Field of science or other note	Meaning
NoteDifference between Geothermal Source & Thermal Source		
Near-surface Geo-structure	Geo-inactive zone	Approximately 5 to 50 feet below local surface
Ground Source	Geo-inactive zone	Near-surface Geo-Structure
<u>**Thermal source**</u> &/or sink	Geo-inactive zone	Ground Source
Ground Source	Geo-inactive zone	Ground Source Thermal Technology "GSTT"
Groundl Source	Geo-inactive zone	Is NOT geothermal source! By definition of geo-inactive
GSTT	Geo-inactive zone	Used for Ground Source/Sink heat transfer. Since there is no geothermal energy in this zone it cannot be used as a geothermal heat pump.

Next: Introductory Video on <u>geothermal</u> energy.
An update comment: Steam will <u>not</u> be the largest producer of electricity

large chunk, ***block***, of earth is used as a heat source. Drill depth is 1 to 2 miles.



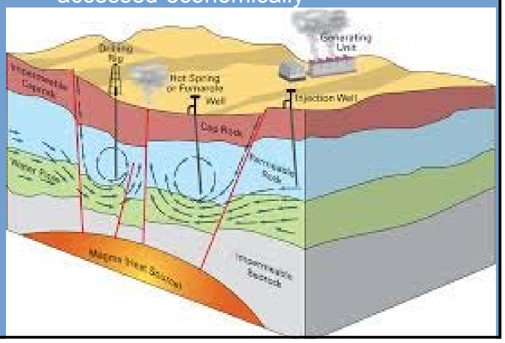
Instructions for videos
The links will be sent to your chat box
From there you can cut and paste or click on it to open and start the video playing
Energy 101
Geothermal Heat pumps
Each will take 5 minutes, we will allow 10 minutes for each.

https://www.youtube.com/watch?v=mCRDf7QxjDk
https://www.youtube.com/watch?v=y_ZGBhy48YI

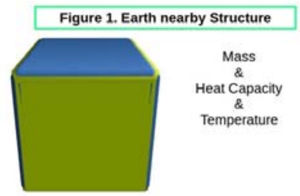
INTRODUCTION

Geothermally active regions in the west occur as pockets of hot water or steam that can be accessed economically

a large chunk, ***block***, of earth is used as a heat source. Drill depth is 1 to 2 miles.



•HEATING BLOCK (chunk of earth)
•size relative to size of structures

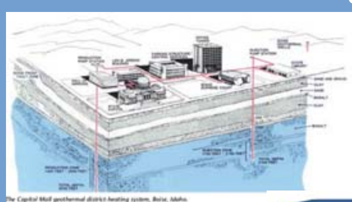


The BLOCK (chunk) of earth

must be of sufficient size and thermal capacity for the structures to be heated

and sufficiently close to the surface so the cost to transport is economic

In Boise Idaho large blocks are used for thermal heating



The block size is many miles in length & width, & 1 to 2 miles deep. This is an exceptional example: cold climate, abundant high source temperature

How the faults & folds are changing with time
Types of Geo Zones, Regions, Location & Energy Source.

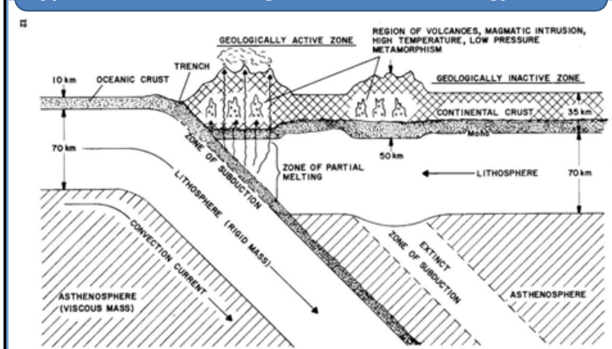


Figure 1.5 Plutons formed by subduction.

Table 1.2b Geo-Regions

Geo-Regions and Their Rate of Change

Rate of thickening of the continental lithosphere	~20 m/billion years
Rate of horizontal extension of the continental lithosphere	~2 m/billion years

Surface Area

region	Billion km^2	%
Continents	149	29.2
Ocean	361	70.8

Because the time frame of changes is billions of years, data from: a) NASA studies; b) USSR geologic commission circa 1960; and c) any others sources during man's existence may be useful.

Next: Review of Basics

Review geo-data, concepts & theories necessary to understand the geothermal fluids available at the earth's surface & therefore how to use them profitably.

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Agenda Item Temperature Gradients

To Understand Temperature and Temperature gradients at/in the Crust, it is important to understand:

1. The source of these throughout the earth
2. The variations of these at a specific geographic location of interest

Therefore the next group of slides will present this information in various formats.

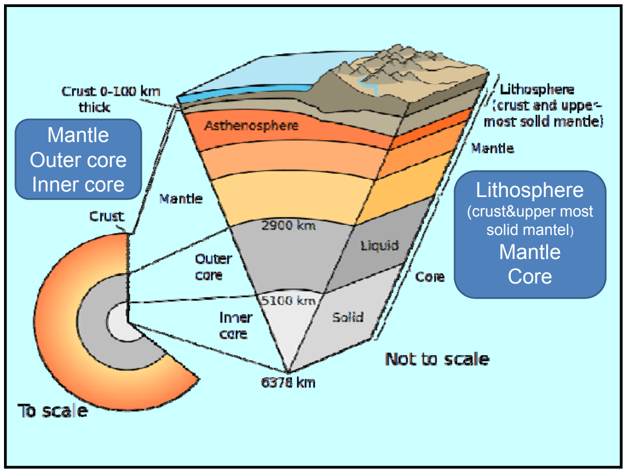


Table 1.2 Schematic of Depth' Geo-Regions, and Temperature

depth km	Geo-regions	temperature °Kelvin	°centigrade
0 (Surface)	Crustal surface	293	20
Ocean: 6 km continents : 70 km	moho		
410	Lithosphere > Aesthenosphere		
660	Upper > Lower Mantle	1,900	1,627
2800 to 2900	Lower Mantle> > Outer Core	3000	2,727
5100	Outer Core > Inner Core	5,000	4,727
6370	Center of Earth (mean)	7,000	6,727

