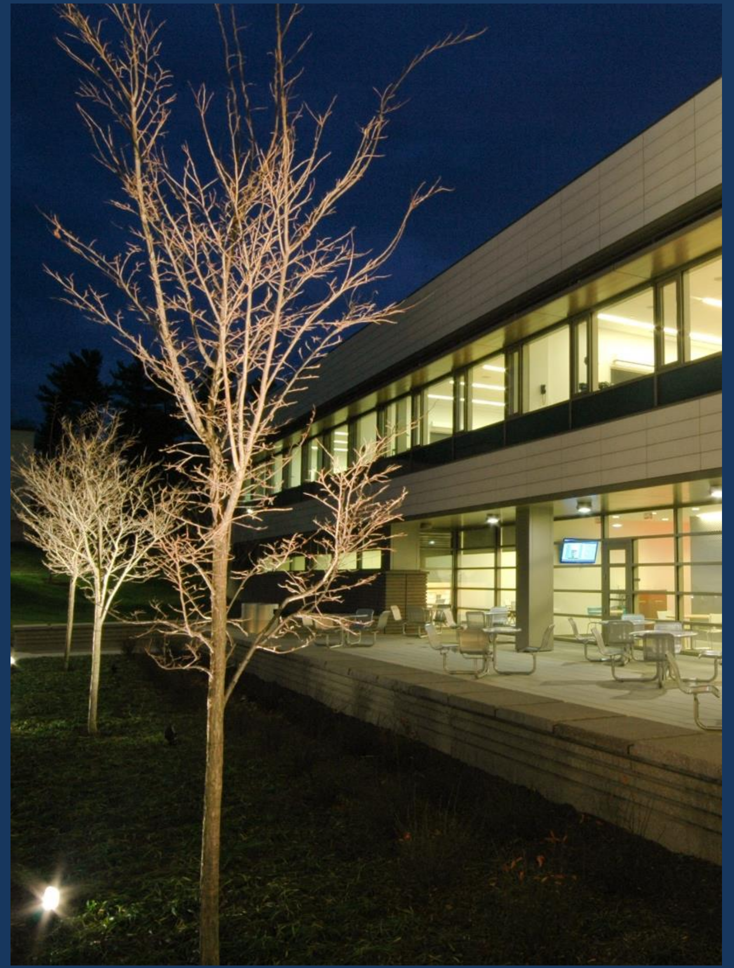
The Gaige Building

Matthew Neal's Senior Thesis



Matthew Neal
Mechanical Option
Dr. Stephen Treado, Adviser

The Gaige Building
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Overview

The Gaige Technology and Business Innovation Building

- Reading, PA – PSU Berks Campus

The Gaige Building

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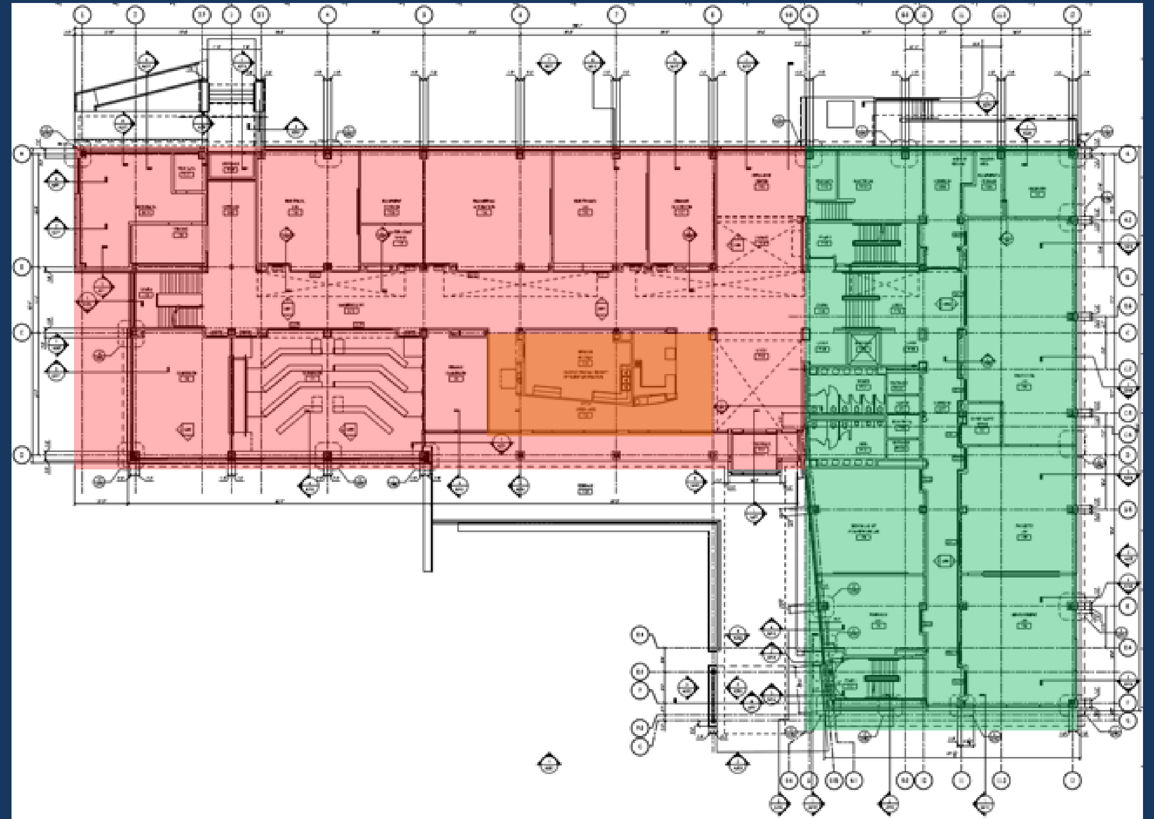
Overview

The Gaige Technology and Business Innovation Building

- Reading, PA – PSU Berks Campus
- Classrooms, Labs and Offices
- ~ 64,000 SF



- Constructed in 2010/2011
- $25.7 Million
- LEED Gold

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Existing Conditions

Mechanical Design

Overview

Existing Conditions

Geothermal Depth

System Alternatives

Energy & Emissions

Life Cycle Cost Analysis

Acoustics

Onsite Measurements

Heat Pumps

Campus-wide Geothermal

Conclusions

- Packaged Roof-Top Units
  - VAV with Reheat
  - CO_2 and Occupancy Sensors
- Fin tube / Radiant Panel Heating
- Natural Gas & Electricity Utilities

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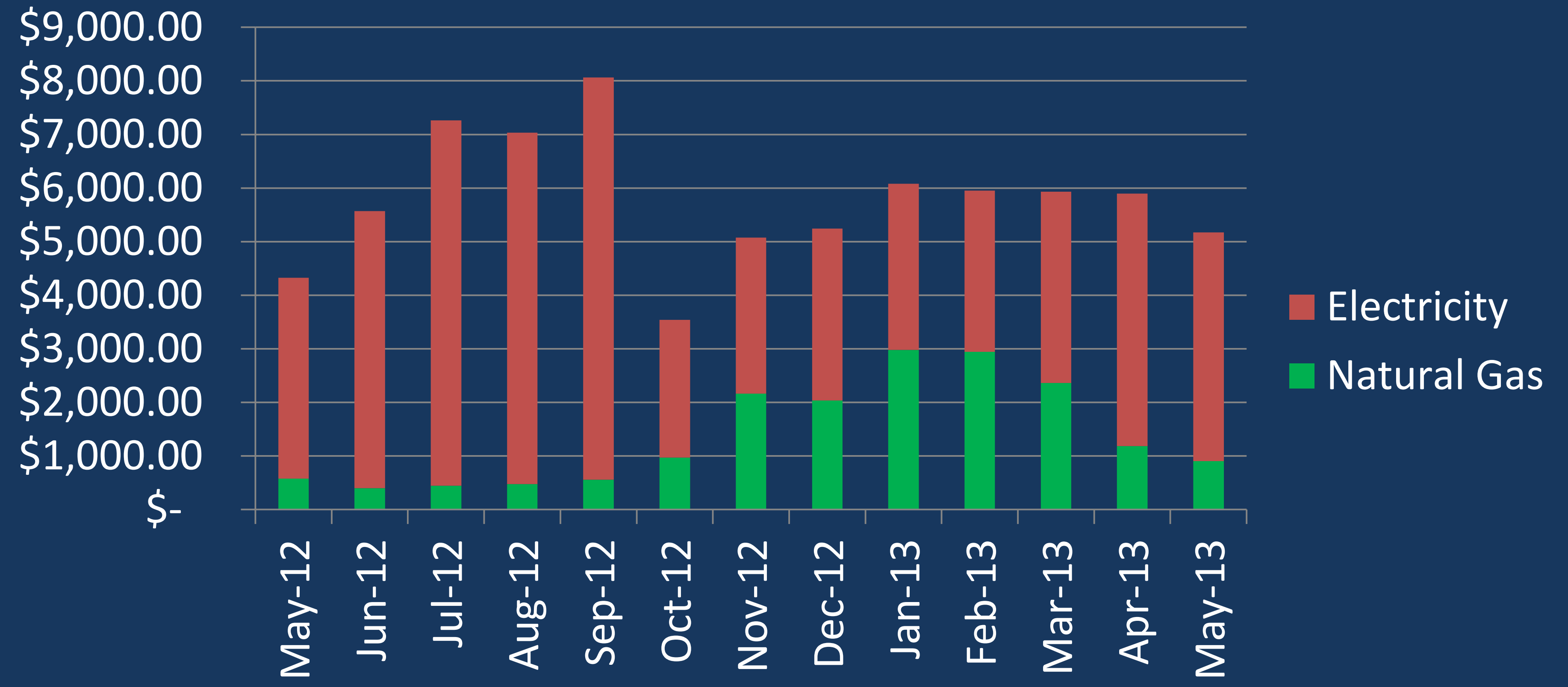
Existing Conditions

Energy Model

- Overview
- Existing Conditions
- Geothermal Depth
  - System Alternatives
  - Energy & Emissions
  - Life Cycle Cost Analysis
- Acoustics
  - Onsite Measurements
  - Heat Pumps
- Campus-wide Geothermal
- Conclusions

