PennState
Lehigh Valley Campus
Center Valley, PA

Michael Joaquino | Mechanical Option
B.A.E. Program

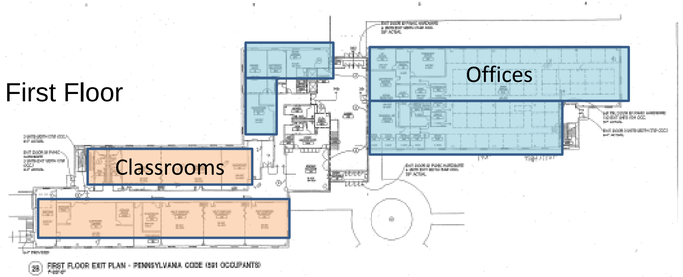
AE Senior Thesis Presentation
Advisor: Dr. Donghyun Rim
April 11th, 2017

General Information

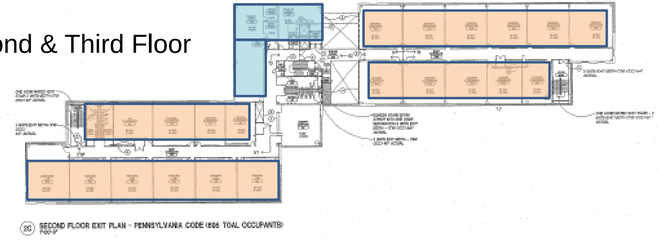
Gross Building: 96,274 SF
Construction: Spring 2002 – Fall 2003
Purchased by Penn State: 2009 - $12 Million USD
Occupancy: 2000 Students

Building Features: Classrooms, Offices, Open Lounges, Computer Labs, Gym, Music Room, library, etc.

First Floor



Second & Third Floor

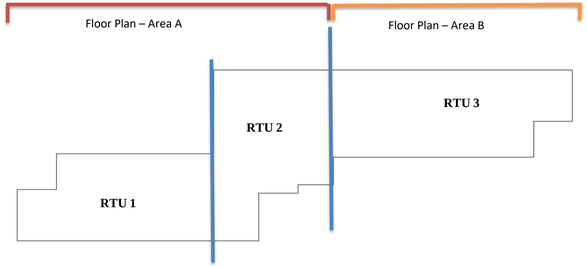


Existing Mechanical System

(3) Packaged Roof-top Units with VAV Electric Reheat
- Cooling – Internal DX-Cooling Cycle
- Heating – Gas Fired Furnace

(77) VAV with Electric Reheat
- Serves individual zones with modulating air dampers to accommodate the room loads.

Existing Mechanical Specification	Cooling (kBtu-h)	Heating (kBtu-h)	CFM	O/A Min.
RTU-1	1492	2350.8	40740	10725
RTU-2	751.6	1059.2	19770	4125
RTU-3	1512	2365.4	33748	14415



Building Overview – RTU placement

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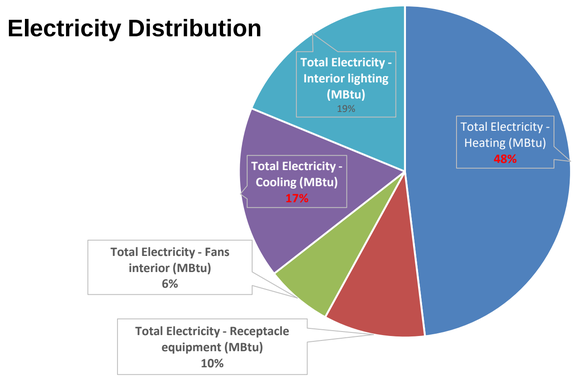
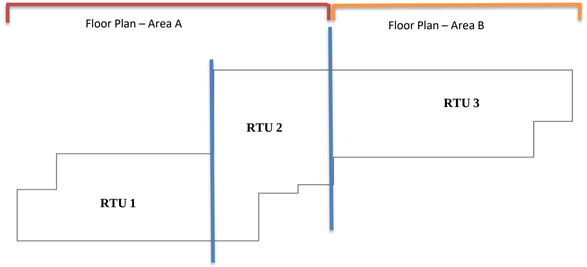