Lithosphere, Crust, & upper most solid mantle; Asthenosphere (viscous mass); Lower Mantle Rigid; Upper Core Liquid; Lower Core Solid

crust; Mantle; Core

Table 1.3 Temperature Distribution and Transition Zones Between Regions of Earth's Interior

Region	State	Connecting Zone	Depth (km)	Temperature (°C)	Density (g/cm^3)	Composition	Region
Crust			0	0-50			Lithosphere
	Rigid Plates		10-20[c]	?	2.7	Na,K alumino-silicates[a]	
					3.0	Fe,Ca,Mg alumino-silicates[b]	
		Moho	6-70	500-1000			
Mantle	Solid						
		Solidus	100-200	1200			
	Viscous Mass				3.6-4.4	Fe,Mg silicates	Asthenosphere
		Solidus	700	1900			
	Rigid Mantle				4.5-5.5	Fe,Mg silicates &/or oxides	Mantle
		Solidus	2800	3700			
Core	Liquid				10-12		Core
		Solidus	5500	4300		Fe,Ni	
	Solid				12-13		
		Center	6340	4500		Fe,Ni	

[a]Sial: Silicic crust - consisting of composition shown, non-existant in oceanic crust.

[b]Sima: Mafic crust - consisting of composition shown.

[c]Conrad discontinuity, 0 under oceans.

Surface Zone Geology, Subduction

Ref: Chapter 1 of Wiley book (optional reference)

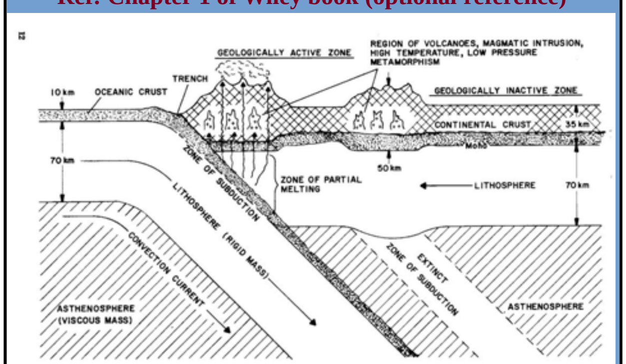
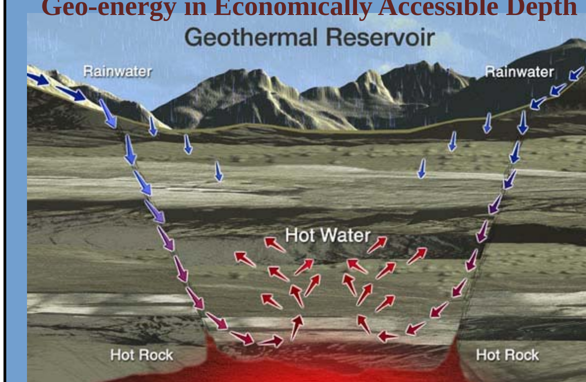
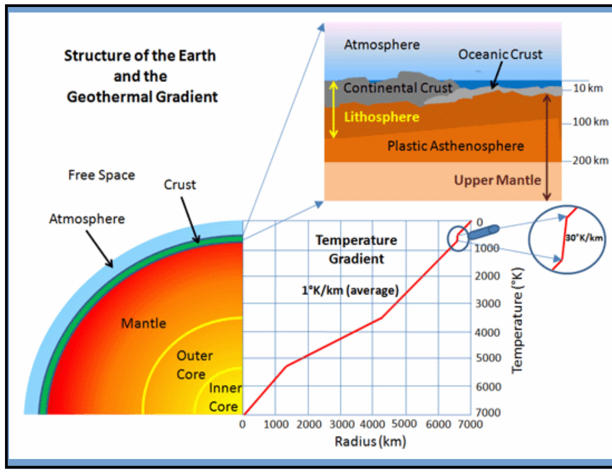


Figure 1.5 Plutons formed by subduction.

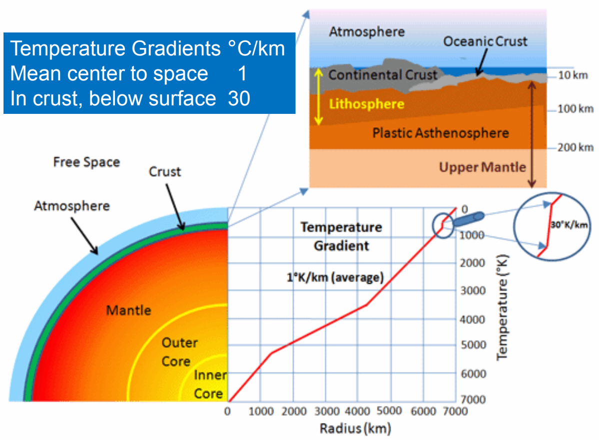
One of Many Scenarios for Formation of Geo-energy in Economically Accessible Depth



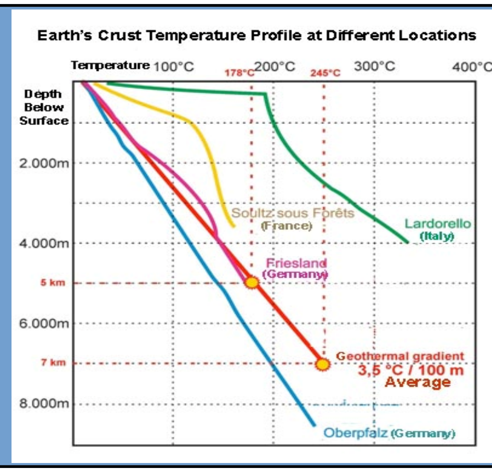
GeoHeat production is result of Rain which percolates down & into hot regions. Drill holes bring the hot fluid to surface for Electricity or Heating