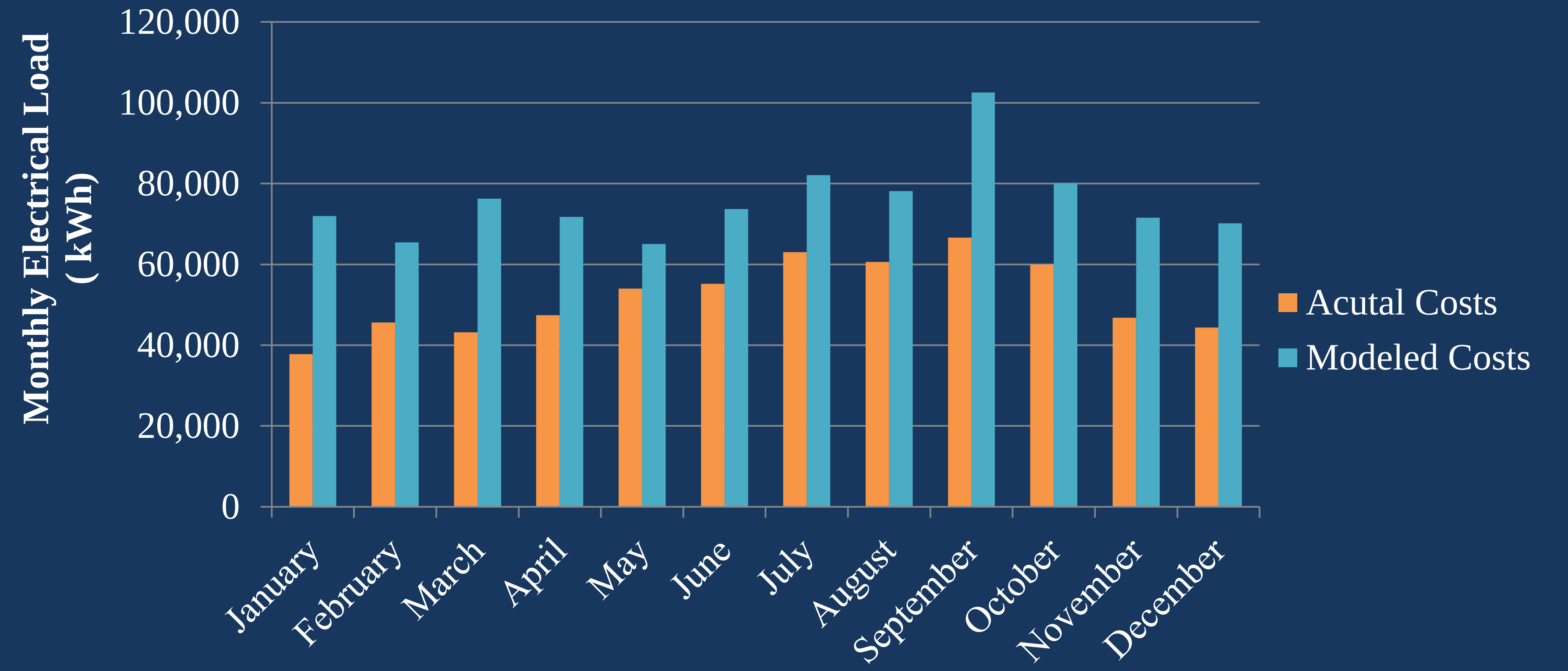
- Initially modeled using Trace 700
  - Based on engineer's model

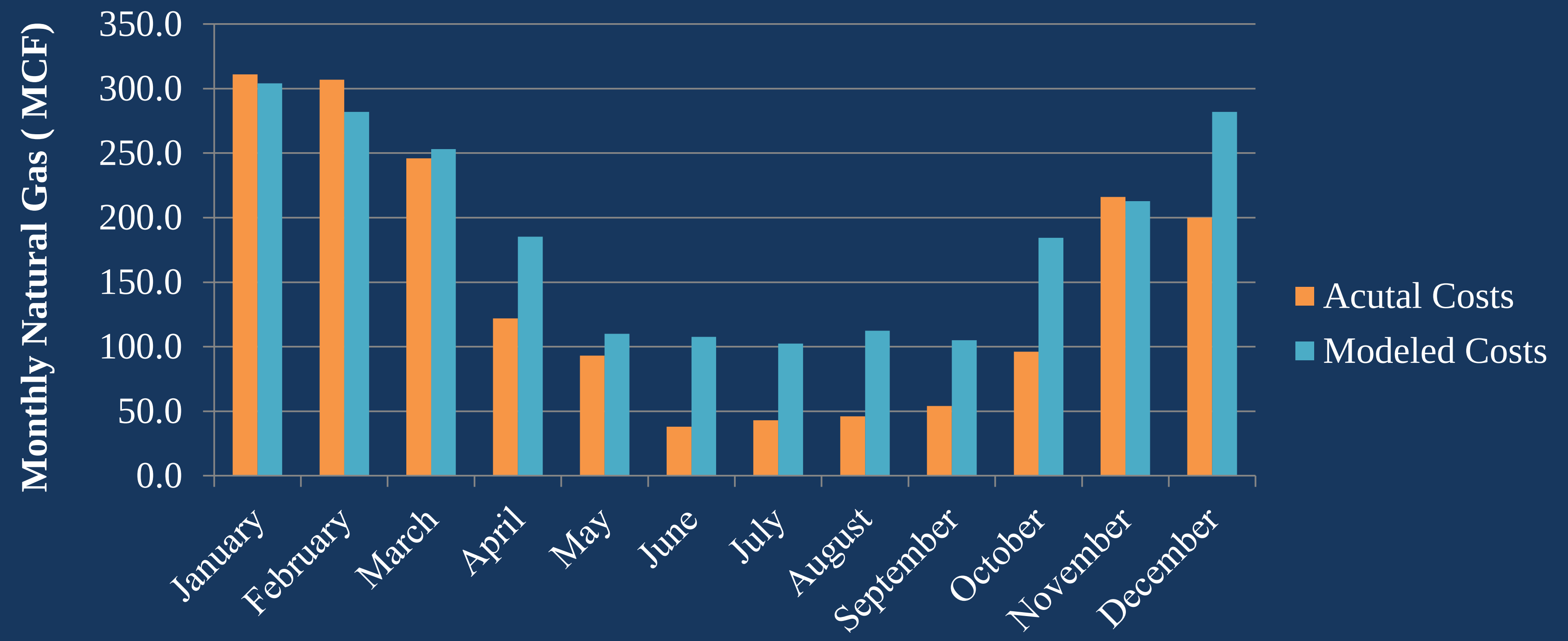


Existing Conditions

Energy Model

- Initially modeled using Trace 700
  - Based on engineer's model
- Compared to Utility Data





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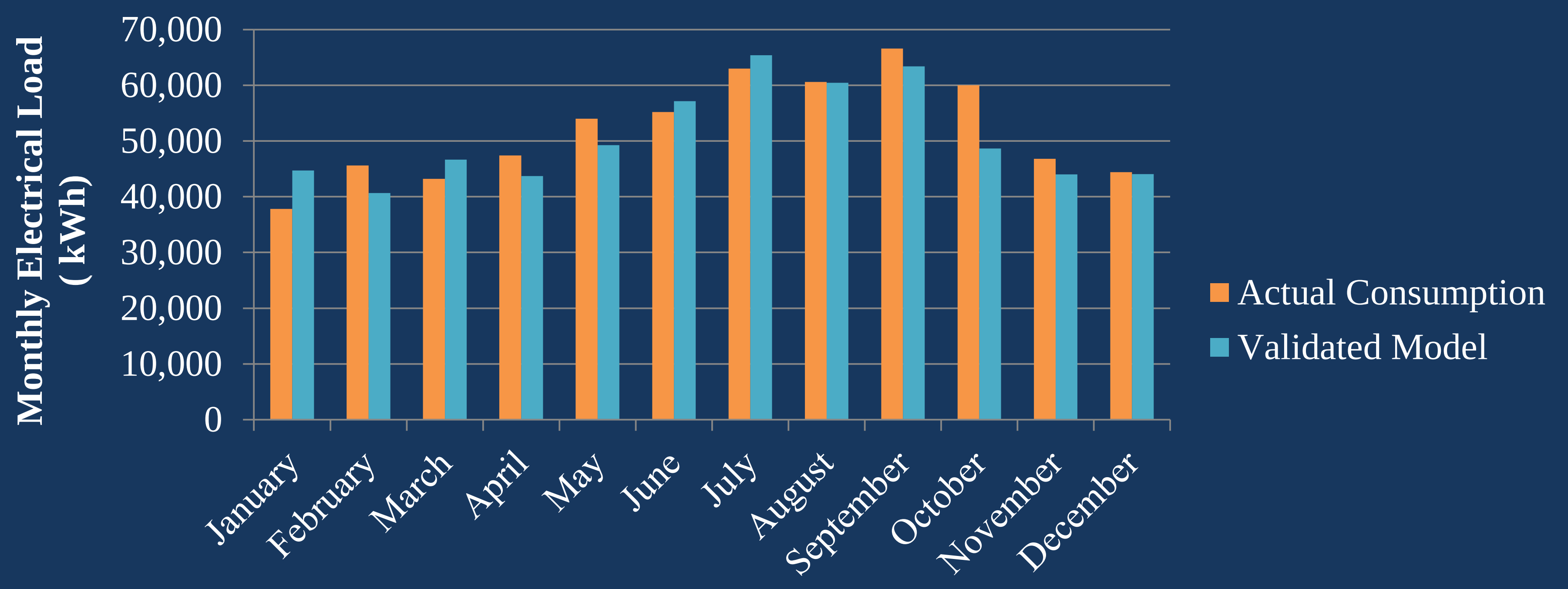
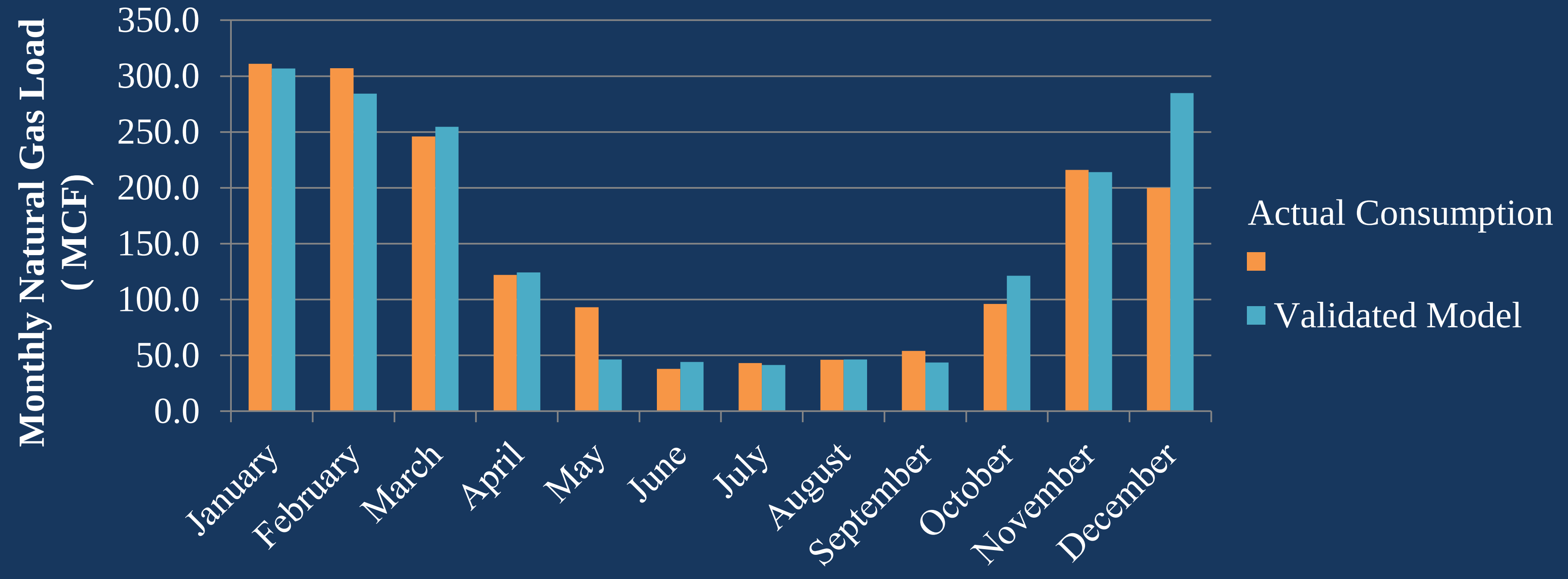
Existing Conditions

Energy Model

- Initially modeled using Trace 700
  - Based on engineer's model
- Compared to utility data
- Validated to utility data
  - 2.1 % maximum error