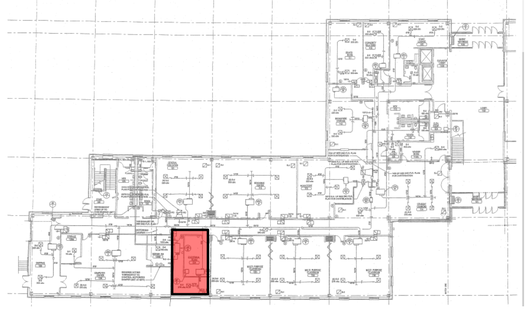


Building Overview – RTU placement

Design Motivation

- **Energy Efficient**
- **Economic Feasibility**
- **Functionality**

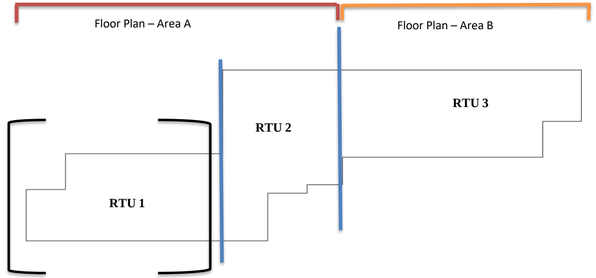
Existing MER



~620 SF

Design Constraints

- Limited MER Space
- No existing CHW/HHW Plumbing



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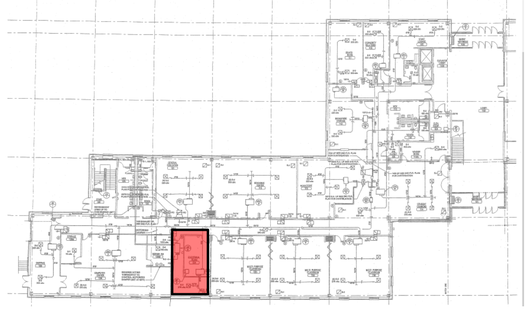

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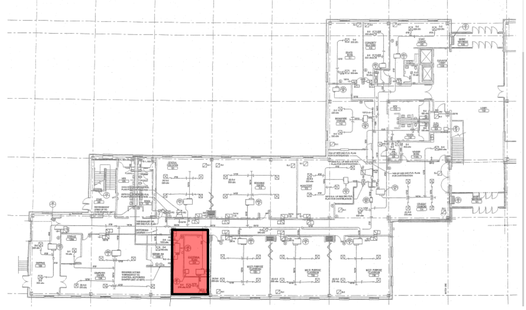

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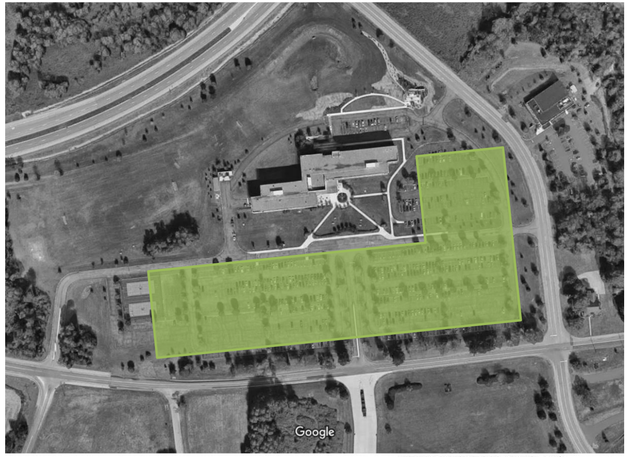

Design Motivation

Centralized Geothermal System
Geothermal GSHP + (Distributed System)

- Utilizing the ground as a heat sink & source
- Potential for large energy savings
- Minimal disruption to academic schedule

Ground Loop Incentives

- Lower Operating Costs
- Lower Carbon Emissions
- Long Life Expectancy
- Efficiency
  - Heat-recovery system
  - High-efficiency heat pumps
  - Utilization of earth temperature

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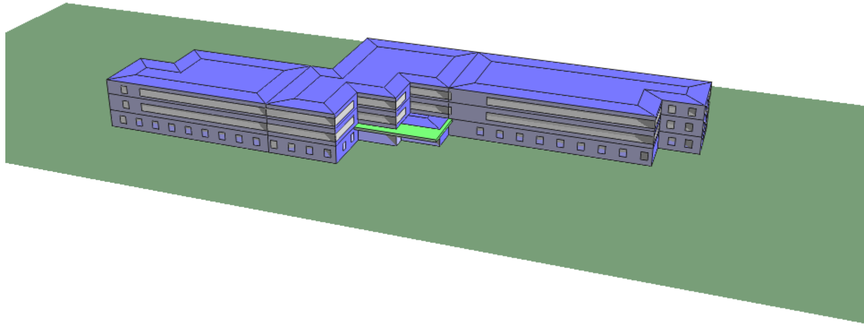
IES Virtual Environment



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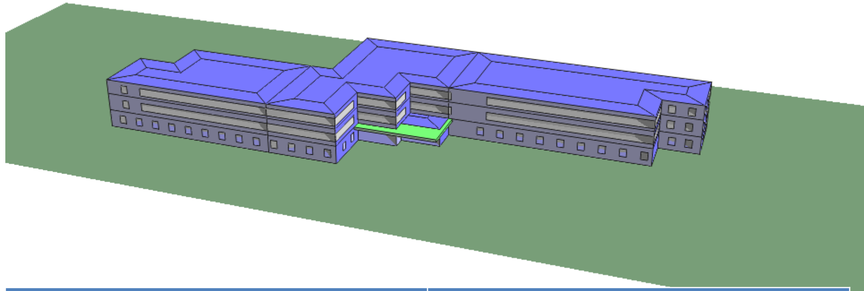
IES Virtual Environment – DOAS with Geothermal Ground Loop



Proposed System	Unit
Central Plant	GSHP
Zone	Split System Heat Pumps

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	CC	HC	CC	HC	CC	HC
kBTU/Hr	676.1	591.5	246.8	243.9	913.3	826.1
Tons	56.3	49.3	20.6	20.3	76.1	68.8