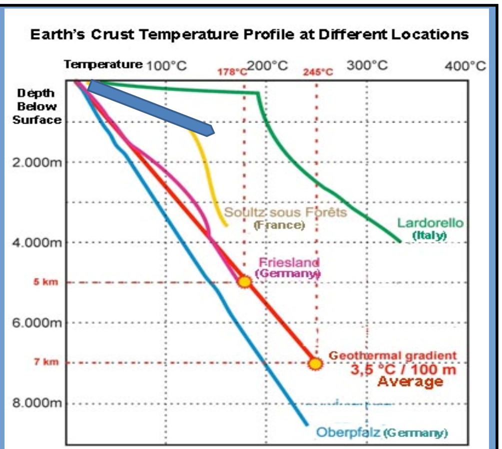
Temperature Gradients °C/km
Mean center to space 1
In crust, below surface 30



Crust Temperature Profile at Different Locations



Temperature Gradients °C/km
Center>Space 1; In Crust 30;
ave gradient (red)35; (blue&yellow)120



Summary of Temperature Gradients In °C/km

Mean from earth center to space	1
In Crust, Just below surface	30
In-active region mean of 30 and 35	32
In Crust, ave of measurementss (red)	35
Higher gradient (blue&yellow)	120

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CHEMICAL COMPOSITION OF ROCKS

Reprinted from "Sedimentary Rocks" (1948) with the permission of F. J. Pettijohn, author, and Harper Brothers, publishers.

Element	Average igneous rock	Average shale	Average sandstone	Average limestone	Average sediment
SiO_2	59.14	58.10	78.33	5.19	57.95
TiO_2	1.05	0.65	0.25	0.06	0.57
Al_2O_3	15.34	15.40	4.77	0.81	13.39
Fe_2O_3	3.08	4.02	1.07	0.54	3.47
FeO	3.80	2.45	0.30		2.08
MgO	3.49	2.44	1.16	[illegible]	[illegible]
CaO	5.08	3.11	5.50	42.57	5.89
Na_2O	3.84	1.30	0.45	[illegible]	1.13
K_2O	3.13	3.24	1.31	0.33	2.86
H_2O	1.15	5.00	1.63	0.77	3.23
P_2O_5	0.30	0.17	0.08	0.04	0.13
CO_2	0.10	2.63	5.03	41.54	5.38
SO_3		0.64	0.07	0.05	0.54
BaO	0.06	0.05	0.05		
C		0.80			0.66
	99.56	100.00	100.00	99.84	99.93

Physical & Chemical Properties

Ref: Chapter 2-4 of Wiley book (optional reference)

The extensive and valuable information in these chapters are not available elsewhere.

Chapter 2. The physical & chemical properties of geothermal fluids
Noteworthy is that Calcium (Ch.3) & Silica (Ch.4) are generally the most serious scale deposition components.

Detailed discussion is beyond the scope of this course but is summarized and provided for your possible interest

Geothermal Brine Physical Properties (w=water; wt=%solids)

Density:

$$\rho = \rho_W + 0.0073 w_t [1 + 1.6 \times 10^{-6} (T - 273)^2] \quad (2.7)$$

Heat capacity:

$$c = c_w \left(1 - \frac{w_t}{100}\right) - 0.002 w_t \quad (2.15a)$$

See also Equations 2.14, 2.15b, and 2.15c.

Vapor pressure:

$$p = p_W \left(1 - \frac{0.004 w_t}{\rho}\right) \quad (2.21)$$

Surface tension:

$$\sigma = 0.0757 (T_c - T)^{0.776} (1 + 0.0039 w_t + 4.35 \times 10^{-5} w_t^2) \quad (2.29b)$$

Viscosity:

$$\mu = \mu_W (1 + 0.021 w_t + 0.00027 w_t^2) \quad (2.25)$$

Enthalpy:

$$h = h_W \left(1 - \frac{w_t}{100}\right) - 0.007 w_t (T - T_0) \quad (2.32)$$

Calcium Carbonate Deposition

Predictable
Dependent on pH
Thus affected by flashing
Also temperature dependent

Please see Chapter 3 of Wiley book optional reference

Silica Deposition

Experience is best predictor
Tests on specific site best.
Polymerization rate varies from minutes to months.
Extensive data is available in the literature for prediction

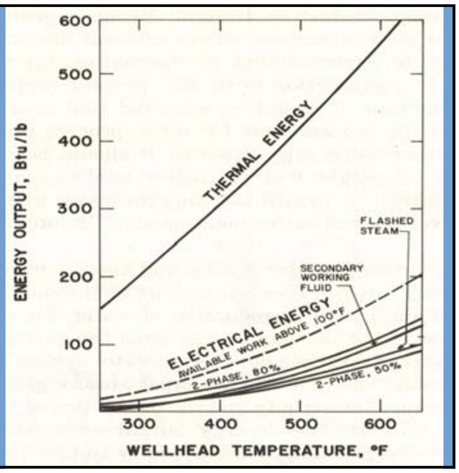
SUMMARY OF THEORY & PREDICTION

On Physical Properties and Deposition

Equations for Physical properties are simple & useful

Deposition can be predicted and/or estimated

Ratio of Thermal to Electrical Output Varies from:
~6 at 600F to ~20 at 300F
Fig 6.5 of Wiley book (optional reference)



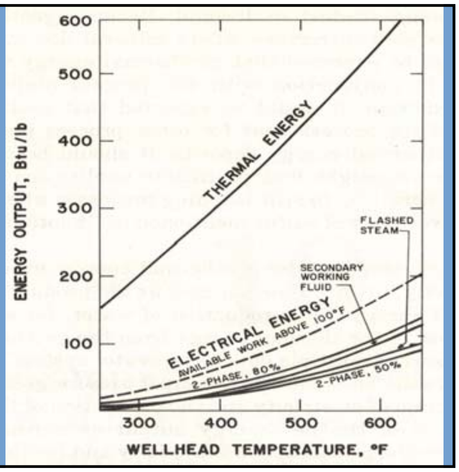
SUMMARY OF PRECEEDING

On Electrical & Thermal Productivity

Sensitive to ambient temperature

Thermal Productivity 6 to 20+ times higher than Electrical Productivity

Ratio of Thermal to Electrical Output Varies from:
~6 at 600F to ~20 at 300F
Fig 6.5 of Wiley book (optional reference)



Pertinent Important Concepts

Ref: Chapters 6-9 of Wiley book(optional reference)