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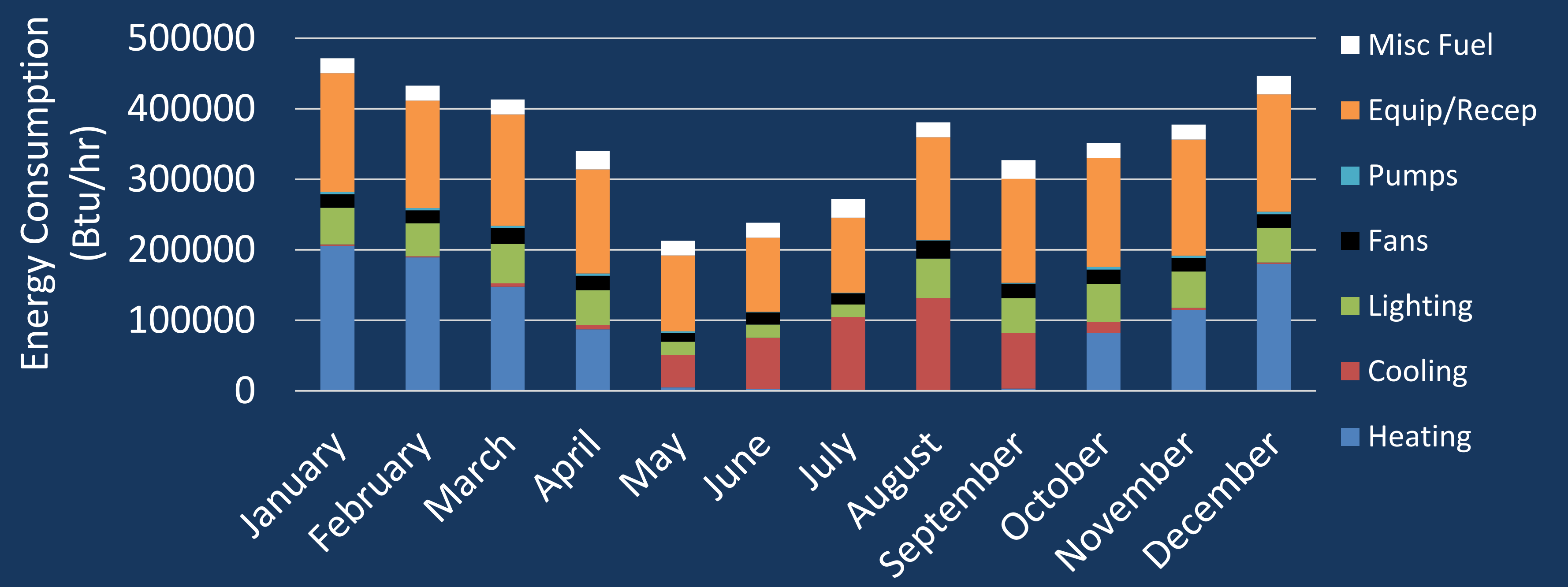
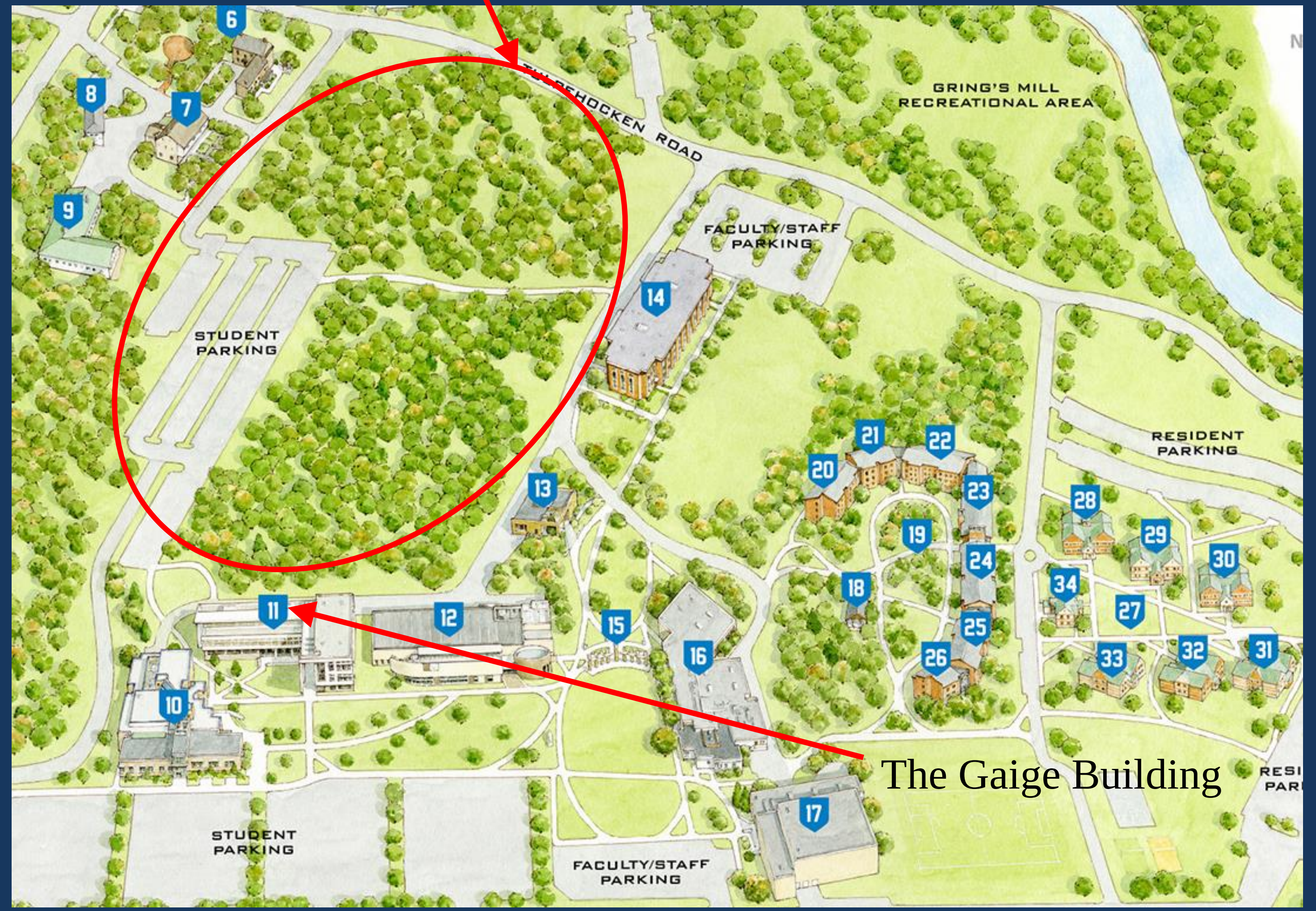
Initial Motivation

- Large open space
- Potential energy savings
- Potential emissions reductions
- Life-costs of system



Open area surrounding Gaige Building



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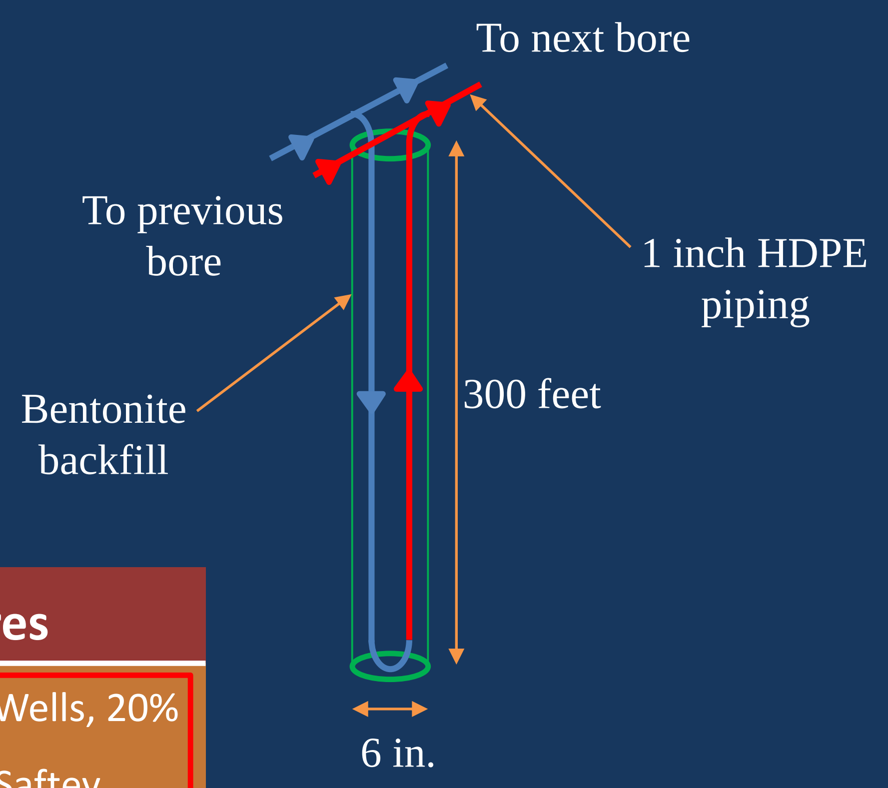
Geothermal Depth

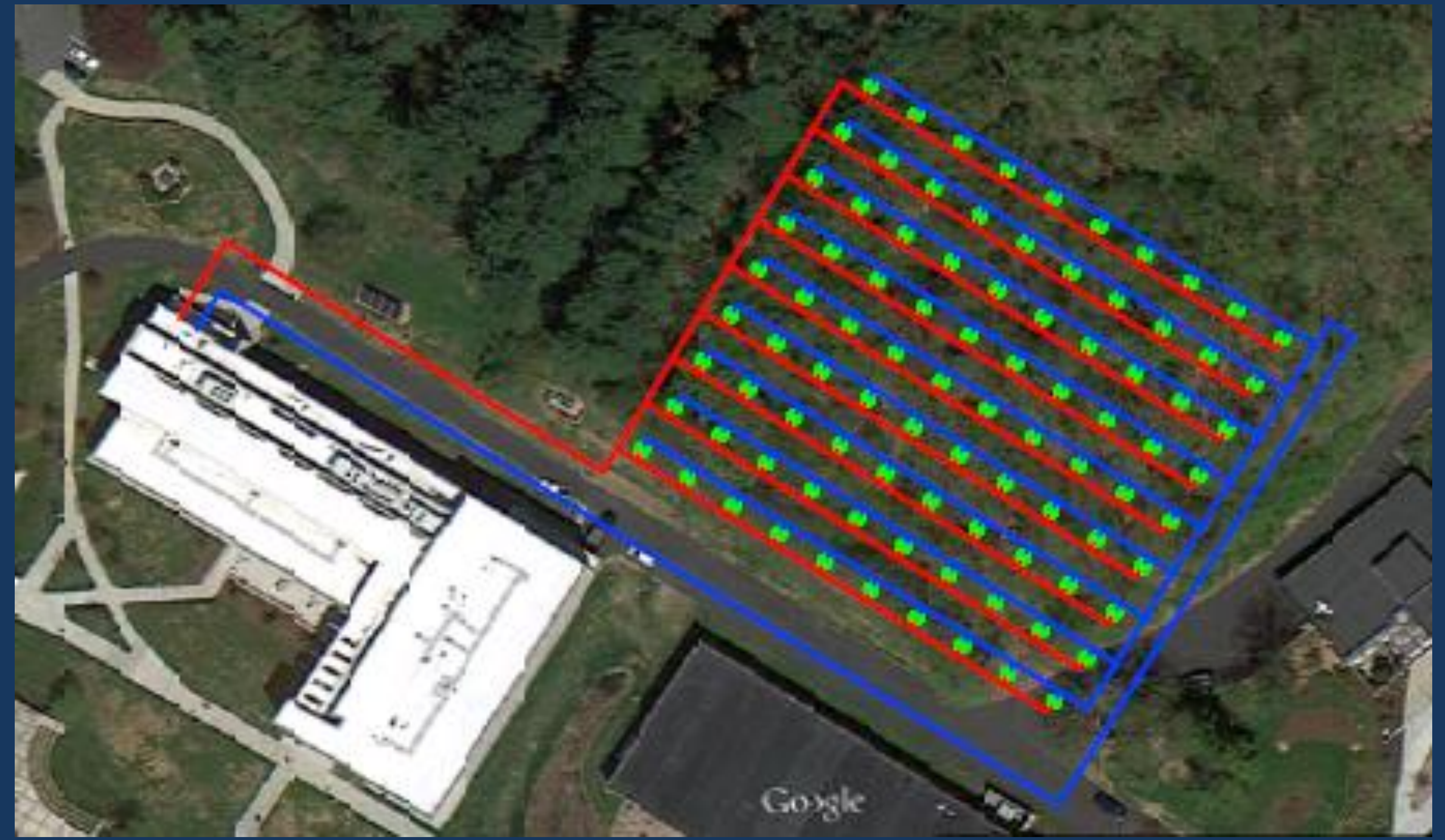
Alternative 1: Vertical Loop System

- 23,636 feet of well required
- 100 required vertical wells
  - 20% safety
  - 300' well depth
  - Costs per well - $3,714.25