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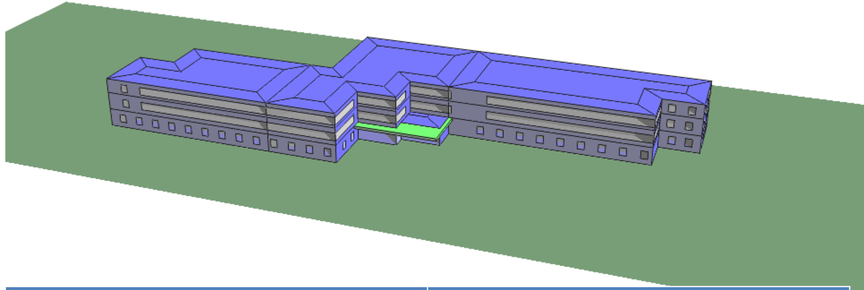

Proposed System	Unit
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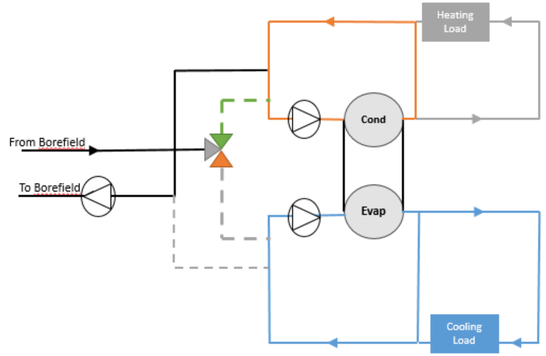
Geothermal System – Distributed System

- Winter – Heating (Heat Source)
- Spring/Fall -
- Summer – Cooling (Heat Sink)

Cooling Only



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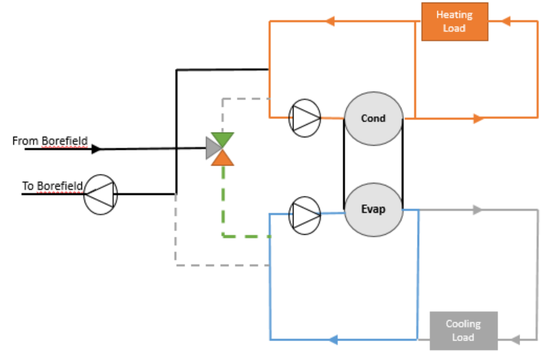
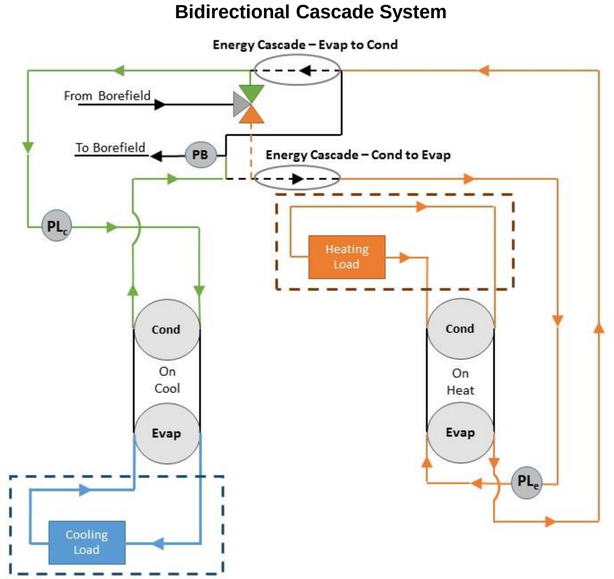


("Central Geothermal System Design and Control" – Trane Commercial.)

Centralized Geothermal System – Bidirectional Cascade System

- Winter – Heating (Heat Source)
- Spring/Fall - Capable of cooling & heating
- Summer – Cooling (Heat Sink)
  - Heat Recovery Chiller



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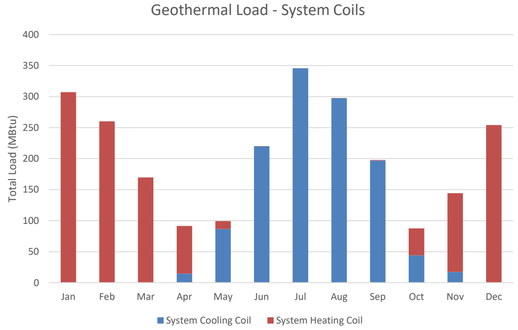
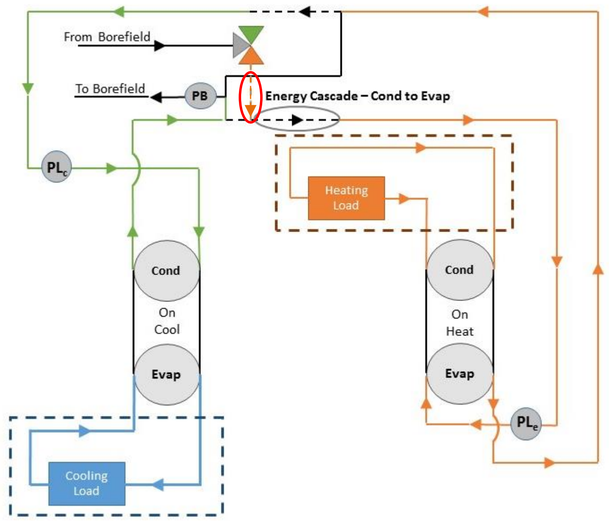
Centralized Geothermal System – Bidirectional Cascade System