Three concepts are
◊ net power produced improves as ambient temperature drops
◊ most valuable product is direct thermal use for process or other heating purposes
◊ as resource temperature drops, thermal use > preferred economic use

Maps show regions of 48 states of continental US (US48) most economically usable

Current Economic drill depth is 6 km

Geologically Active Regions
Geo-Thermal for Electric Power
Geo-Thermal for Process & Water Heating
District Geo-Thermal heating

Geo-Inactive region

Ground Source Thermal Technology applies to a large portion of inactive region as well as the active region

Maps show regions of US48 economically usable for Ground Source Technology

Current Economic usable depth for near source/sink blocks is

Small systems: 5 to 100 ft (2 to 35 m)

Large commercial systems: 100 to 1000 ft (300 to 3000 m)

There are many newer maps showing heat flow & other information

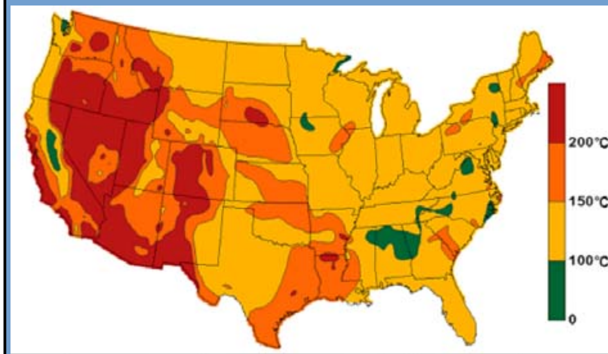
****

The 2 maps used herein are older but more suitable for understanding the fundamentals, the course purpose

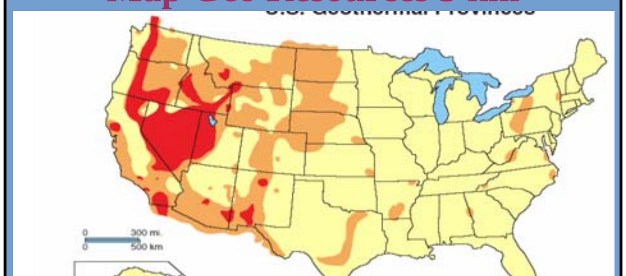
They present a clear overall picture of **geothermal sources** and **heat sink & sources**

They were likely produced by the DOE or Geothermal Resource Board

Map Geo Resources to 6 km



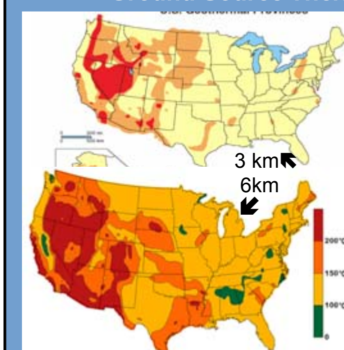
Map Geo Resources 3 km



Temp > 100 °C RED
Temp < 100 °C ORANGE
Source/sink no heat source 32°C YELLOW

Geo-Inactive Region

Ground Source Thermal Technology



applies to a large portion of inactive region as well as the active region

Add rivers & lakes which are abundant in populated areas

Maps (next slide) show % area economically usable for Ground Source Technology

Current Economic usable depth for near source/sink blocks is

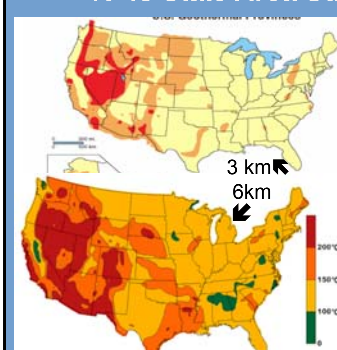
Small systems: 5 to 100 ft (2 to 35 m)

Large commercial systems: 100 to 1000 ft (300 to 3000 m).

Also applies to a portion of the active region for specific cases.

Geo-Inactive Region

% 48 State **Area Suitable for GSTT**



3 km map
Yellow 65%
Orange 15%

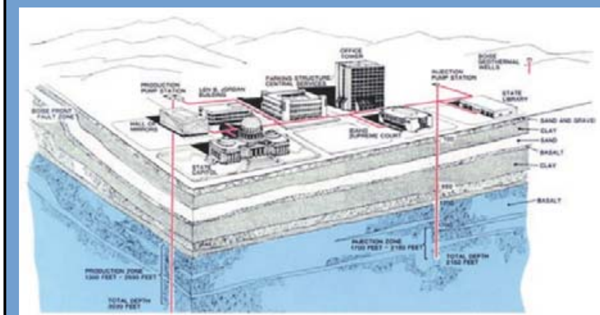
6 km map
Green >100 °C 1.6%
Orange l00>150 °C 25 %

Add rivers & lakes which are abundant in populated areas

District Heating Boise Idaho

A Case Example of Direct Thermal Heating

District Heating Boise Idaho



The Capitol Mall geothermal district-heating system, Boise, Idaho.

District Heating Boise Idaho

Production Zone 1300 – 2550 Ft
Depth of Wells 3000 Ft
Injection Zone 1700 – 2700 Ft

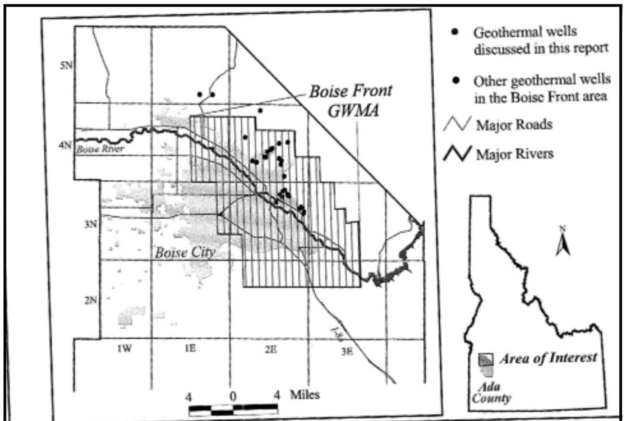


Figure 2. Location map showing geothermal wells in the Boise Front area and the Boise Front Low Temperature Geothermal Resource Ground Water Management Area (Boise Front GWMA).