Required Number of Vertical Bores

Well Depth	Required Bore Length	# of Wells	# of Wells, 20% Saftey
100	23636.4	237	284
200	23636.4	119	142
300	23636.4	79	95
400	23636.4	60	71



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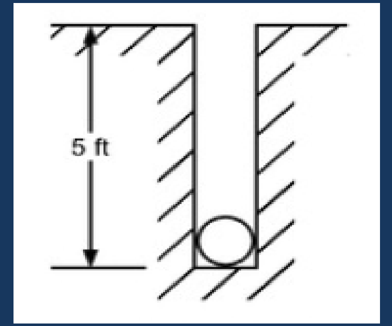
Geothermal Depth

Alternative 2: Horizontal Loop System

- 28,550 ft. of horizontal loops
  - Based on 20% safety
  - Cost per 300': **$3,435.62**



Required Number of Horizontal Loops		
Loop Length	Number of Loops	Total Length
800	20	16000
775	1	775
750	4	3000
700	5	3500
675	1	675
650	4	2600
400	5	2000
	Total Length	28550

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Geothermal Depth

Alternative Cost Comparisons

- Increased first costs:
  - Savings from original design
  - Added geothermal costs
  - Time & Location adjustments

Vertical - Increased First-Costs

Cost Item	Amount
Increased First Cost - General	$ 655,736.06
Location Multiplier - Reading PA	0.988
Increased First Cost - Reading	$ 647,867.23
Savings from Original Design - 2009	$ 484,710.00
Time Multiplier - 2014 to 2009	0.889
Savings from Original Design - 2014	$ 545,230.60
Overall First Cost Increase:	$ 102,636.63

Horizontal - Increased First-Costs

Cost Item	Amount
Increased First Cost - General	$ 601,959.52
Location Multiplier - Reading PA	0.988
Increased First Cost - Reading	$ 594,736.01
Savings from Original Design - 2009	$ 484,710.00
Time Multiplier - 2014 to 2009	0.889
Savings from Original Design - 2014	$ 545,230.60
Overall First Cost Increase:	$ 49,505.41

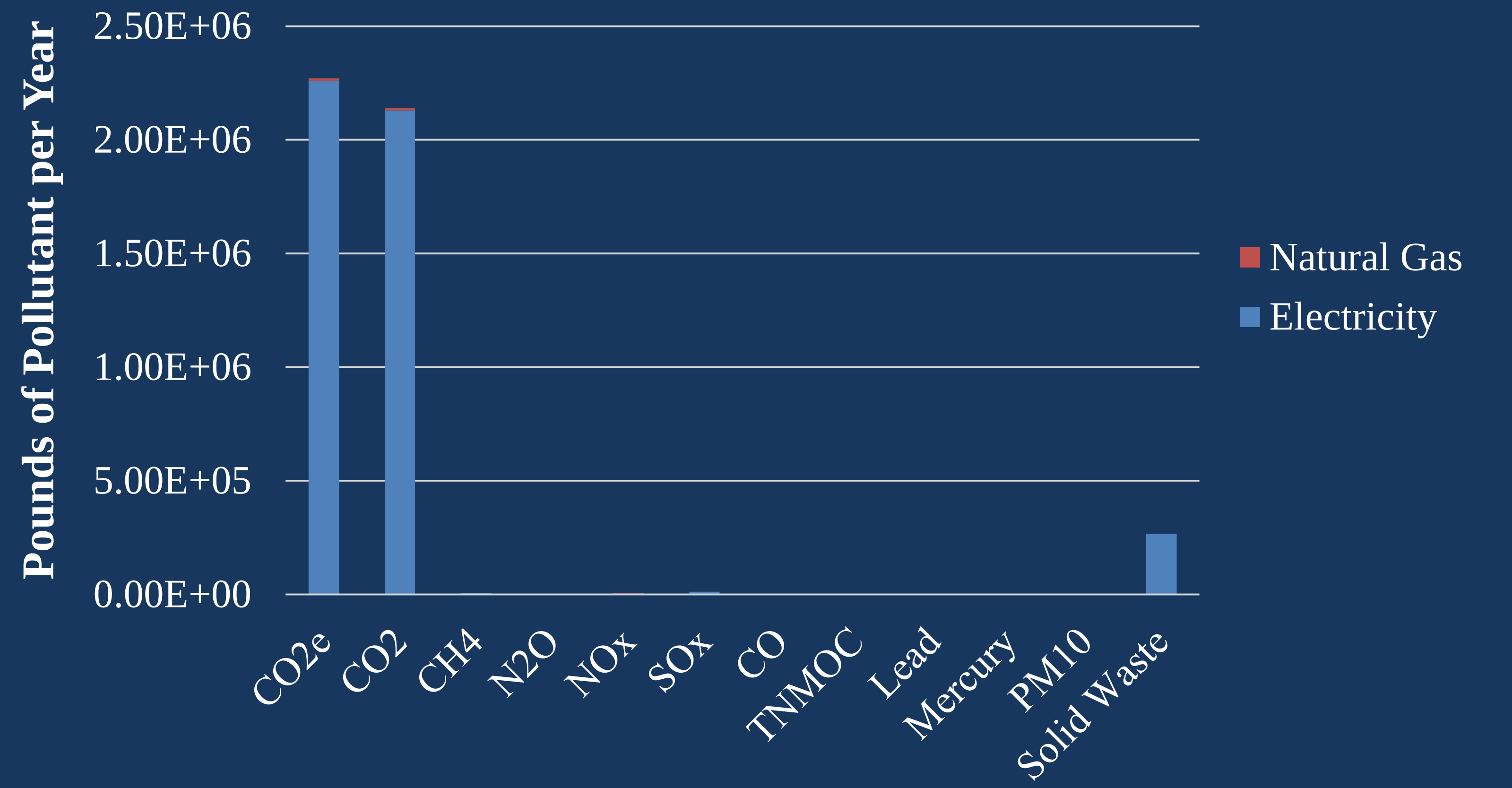
Geothermal Depth

Annual Emissions Reductions

- Little change in emissions
  - Decreased natural gas emissions
  - Increased electricity emissions

Difference in Total Annual Emissions

Pollutant	Original Emissions (lb/yr)	Geothermal Emissions (lb/yr)	Decrease %
CO2e	2321124.8	2270409.1	2.18%
CO_2	2194071.2	2140470.1	2.44%
CH4	4526.3	4661.8	-2.99%
NOx	3896.3	3905.4	-0.23%
SOx	10799.6	11128.1	-3.04%
CO	1173.6	1117.3	4.80%
Solid Waste	258316.8	266191.0	-3.05%



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Geothermal Depth

Annual Energy Savings

Overview

Existing Conditions

Geothermal Depth

System Alternatives

Energy & Emissions

Life Cycle Cost Analysis

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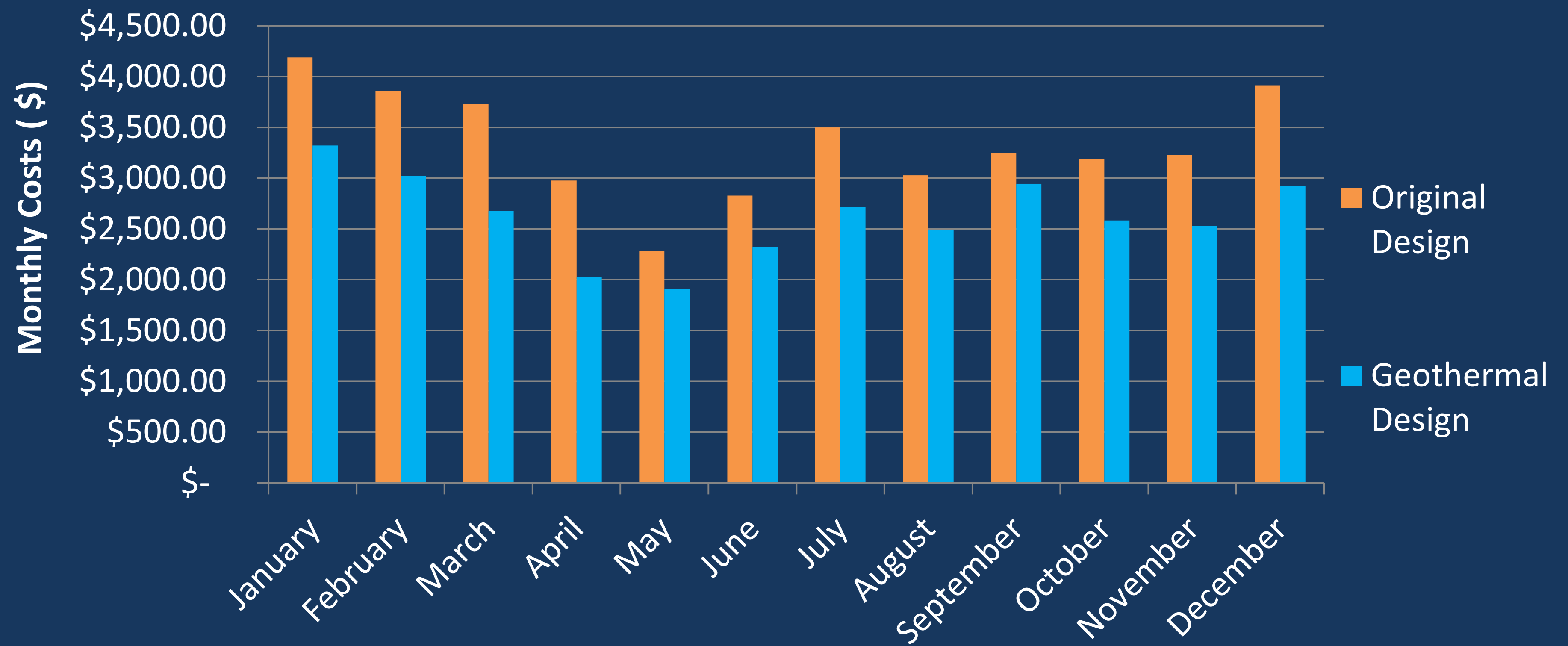
Campus-wide Geothermal

Conclusions

- Almost eliminated natural gas consumption
- Similar annual electricity consumption
  - Heat pump operation
- **Annual Energy Savings: $8,494.00**