Centralized Geothermal System
Building Cooling & Heating Demand



Bidirectional Cascade System
Heating Dominate



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Comparing Heating & Cooling Performance

- Geothermal with Split System
- Geothermal with Chiller/Boiler
- Existing Mechanical

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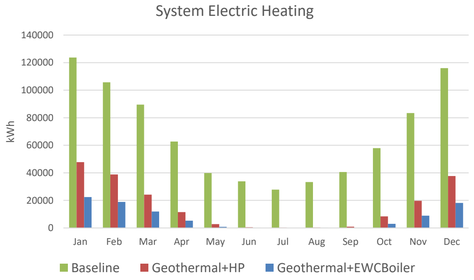
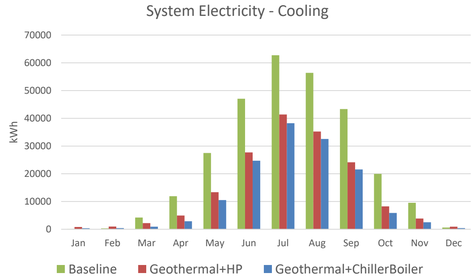
…Electricity Consumption

Annual Electric Heating	GSHP+CHW/HHW	GSHP+HP	Baseline
Summed total (kWh)	89,554.2	269,383.2	814,526.9
Difference %	0.89	0.76	-



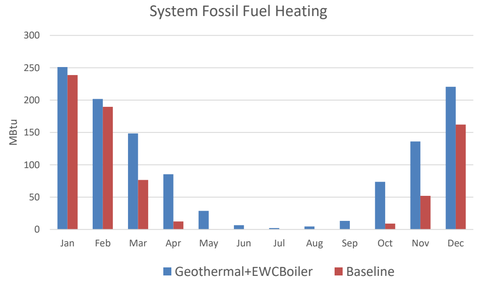
Annual Electricity - Cooling	GSHP+CHW/HHW	GSHP+HP	Baseline
Summed total (kWh)	141,037	163,910.62	283,758
Difference %	0.50	0.42	-



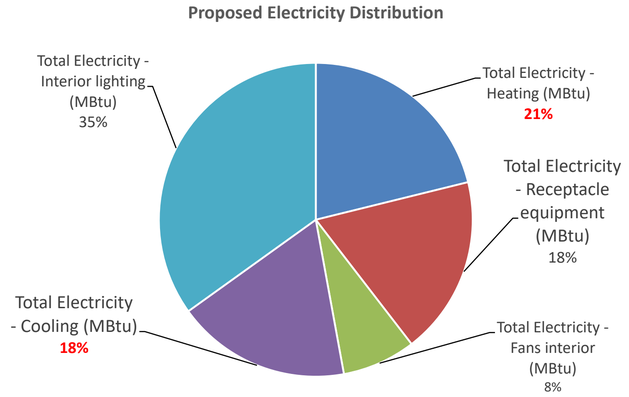
Comparing Heating & Cooling Performance

…Fossil Fuel Consumption

- Geothermal with Split System
- Geothermal with Chiller/Boiler
- Existing Mechanical



Annual Electricity Distribution – Proposed System



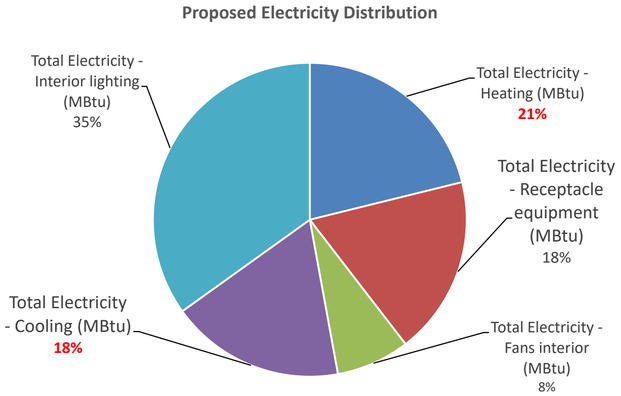
Comparing Heating & Cooling Performance

…In Summary

- Geothermal with Split System
- Geothermal with Chiller/Boiler
- Existing Mechanical

Annual Total	boilers energy (MBtu)	chillers energy (MBtu)	DX cooling systems energy (MBtu)	EHC heating energy (MBtu)
Geothermal+ CHW/HHW	9,561.95	480.867	0.00	0
Geothermal+ HP	8,388.67	310.931	247.92	0
Baseline	8,388.67	0	967.48	**2,777.137**

Annual Electricity Distribution – Proposed System



Cost Analysis

Annual Heating/Cooling	Fossil Fuel (Mbtu)		Electric (Mbtu)		Cost		Total
	Heating	Cooling	Heating	Cooling	Heating	Cooling	
Baseline	-	-	3411.93	967.48	$ 90,994.2	$ 25,802.1	$ 107,761.22
Mech. Proposed Geothermal	-	-	657.49	558.86	$ 17,534.9	$ 14,904.4	**$ 32,439.27**
Traditional Chiller-Boiler	1568.54	-	918.47	462.17	$ 41,198.7	$ 12,325.9	$ 53,524.56
Alt. Geothermal+EWC/Boiler	1173.29	-	305.34	480.87	$ 20,637.7	$ 12,824.5	$ **33,462.21**