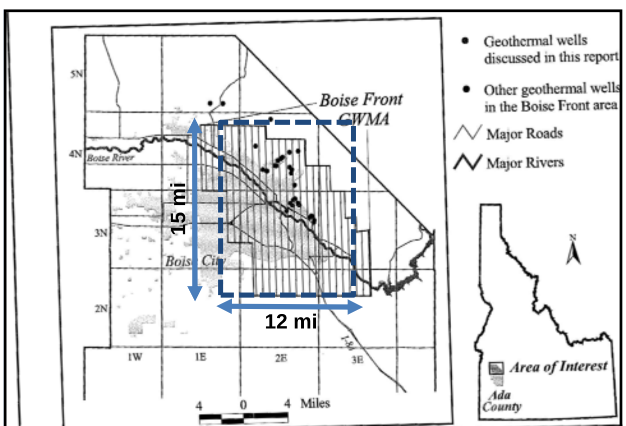
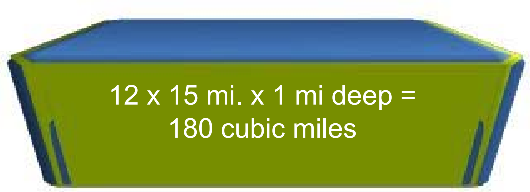


Figure 2. Location map showing geothermal wells in the Boise Front area and the Boise Front Low Temperature Geothermal Resource Ground Water Management Area (Boise Front GWMA).

District Heating Boise Idaho

BLOCK IS 180 Cubic Miles



Definition of (HDD) Heating Degree Days

HDD is an estimate of the energy to heat a building to a comfort level (~65°F).

Table 1. Annual production for the Capitol Mall geothermal system, 1983-1994 (in millions of gallons).

Year	Berkeley Group Inc. (1990)	Daily Logs	Trend Logs
1983	79.1	65.8	
1984	204.8	169.5	
1985	196.4	187.5	
1986	188.6	179.7	
1987	N/A	148.6	
1988	212.6*	122.7	
1989	106.3*	155.6	
1990		83.4	
1991		159.4	43.6
1992		136.3	75.3
1993		240.2	180.3
1994		167.9	96.3

* Estimated from Totalized value of 3.10 x 10 gallons for the period from January, 1988 through June, 1989 (Berkeley Group Inc. (1990)).

Monthly Production

Figure 6 shows the total monthly production for 1983 to 1994 as calculated from the Daily and Trend Logs. Monthly production ranged from 0 to 30.5 million gallons. Appendix A lists the monthly production data.

Daily Discharges

Figures 7 through 18 show the daily discharge readings from the Daily Logs for

CALCULATION OF HEATING DEGREE DAYS

Annual HDD = Sum [daily HDD] for all seasonal heating days.

(outdoor temperature < building comfort temperature)

[daily HDD] = [building comfort temperature (~65°F)] – [mean outdoor temperature]

last 20 years show that: 1) annual heating degree days were generally less than the 30-year average for heating years 1978 though 1983, 2) annual heating degree days were significantly more than the 30-year average for heating years 1984 through 1986, and 3) annual heating degree days were generally less than the 30-year average for heating years 1987 through 1997 (Figure 4).

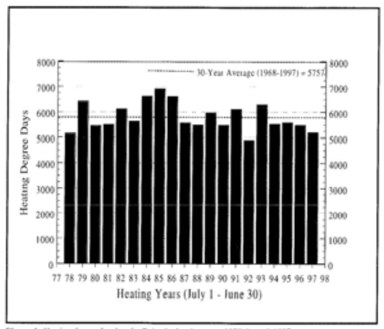


Figure 4. Heating degree day data for Boise for heating years 1978 through 1997

Calculation of HDD and CDD

Practical and accurate estimate of the energy to heat and/or cool a building is best done using NOAA data/website.

CALCULATION OF HEATING DEGREE DAYS

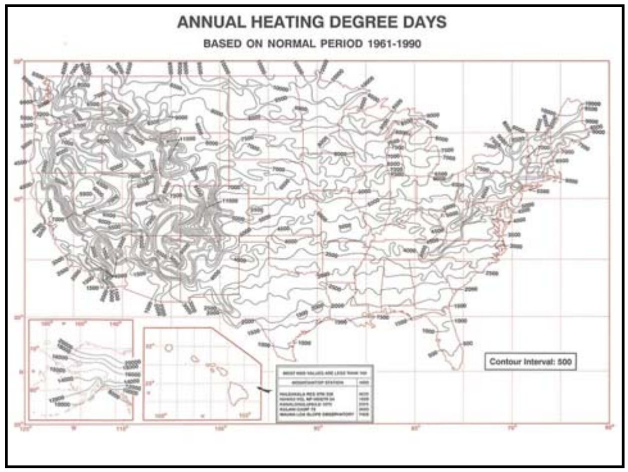
Annual HDD = Sum [daily HDD] for all seasonal heating days.

(outdoor temperature < building comfort temperature)

[daily HDD] = [building comfort temperature (~65°F)] – [mean outdoor temperature]

COMPLICATIONS IN CALCULATION OF HDD

- ⇨ **Value is Site Specific**
- ⇨ Size of structure
- ⇨ Immediate environment: shade & exposure; wind
- ⇨ Structure insulation
- ⇨ Internally produced heat: lighting, machines (refrigerators), electronic equipment and so on



Fundamentals of Heating & Cooling for Geo-inactive Regions

All the theory, procedures, available data & calculations for heating are the same for cooling.