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- Overview
- Existing Conditions
- Geothermal Depth
  - System Alternatives
  - Energy & Emissions
  - Life Cycle Cost Analysis
- Acoustics
  - Onsite Measurements
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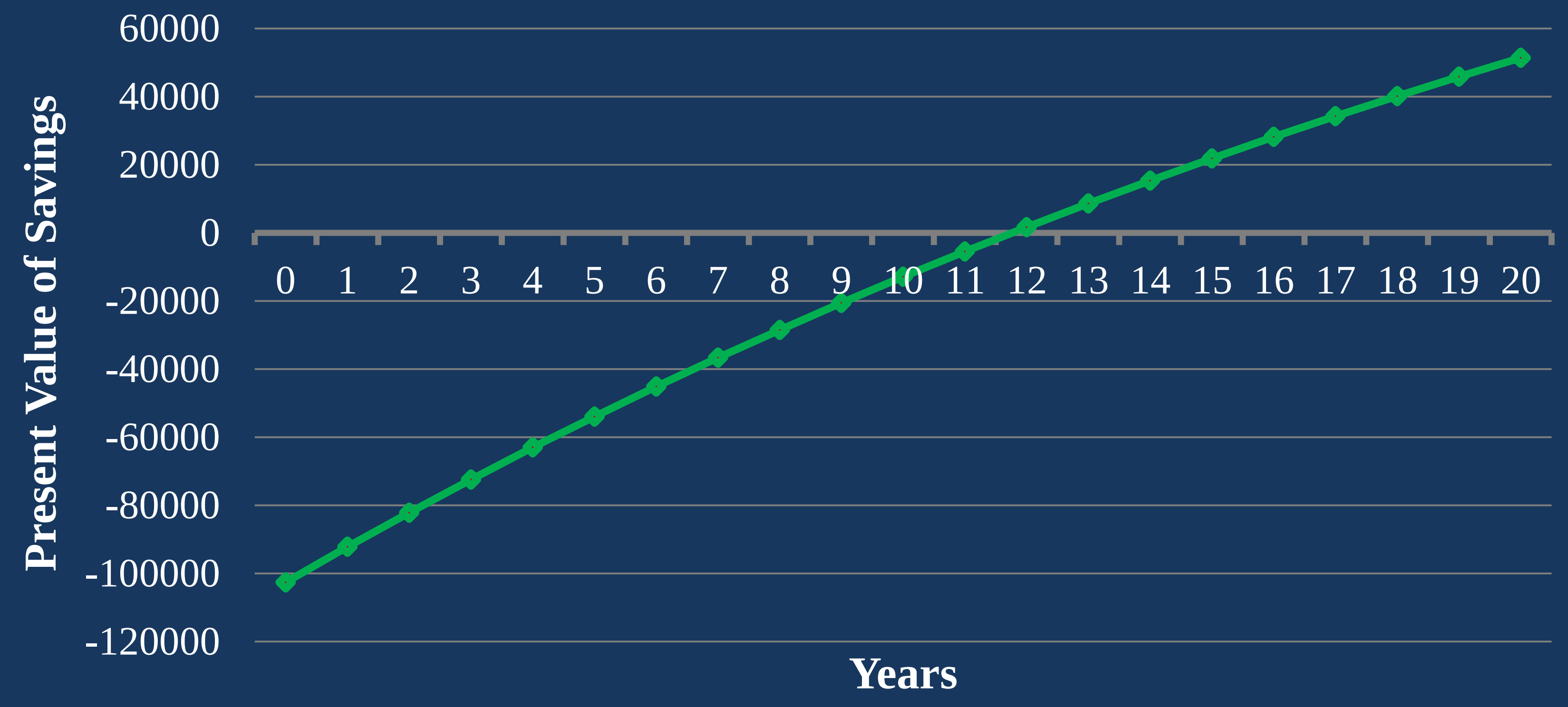
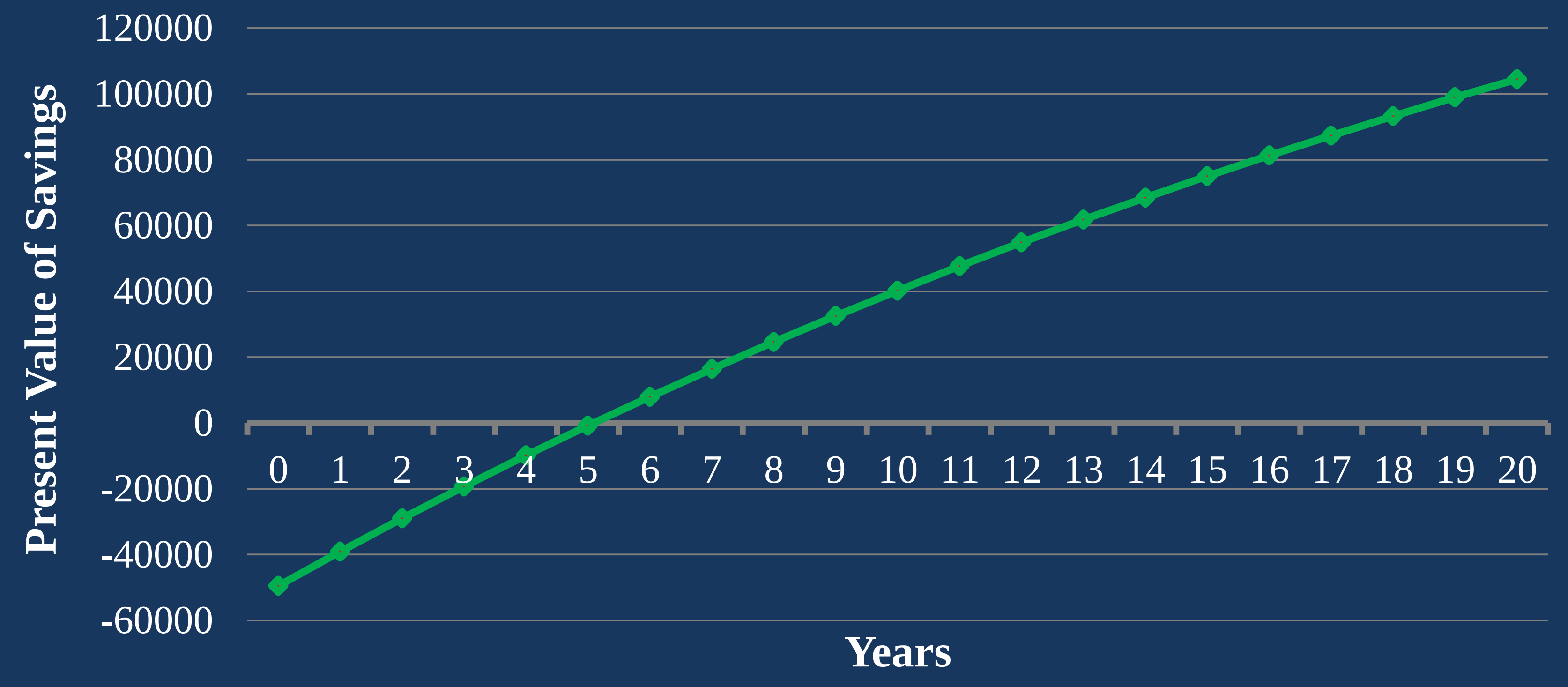
Life Cycle Cost Analysis

- Vertical Well Design:
  - Simple: 12.1 years
  - Discounted: **12.7 years**



- Horizontal Loop Design:
  - Simple: 5.8 years
  - Discounted: **6.1 years**



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Geothermal Depth

- Overview
- Existing Conditions
- **Geothermal Depth**
  - System Alternatives
  - Energy & Emissions
  - **Life Cycle Cost Analysis**
- Acoustics
  - Onsite Measurements
  - Heat Pumps
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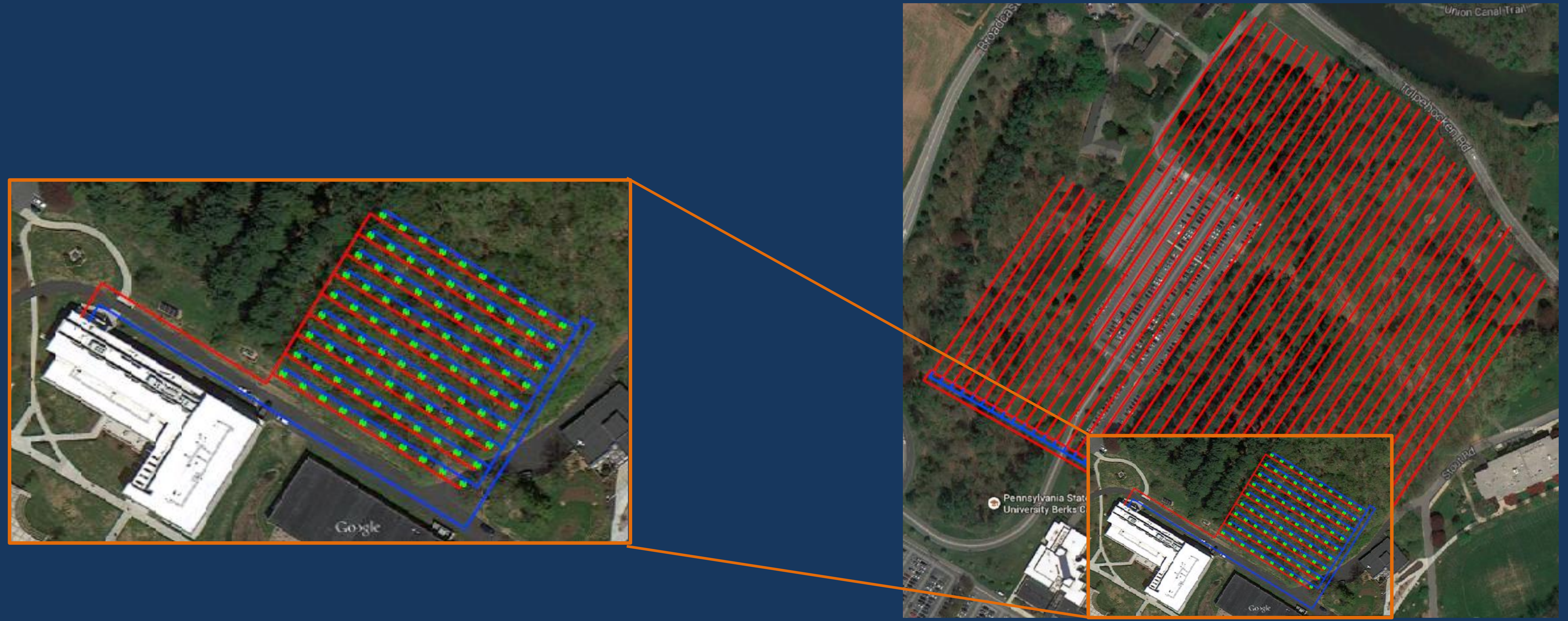
- Conclusions