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Vertical Well – Payback Calc	Proposed System	Original
Operating Cost	$ 32,439.27	$ 107,761.22
Yearly Savings	$ 75,321.95	-
Equipment & Installation	$ 3,353,074.40	$ 2,642,025.00
Total (Years)	9.4	

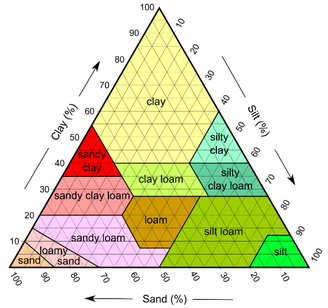
Horizontal Well -Payback Calc	Proposed System	Original
Operating Cost	$ 32,439.27	$ 107,761.22
Yearly Savings	$ 75,321.95	-
Equipment & Installation	$ 2,277,274.40	$ 2,642,025.00
Total (Years)	-4.8	

Construction Layout – Geothermal System

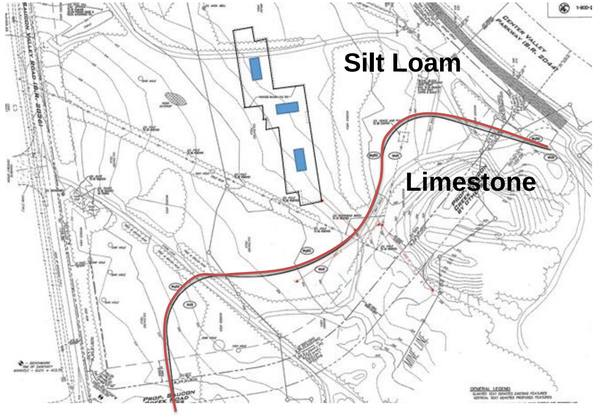
Silt Loam vs. Limestone

Geothermal Well types
Horizontal vs Vertical

Geothermal Cost	Vertical	Horizontal
$/Ft.	$16	$4
Ft. Req.	47,211.3	54,370.2
Cost	**$755,380.8**	217.480.8



Proposed Geothermal Location



Heating	Limestone	Silt Loam
Lh [ft]	41,053.3	47,278.43
safety 15%	**47,211.29**	**54,370.19**

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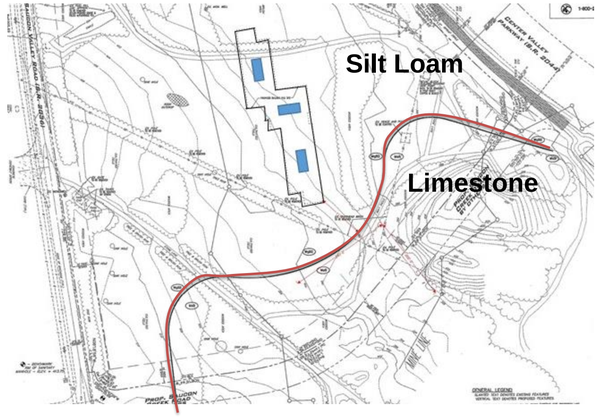
Table 5 Thermal Properties of Selected Soils, Rocks, and Bore Grouts/Fills

	Dry Density, lb/ft³	Conductivity, Btu/h·ft·°F	Diffusivity, ft²/day
Soils			
Heavy clay, 15% water	120	0.8 to 1.1	0.45 to 0.65
5% water	120	0.6 to 0.8	0.5 to 0.65
Light clay, 15% water	80	0.4 to 0.6	0.35 to 0.5
5% water	80	0.3 to 0.5	0.35 to 0.6
Heavy sand, 15% water	120	1.6 to 2.2	0.9 to 1.2
5% water	120	1.2 to 1.9	1.0 to 1.5
Light sand, 15% water	80	0.6 to 1.2	0.5 to 1.0
5% water	80	0.5 to 1.1	0.6 to 1.3
Rocks			
Granite	165	1.3 to 2.1	0.9 to 1.4
Limestone	150 to 175	1.4 to 2.2	0.9 to 1.4
Sandstone		1.2 to 2.0	0.7 to 1.2
Shale, wet	160 to 170	0.8 to 1.4	0.7 to 0.9
dry		0.6 to 1.2	0.6 to 0.8
Grouts/Backfills			
Bentonite (20 to 30% solids)		0.42 to 0.43	
Neat cement (not recommended)		0.40 to 0.45	
20% bentonite/80% SiO_2 sand		0.85 to 0.95	
15% bentonite/85% SiO_2 sand		1.00 to 1.10	
10% bentonite/90% SiO_2 sand		1.20 to 1.40	
30% concrete/70% SiO_2 sand, s. plasticizer		1.20 to 1.40	

Source: Kavanaugh and Rafferty (1997).