==

The US map for cooling, and the calculation of CDD replaces HDD using same procedures

•BASIC CONCEPT OF

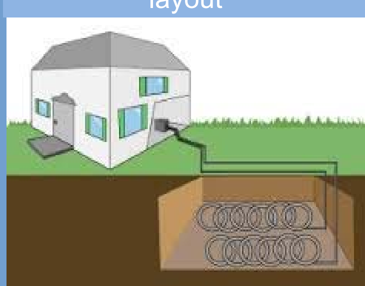
•Ground Source GSTT ThermalTechnology

a relatively large chunk of Earth can be used as a thermal heat source or sink for heating or cooling a single or number of structures

•BASIC CONCEPT OF

•Ground Source GSTT Thermal Technology

Small structure conceptual layout

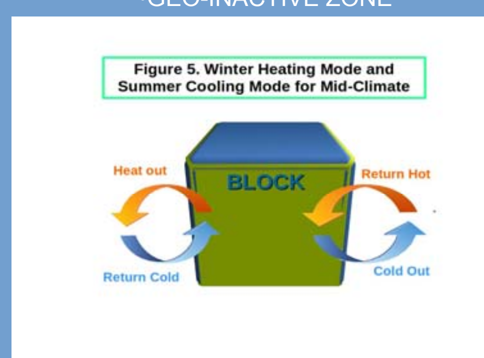


Thermal energy is transported between this block and the structures to be heated and cooled.

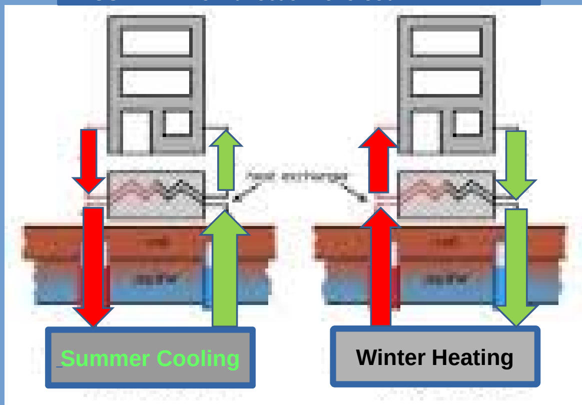
In this case by a set of inexpensive tubing loops

a circular loop moves the fluid between the ground source and the building

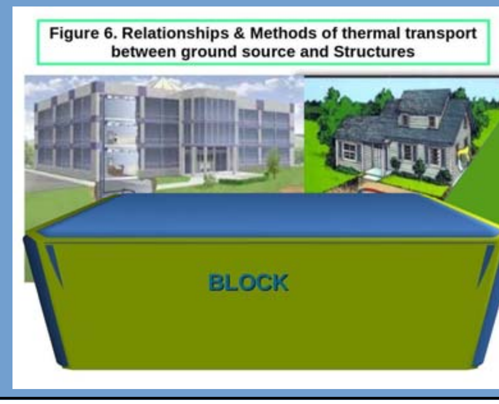
•APPLICATION for
•GEO-INACTIVE ZONE



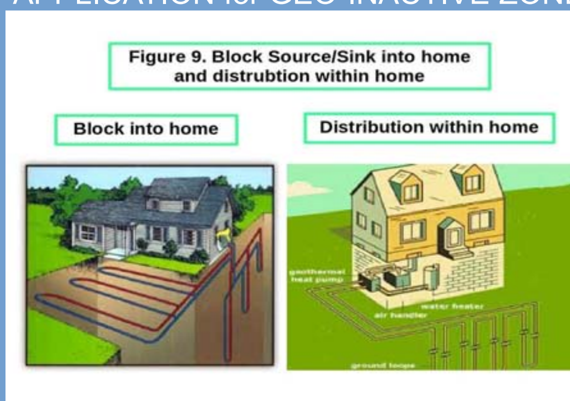
SUMMER flow direction reversed in WINTER



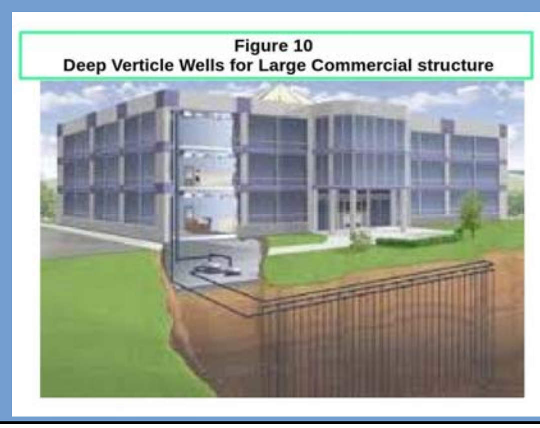
•APPLICATION for GEO-INACTIVE ZONE



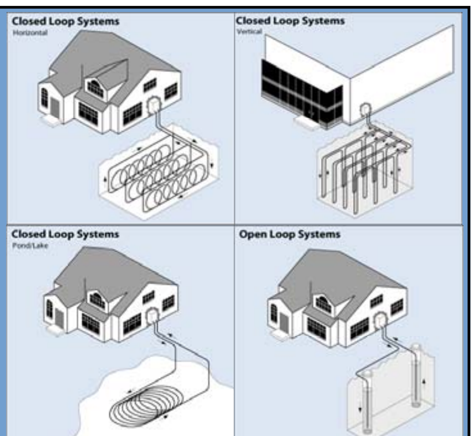
•APPLICATION for GEO-INACTIVE ZONE



•APPLICATION for GEO-INACTIVE ZONE

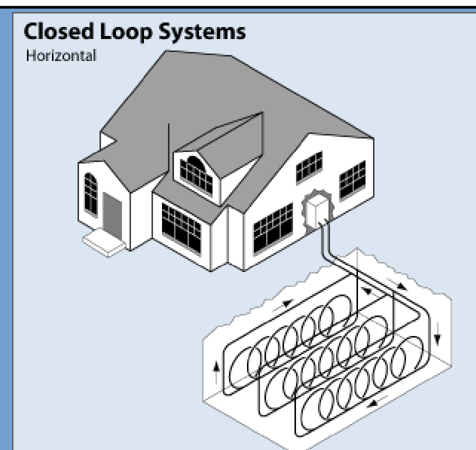


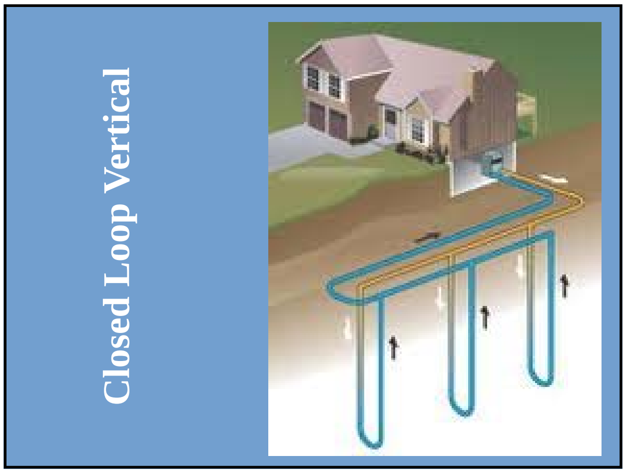
Closed & Open Loop Ground Source Systems