Alternative Selection

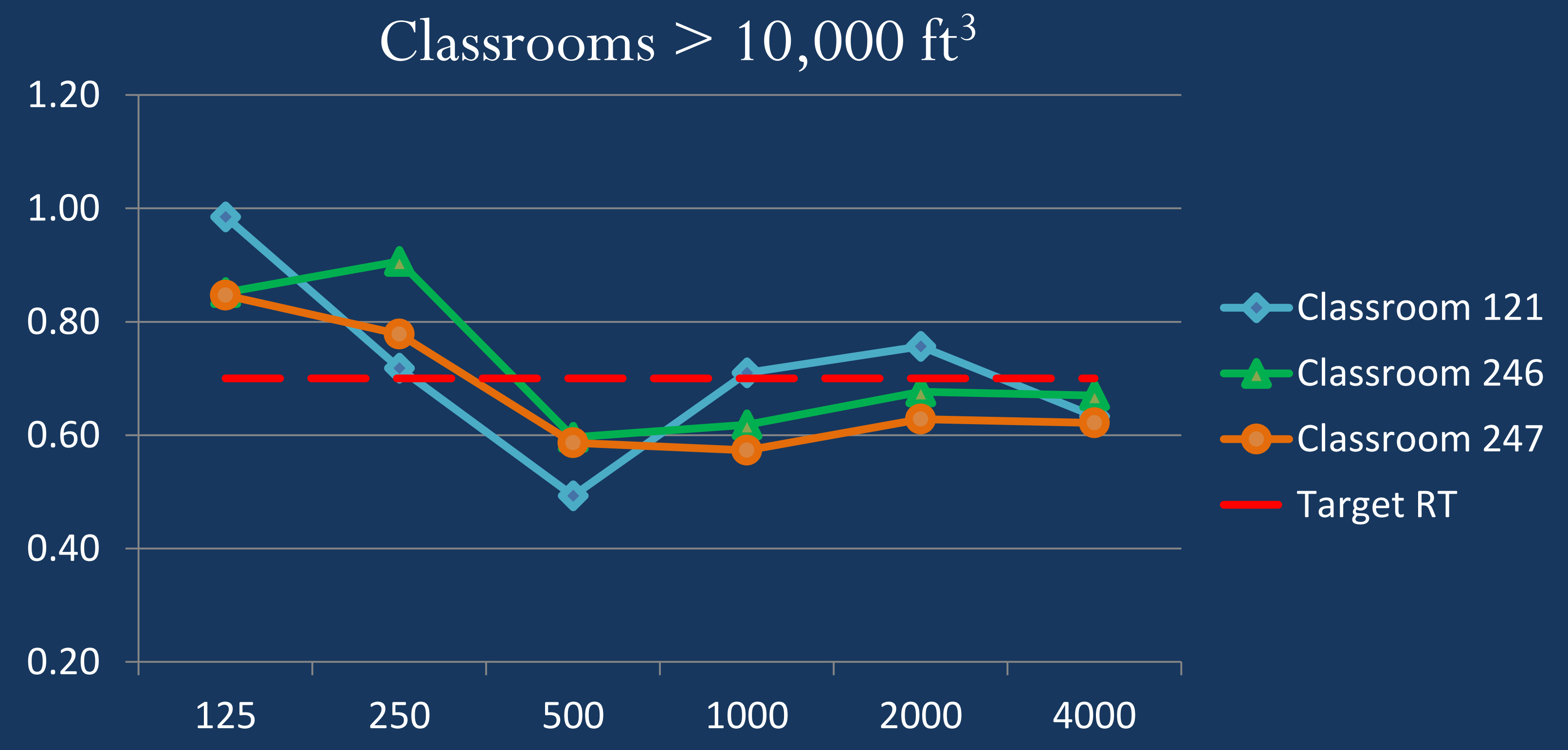
- Horizontal Design
  - Best Payback – 6.1 years
  - Large space requirements
- Vertical Design
  - Favorable Payback – 12.7 years
  - Less space requirements

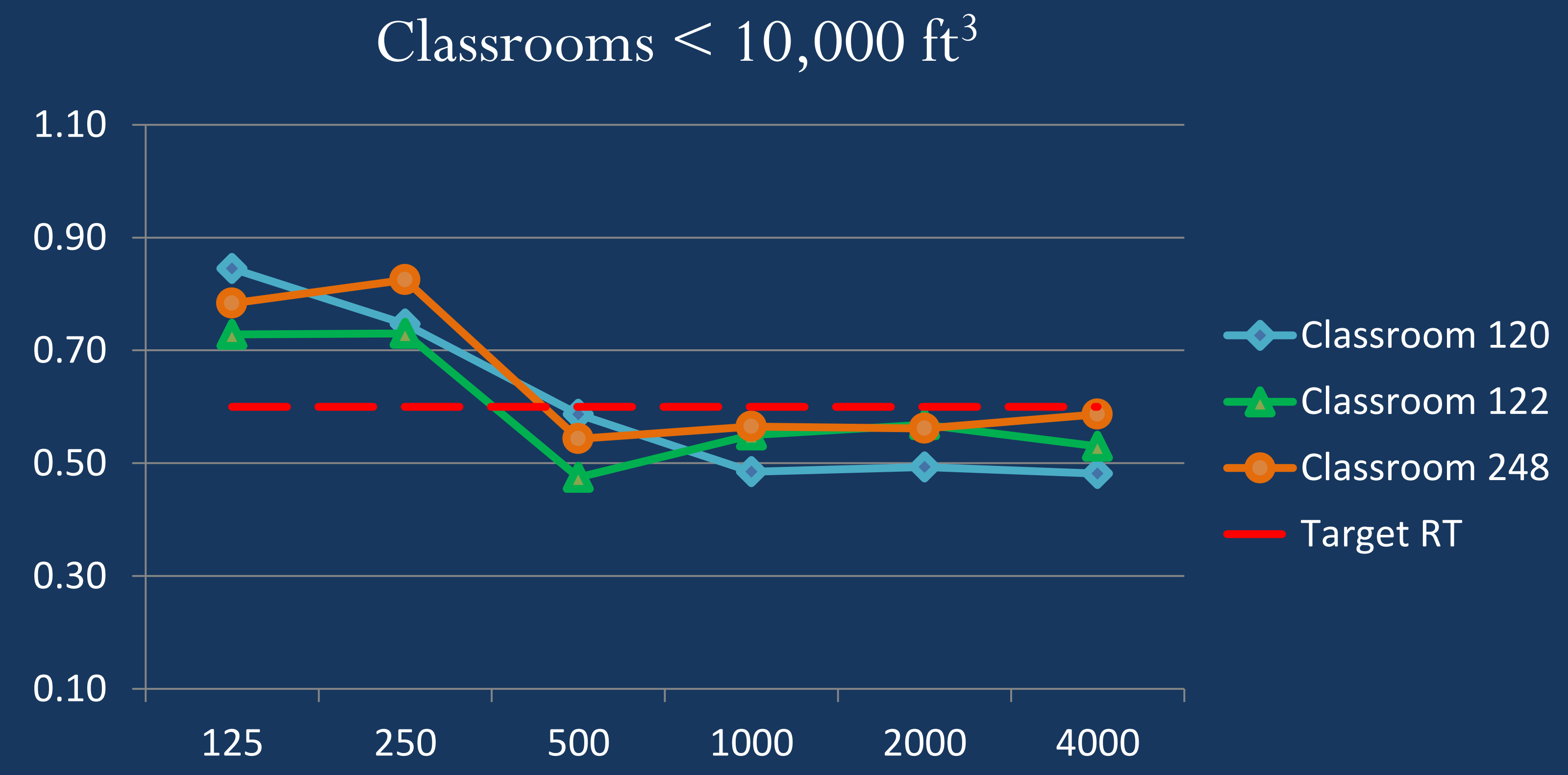


Acoustics Breadth

Onsite Measurements

- Comparisons to ANSI S12.60
- Reverberation Time (T30)
  - 0.7 for > 10,000 ft^3
  - 0.6 for < 10,000 ft^3





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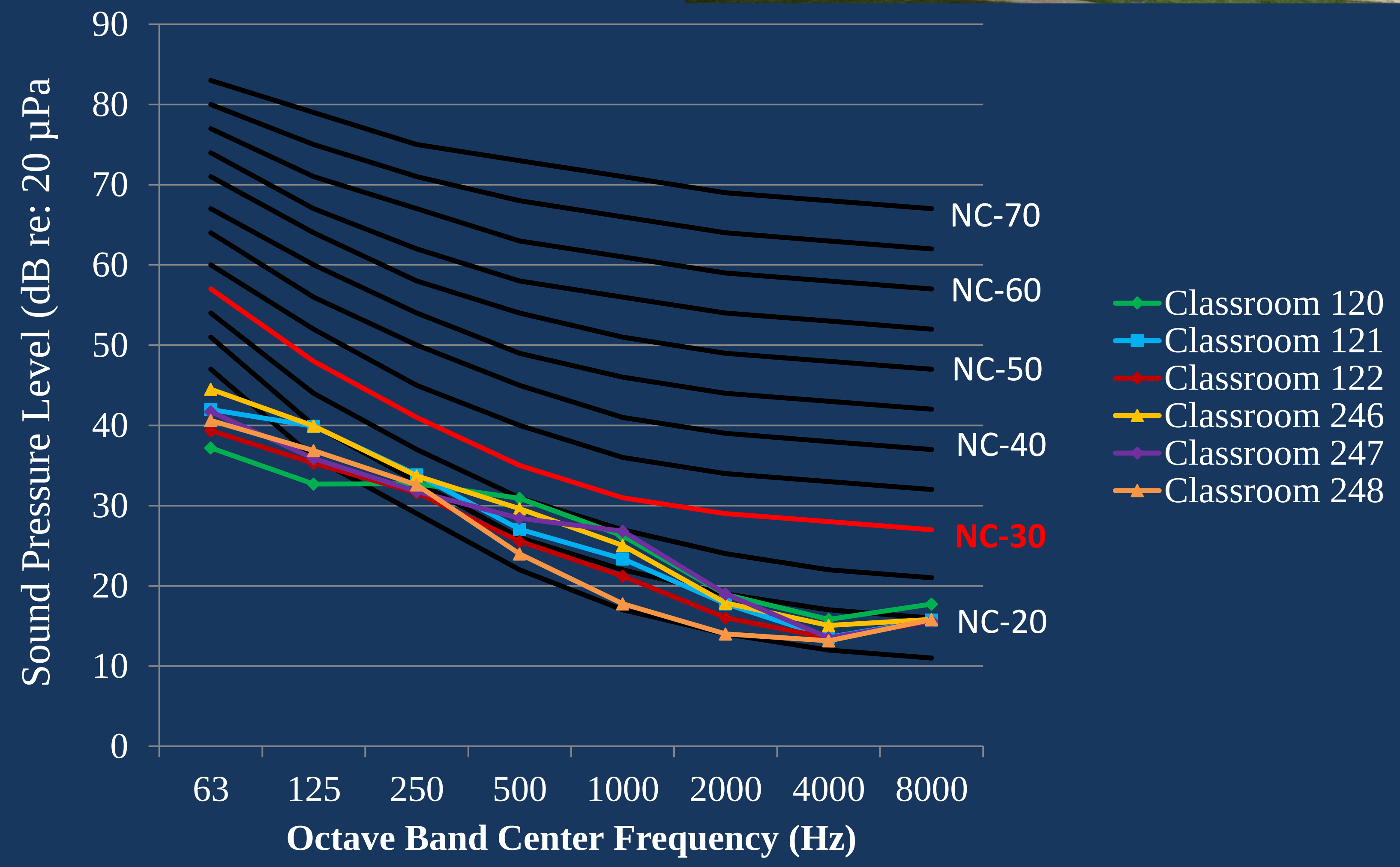
Acoustics Breadth