ASHRAE 2007 Fundamentals: HVAC Applications

Proposed Geothermal Location



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Silt Loam vs. Limestone

Geothermal Well types

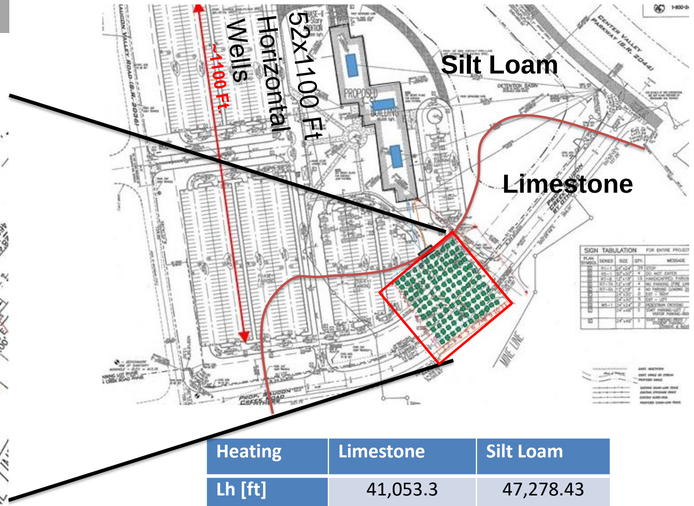
~~Horizontal~~ vs Vertical

Approximately 47,000 Ft. of Bore

- 11x11 Grid
- 400’ Bore Depth

Wall Depth (ft)	Required Length	Number of Wells
100	47,211.3	472
200	47,211.3	236
300	47,211.3	158
400	**47,211.3**	**118**

Proposed Geothermal Location



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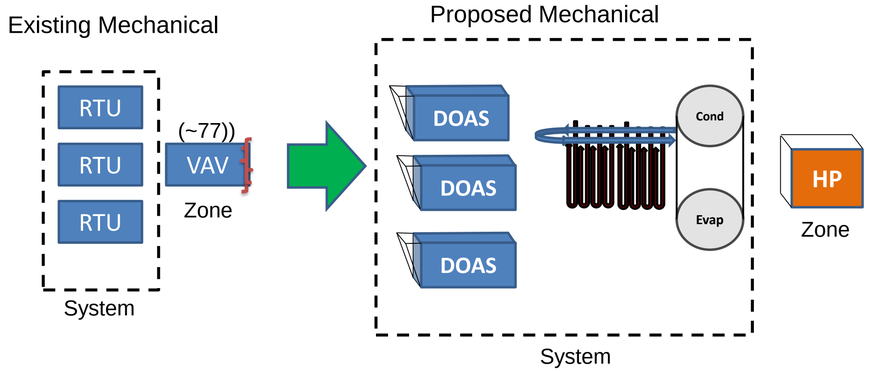
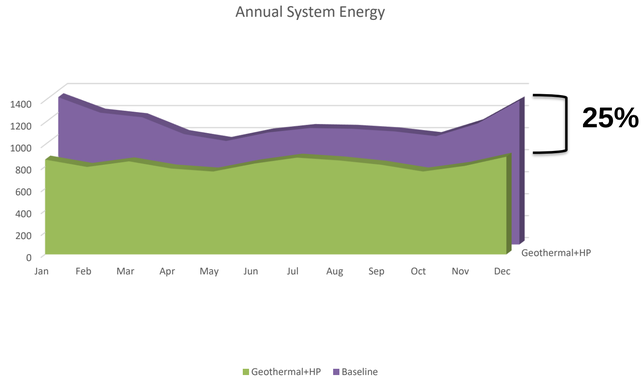
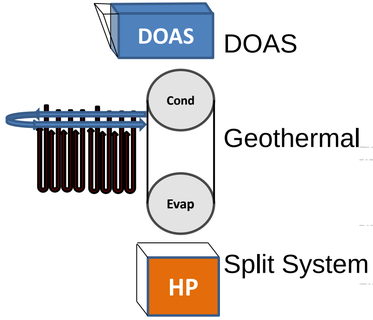




Summary & Conclusion

Recommendation

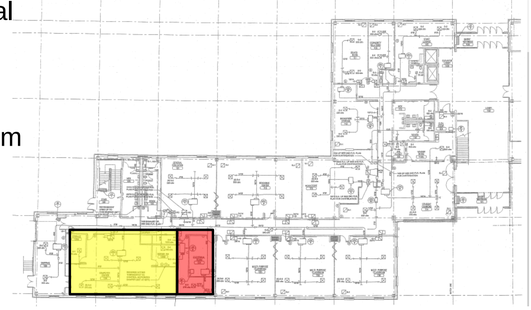


DOAS

Geothermal

Split System

Existing MER



Acknowledgements

- **Dr. Donghuyn Rim – Thesis Advisor**
- **Penn State & the Office of Physical Plant**
- **Friends and Family**
- **PSU AE Department & Class of 2017**