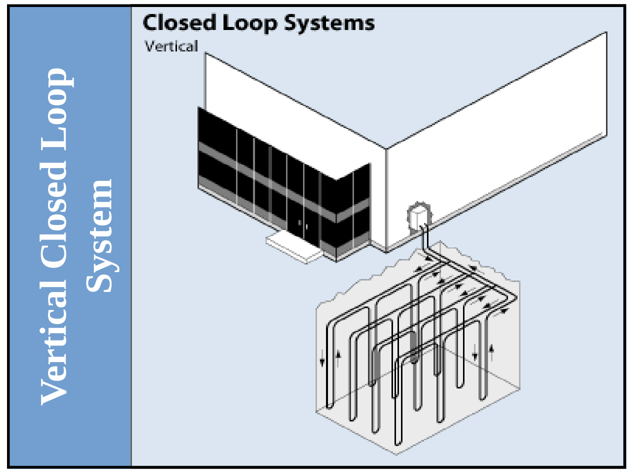


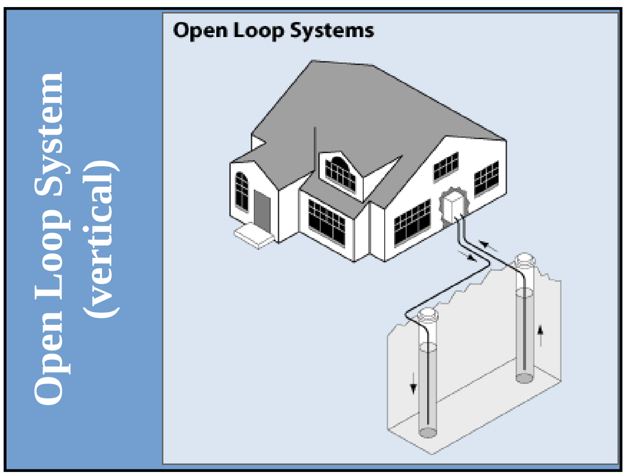
Types of Ground Source Heat Pumps

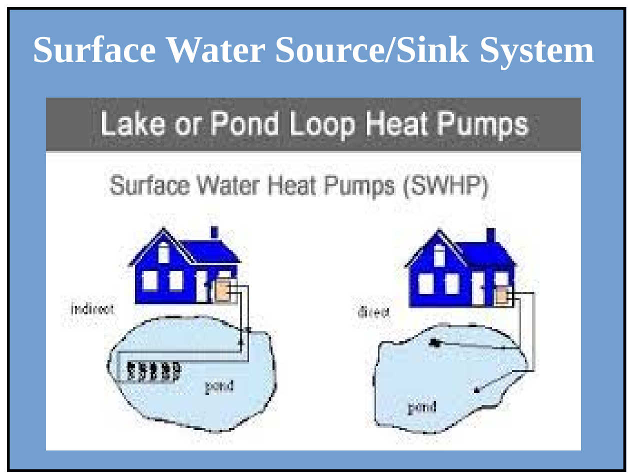
Horizontal Closed Loop System

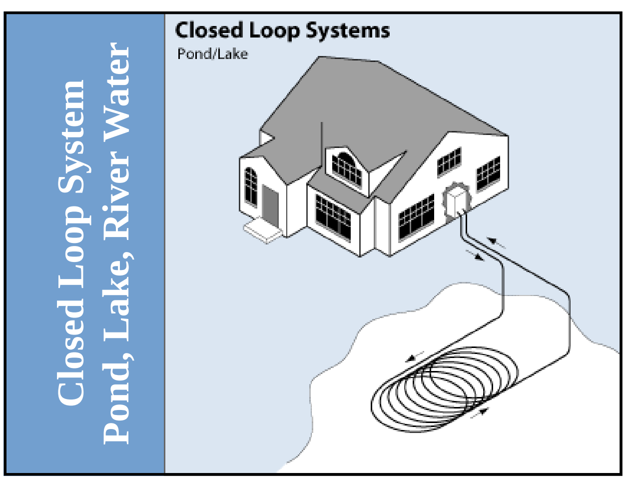


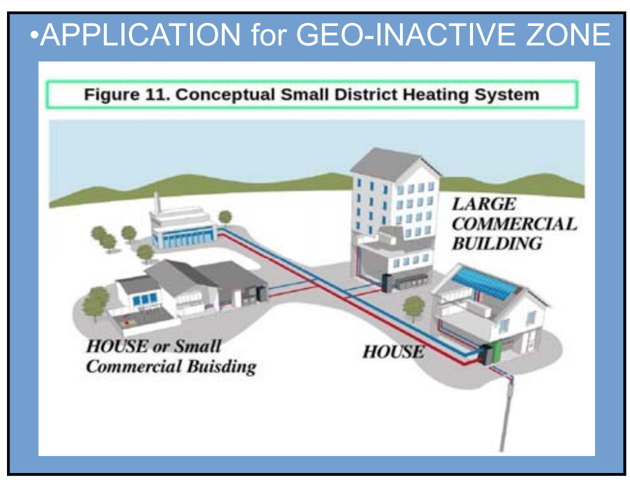

Closed Loop Vertical

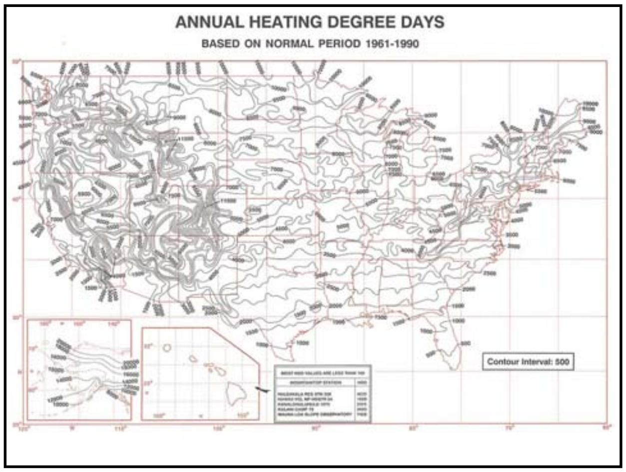

Vertical Closed Loop System
Closed Loop Systems
Vertical


Open Loop System (vertical)
Open Loop Systems


Surface Water Source/Sink System
Lake or Pond Loop Heat Pumps
Surface Water Heat Pumps (SWHP)
indirect
pond
direct
pond