Onsite Measurements

- Comparisons to ANSI S12.60
- Background Noise Level (BNL)
  - NC – 30



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Acoustics Breadth

Onsite Measurements

- Overview
- Existing Conditions
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  - System Alternatives
  - Energy & Emissions
  - Life Cycle Cost Analysis
- Acoustics
  - Onsite Measurements
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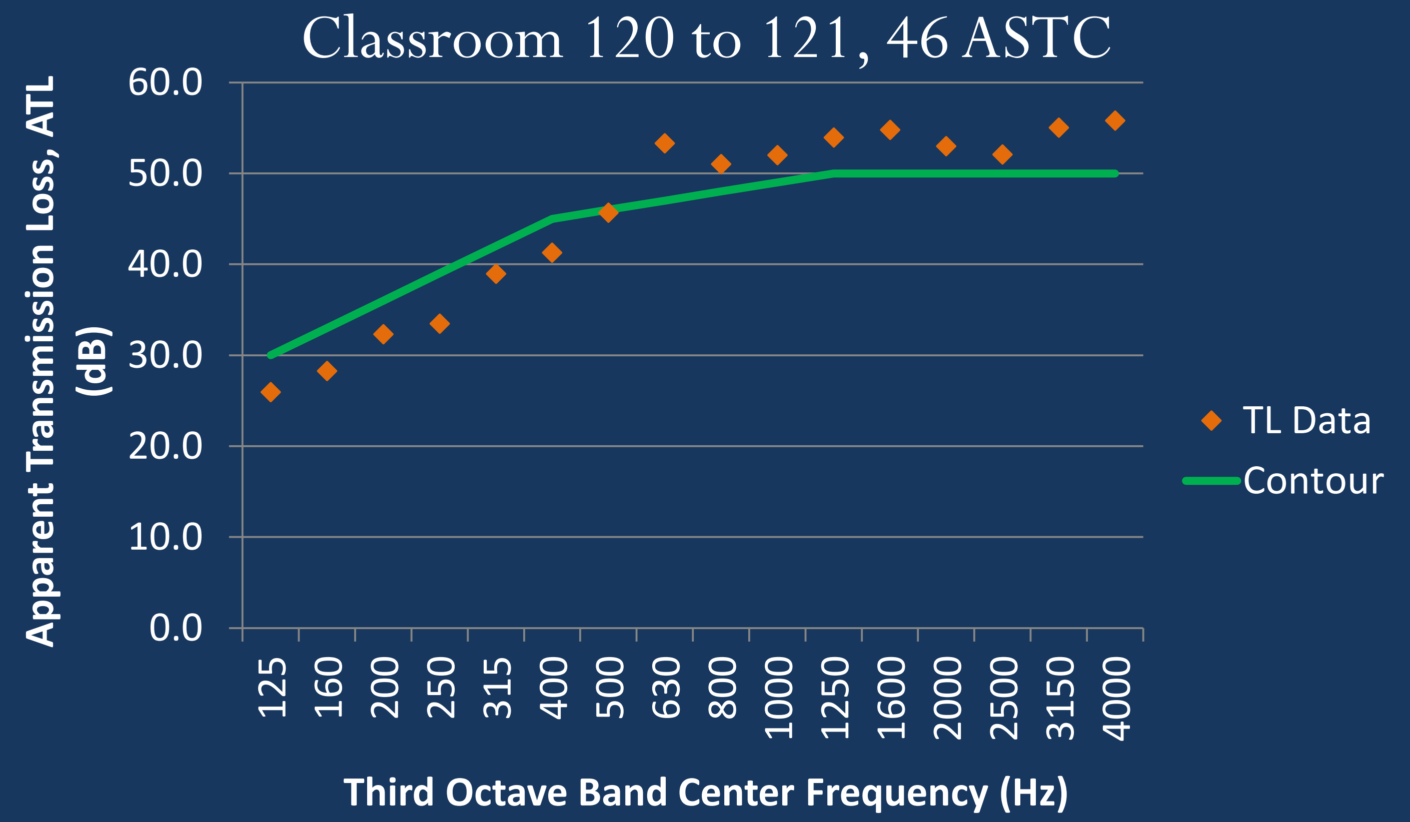
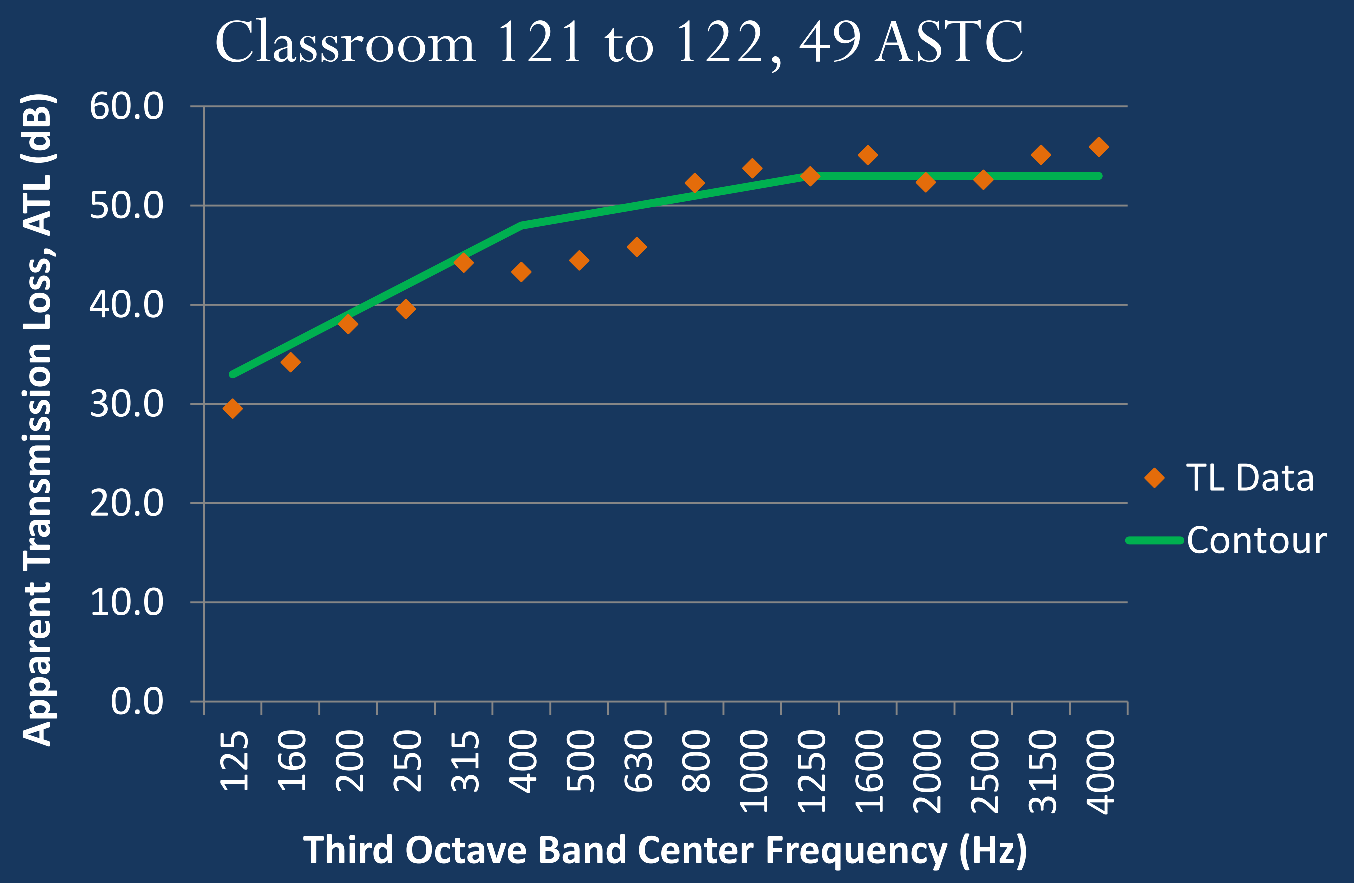
- Comparisons to ANSI S12.60
- Transmission Loss (TL) & Sound Trans. Coefficient (STC)
  - STC – 50 between classrooms





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Acoustics Breadth

Onsite Measurements

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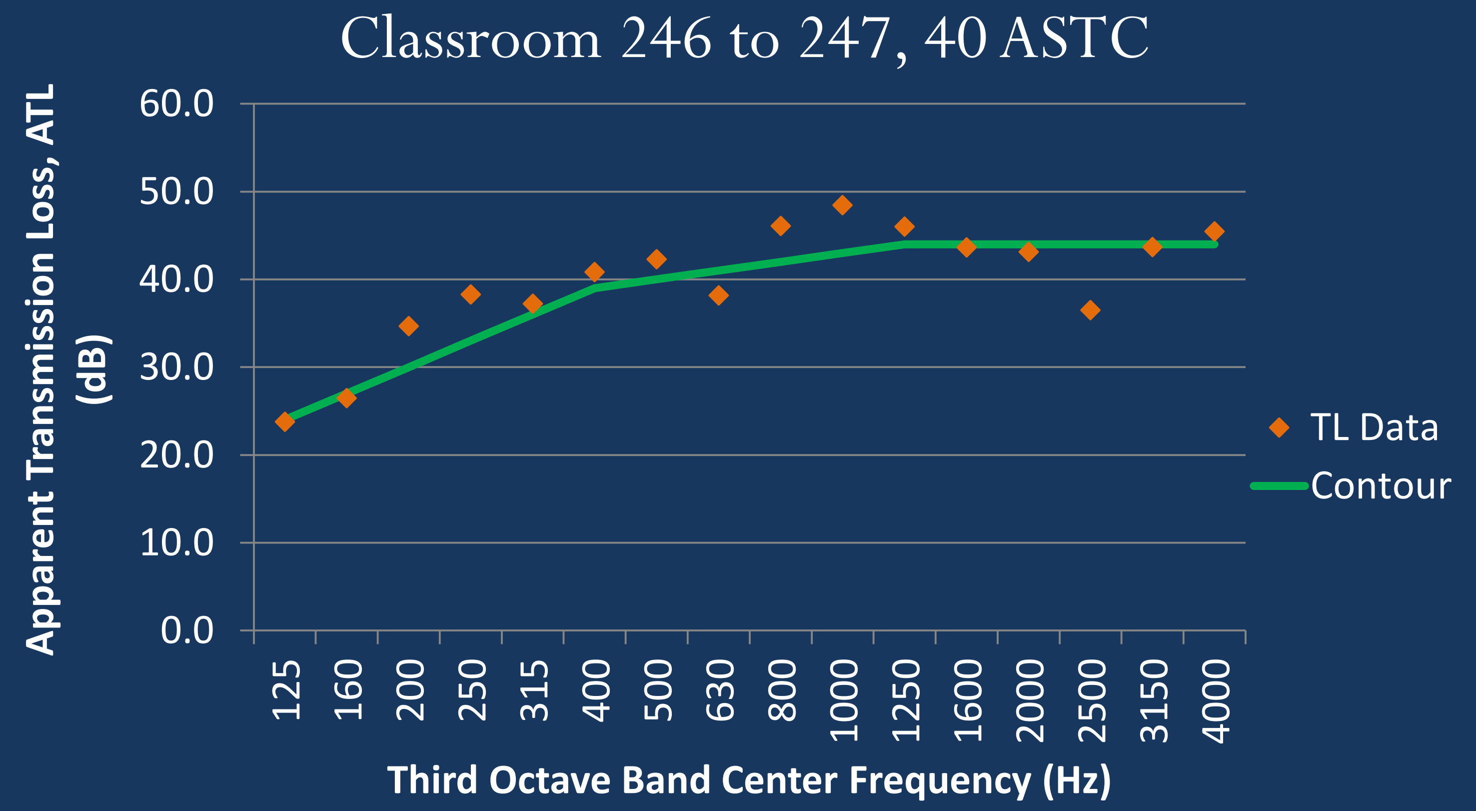