Questions

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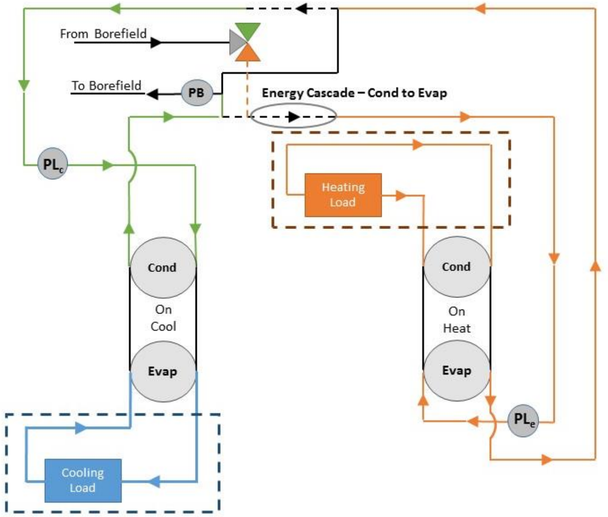
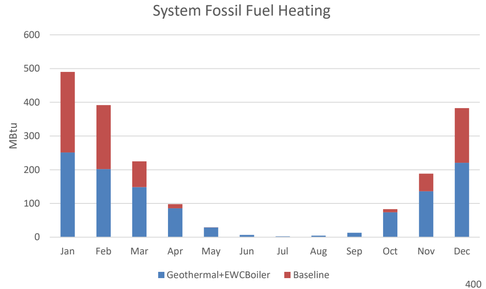
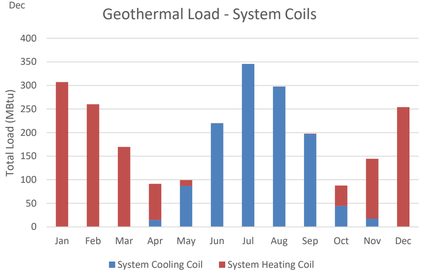
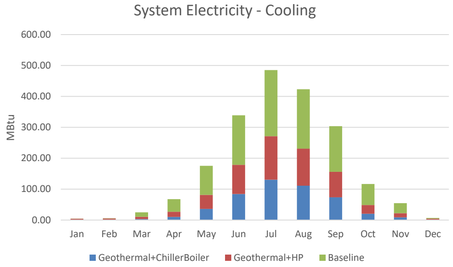
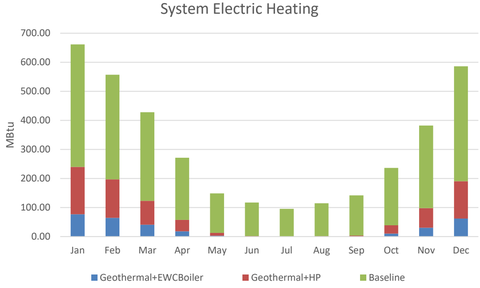


Appendix – Heat and Cooling Load









Appendix - Annual Loads

System Cooling Coil - Geothermal Supplied	Total load (MBtu)	Total load (MBtu)	Total load (MBtu)
Cooling Coil	CC000777	CC000779	CC000781
Date	p_3.18.17 [Proposed-DOASx3-GSHP1.0].aps	p_3.18.17 [Proposed-DOASx3-GSHP1.0].aps	p_3.18.17 [Proposed-DOASx3-GSHP1.0].aps
Jan	0	0	0
Feb	0	0	0
Mar	0.091	0.07	0.046
Apr	5.325	2.093	7.22
May	31.03	12.269	43.36
Jun	78.853	30.122	110.808
Jul	123.913	48.856	172.944
Aug	107.06	40.731	149.675
Sep	70.99	27.024	98.829
Oct	15.893	6.244	22.01
Nov	6.27	2.373	8.782
Dec	0	0	0
Summed total	439.425	169.782	613.673
Total Annual MBtu	**1222.88**		
Total Annual Tons	**101906.67**		
Total Annual kBTU/Hr	**139.60**		

System Heating Coil - Geothermal Supplied	Sensible load (MBtu)	Sensible load (MBtu)	Sensible load (MBtu)
Heating Coil	HC002820	HC002822	HC002824
Date	p_3.18.17 [Proposed-DOASx3-GSHP1.0].aps	p_3.18.17 [Proposed-DOASx3-GSHP1.0].aps	p_3.18.17 [Proposed-DOASx3-GSHP1.0].aps
Jan	109.231	45.041	152.924
Feb	92.52	38.15	129.528
Mar	60.249	24.843	84.349
Apr	27.274	11.246	38.183
May	4.479	1.847	6.271
Jun	0.098	0.04	0.137
Jul	0	0	0
Aug	0.006	0.003	0.009
Sep	0.318	0.131	0.445
Oct	15.453	6.372	21.634
Nov	45.109	18.6	63.152
Dec	90.328	37.246	126.46
Summed total	445.066	183.519	623.093
Total Annual MBtu	**1251.678**		
Total Annual Tons	**104306.50**		
Total Annual kBTU/Hr	**142.89**		

Total System Energy	Total system energy (MBtu)	Total system energy (MBtu)	Total system energy (MBtu)	Total system energy (MBtu)
	p_3.27.17 Proposed2.0.aps	p_3.19.17 Alternative Proposed.aps	p_3.18.17 [Proposed-DOASx3-GSHP1.0].aps	p_3.16.17 Baseline.aps
Date	Geothermal+ ChillerBoiler	ChillerBoiler	Geothermal+ HP	Baseline
Jan	1030.38	1280.64	863.841	1339.67
Feb	932.74	1147.46	797.172	1199.06
Mar	955.56	1095.86	848.004	1157.32
Apr	846.48	909.42	782.836	1004.22
May	776.46	783.46	755.547	942.43
Jun	833.61	824.98	828.633	1019.70
Jul	883.43	865.75	881.603	1059.81
Aug	861.46	845.86	856.314	1052.59
Sep	827.67	818.72	817.083	1029.44
Oct	810.15	840.29	755.801	986.09
Nov	906.42	1006.67	806.934	1102.37
Dec	1045.53	1251.64	890.097	1310.17
Summed total	**10709.88**	**11670.73**	**9883.867**	**13202.87**
% vs Baseline	**0.19**	**0.12**	**0.25**	