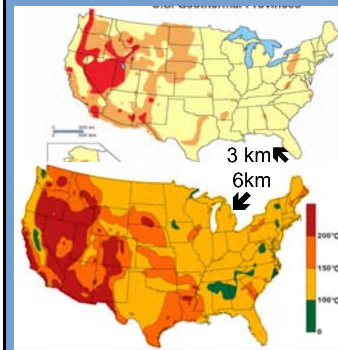

Closed Loop System Pond, Lake, River Water
Closed Loop Systems
Pond/Lake


•APPLICATION for GEO-INACTIVE ZONE
Figure 11. Conceptual Small District Heating System
LARGE COMMERCIAL BUILDING
HOUSE or Small Commercial Buisding
HOUSE



Geo-Inactive region

% 48 State Area Suitable for GSTT



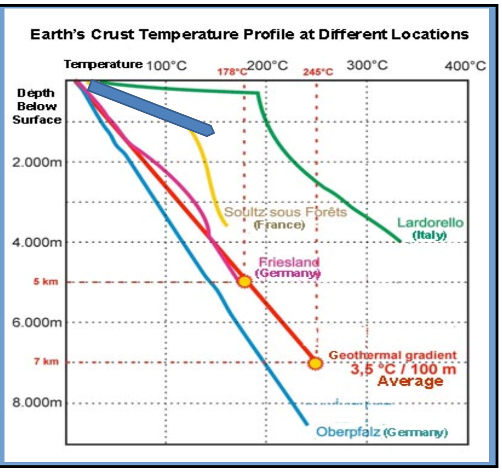
3 km map
Yellow 65%
Orange 15%

6 km map
Green >100 °C 1.6%
Orange l00>150 °C 25 %

Add rivers & lakes which are abundant in populated areas

Crust Temperature Profile at Different Locations

New Data per Download References



Calculation Template For Estimating Monthly Production Value per Well				
d	3.068	inches	pipe id	
1	9,000	gal/hr		
Pounds/hr	67,320		delta t * Cp	
Btu/hr	10,995,130		NET (Gross less pump work for friction loss)	
description	meters	ft units	Source C	Source F
producing depth top	800	2624.8	80	176
producing depth bottom	1300	4265.3	120	248
mean temp of source		1640.5	Top-bottom	212
surface temperature				50
delta t of heating fluid	mean temp of source - surface temp			162
Specific heat capacity water	BTU/LB-F	0.9800	Cp	
therm heat produced/ well	Btu/hr	10,995,130	from line 5 above	
therm heat produced/ well	watts	3222673	.2931*BTU/hr	
therm heat produced/ well	Kw-hr/month	2320324	watts/(1000*30da/mo*24hr/da)	
value kwh	$/kwh	$0.11		
value per well / month	$ /month/well	$255,236		

Benefit of Relatively Deep Wells

As shown by the prior calculation,
the monthly thermal power generated has a value of
$255,236 per well per month.
For 2 inch pipe, the value is $107,335

For net value, the capital cost of the installation, maintenance and other operating costs must be deducted.

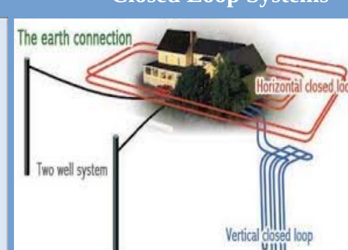
Open & Closed-Loop Systems

ponds, lakes, rivers & similar are used advantageously

Economics =f [Location, climate, distance from geothermal source, geology of crustal surface down to 200 feet.

Open Loop System

Closed Loop Systems

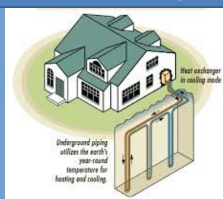


Summary of GSTT

open & closed-loop; surface (ponds, lakes, rivers) **or underground water**

Economics =f [Location, climate, distance from geothermal source, geology of crustal surface down to 200 feet.

From 1 building to **Small District System**



Summary of Key Points in Course pg 1

Temperature Gradients In °C/km
Geothermally active areas (ex steam fields) 35-350
Geothermally inactive areas 32

Geographical region best for geothermal heating of US48 **projects is:**
Pacific Northwest region

Geothermal heating of Boise Idaho, case study, includes City mall, the city region, and the regional area around the city region

Summary of Key Points cont'd pg 2

Concepts
Power ⬆ as ambient temp ⬇
Best product is for thermal heating uses
As resource temp ⬇ thermal use >preferred economic use

HDD is the sum of all the seasonal HDD for each day summed for one year
HDD is estimated by a) using monthly averages from NOAA data and adjusting load for building b) location, c)insulation and d) internal hear generated

Summary of Key Points cont'd pg 3

GSTT closed loop systems may be vertical, horizontal, or angled.
Vertical **GSTT** systems can be used for commercial buildings, small district systems and large structures such as schools & public buildings
(GSTT systems used for heating can benefit by supplementation with solar energy & a short term storage system.

Blocks or large chunks of earth's crust that are used as **thermal** sources may be used for cooling and/or heating.

Summary of Key Points cont'd pg 4

For the large commercial example project utilizing very deep wells to access higher ground source temperatures :
1. Vertical "Ground Source" pipe loops could use well pipes about 2 to 3 inches inside diameter.
2. could generate thermal heat with a monthly value of about $254,000 per well.

End of Review

Thank you for attending.