Appendix – Geothermal Calcs

Cooling	Limestone	Silt Loam	Difference
Fsc	1.04	1.04	
PLFm	1	1	
Qa [Btu/Hr]	-133713.1	-133713.1	
Rga	0.201	0.225	
Rgd	0.120	0.108	
Rgm	0.225	0.201	
Rb	0.09	0.09	
tg	52	52	
tp	-1.8	-1.8	
ELT	78	78	
LLT	85	85	
qlc [Btu/Hr]	-1532563	-1532563	
Wc [W]	4340	4340	
Lc [ft^2]	**25478.62**	**23562.02**	**-1916.60**
safety 15%	**29300.41**	**27096.33**	

Heating	Limestone	Silt Loam	Difference
Fsc	1.04	1.04	
PLFm	1	1	
Qa [Btu/Hr]	136409	136409.1	
Rga	0.201	0.225	
Rgd	0.120	0.108	
Rgm	0.225	0.201	
Rb	0.09	0.09	
tg	52	52	
tp	1.8	1.8	
ELT	38	38	
LLT	33	33	
qlc [Btu/Hr]	1663419	1663419	
Wc [W]	4340	4340	
Lh [ft^2]	**41053.2971**	**47278.43**	**6225.13**
	47211.29	**54370.19**	

F_{sc} = short-circuit heat loss factor

L_c = required bore length for cooling, ft.

L_h = required bore length for heating, ft.

PLF_m=part-load factor during design month

q_a = net annual average heat transfer to ground, Btu/h.

q_{lc} = building design cooling block load, Btu/h.

q_{lh} =building design heating block load, Btu/h.

R_{ga} = effective thermal resistance of ground (annual pulse), ft-h-$^{\circ}F$ /Btu.

R_{gd} = effective thermal resistance of ground (peak daily pulse: 1 hr min, 4 – 6 hr recommended), ft-h-$^{\circ}F$ /Btu.

R_{gm} = effect thermal resistance of ground (monthly pulse), ft-h-$^{\circ}F$ /Btu.

R_b = thermal resistance of bore, ft-h-$^{\circ}F$/Btu.

t_g = undisturbed ground temperature, $^{\circ}F$

t_p = temperature penalty for interference of adjacent bores, $^{\circ}F$

t_{wi} = liquid temperature at heat pump inlet, $^{\circ}F$

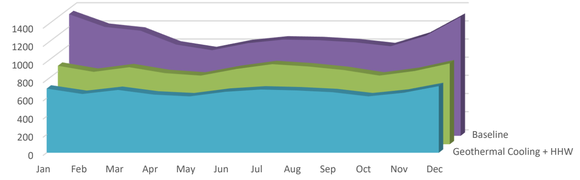
t_{wo} = liquid temperature at heat pump outlet, $^{\circ}F$

W_c = system power input at design cooling load, W

W_h = system power input at design heating load, W

Appendix – Z_Proposal

Annual Heating/Cooling	Fossil Fuel (Mbtu)		Electric (Mbtu)		Cost		Total
	Heating	Cooling	Heating	Cooling	Heating	Cooling	
Baseline	741.313	-	2777.14	967.48	$ 81,959.2	$ 25,802.1	$ 107,761.22
Mech. Proposed	-	-	657.49	558.86	$ 17,534.9	$ 14,904.4	$ 32,439.27
Chiller-Boiler	1568.54	-	918.47	462.17	$ 41,198.7	$ 12,325.9	$ 53,524.56
Geothermal w/ CHW/HW	1173.29	-	305.34	480.87	$ 20,637.7	$ 12,824.5	$ 33,462.21
Geothermal+VAV(Reheat)	-	-	1512.396	924.719	$ 40,334.8	$ 24,661.8	$ 64,996.54
5th Alt. System	**539.384**	**-**	**-**	**510.285**	**$ 5,744.0**	**$ 13,609.0**	**$ 19,353.05**



Annual System Energy

Geothermal Cooling + HHW Geothermal+HP Baseline

	Total system energy (MBtu) Geothermal+ChillerBoiler	Total system energy (MBtu) Chiller-Boiler	Total system energy (MBtu) Geothermal+HP	Total system energy (MBtu) Baseline	Total system energy (MBtu) Geothermal Cooling + HHW
Summed total	10709.88	11670.73	9883.867	13202.87	8035.876
% vs Baseline	0.19	0.12	0.25	-	0.39

Cooling	Limestone	Silt Loam	Difference
Fsc	1.04	1.04	
PLFm	1	1	
Qa [Btu/Hr]	-44.61	-44.61	
Rga	0.201	0.225	
Rgd	0.120	0.108	
Rgm	0.225	0.201	
Rb	0.09	0.09	
tg	52	52	
tp	-1.8	-1.8	
ELT	78	78	
LLT	85	85	
qlc [Btu/Hr]	-1352750	-1352750	
Wc [W]	4340	4340	
Lc [ft]	21660.21	19864.37	-1795.84
safety 15%	24909.24	22844.02	