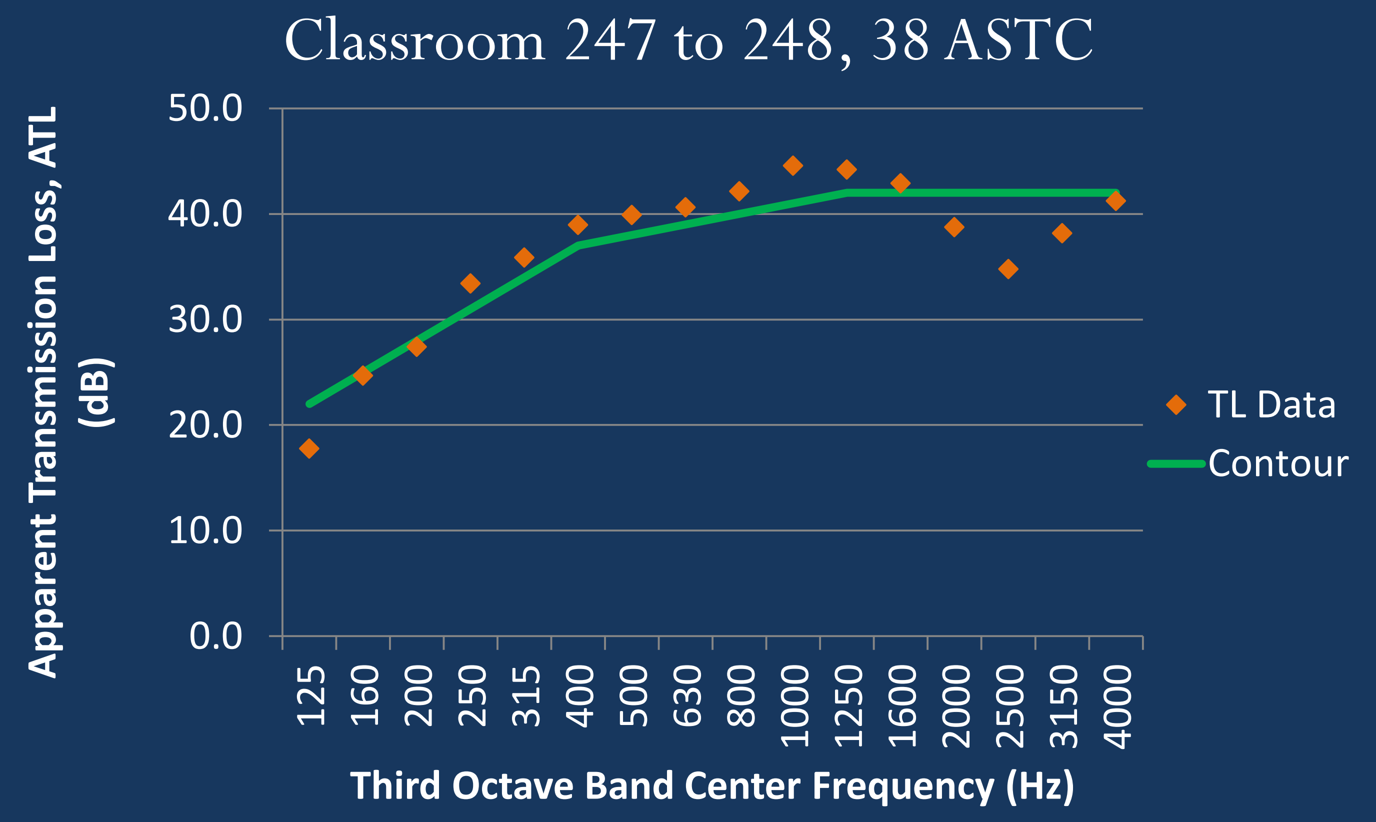

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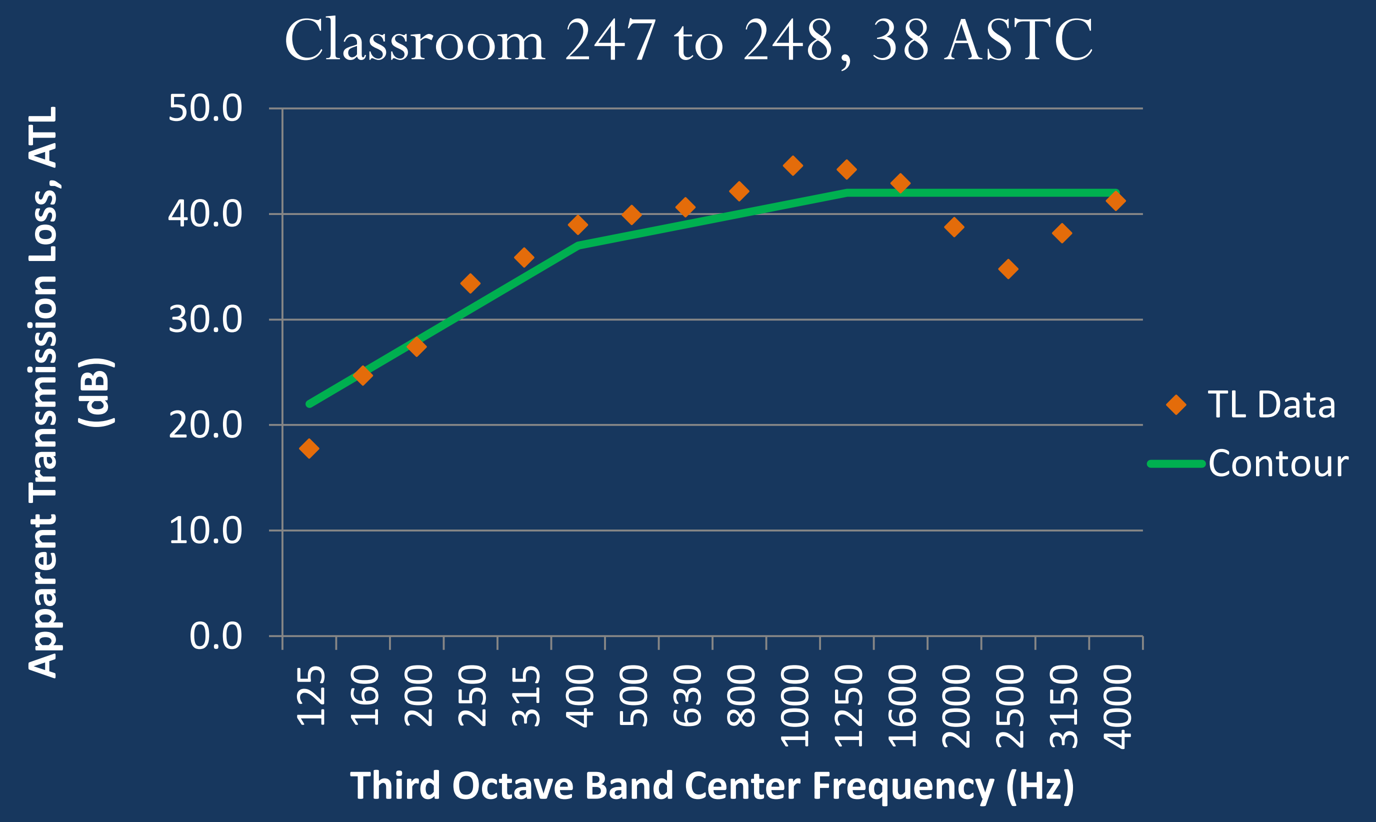
Acoustics Breadth

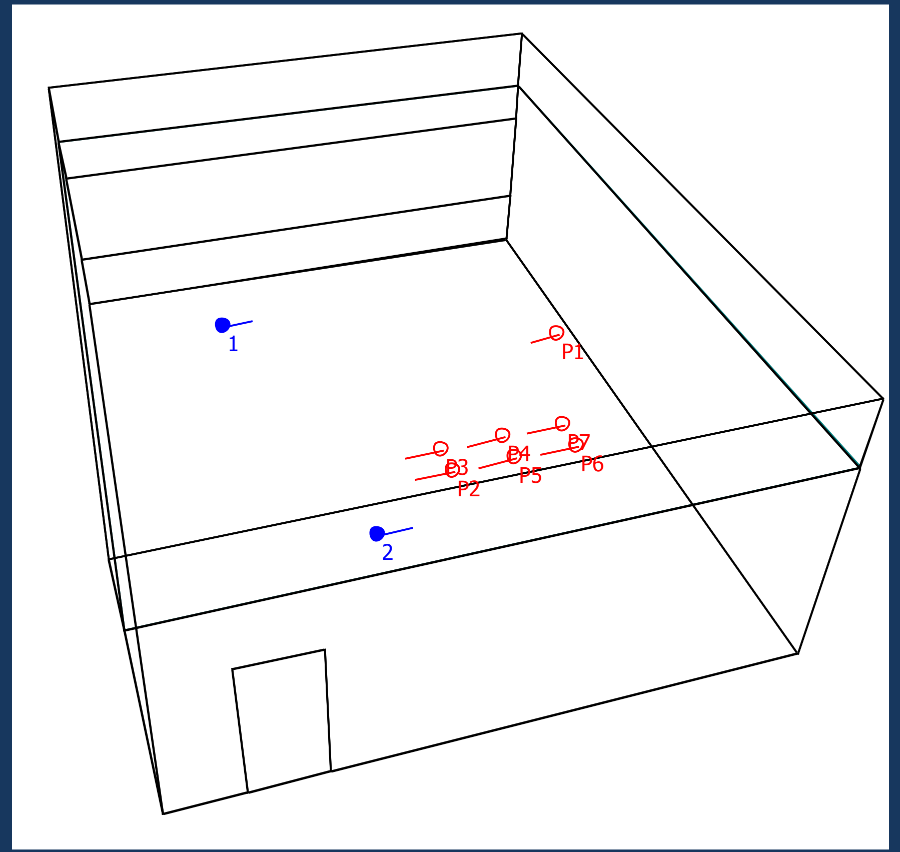
Onsite Measurements



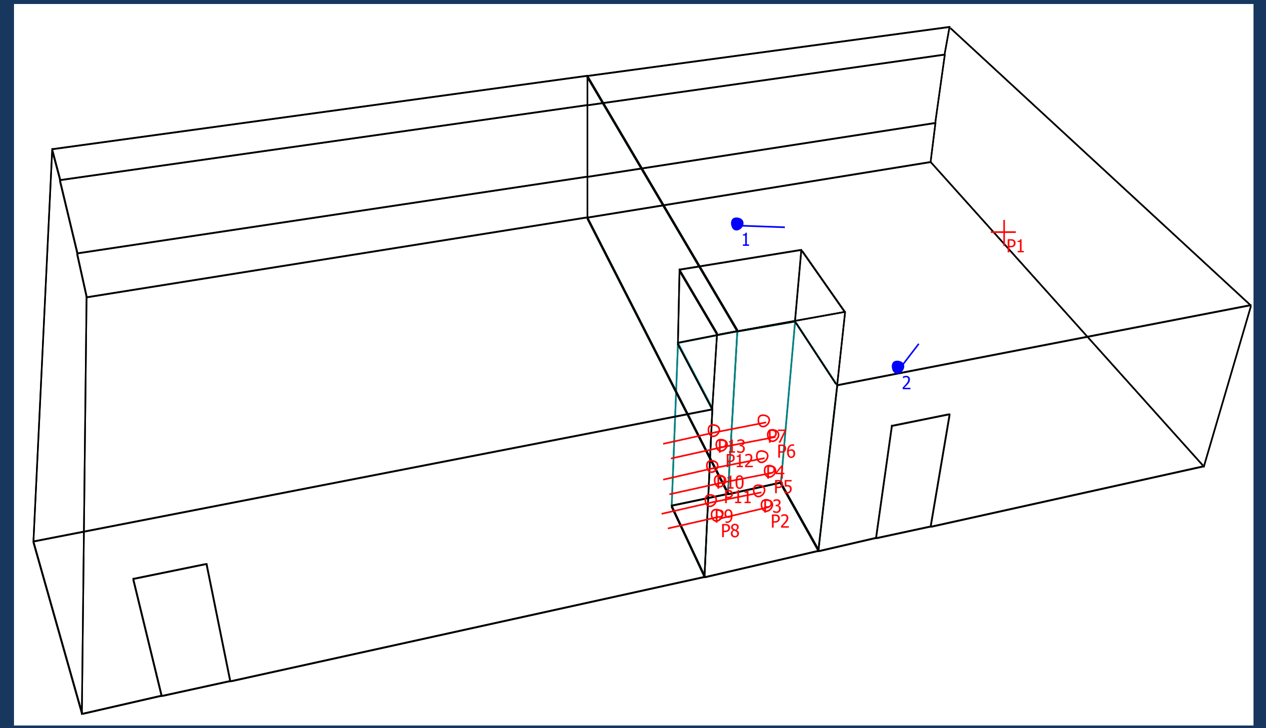
Acoustics Breadth

Heat Pump Sound Isolation

- Option 1: ceiling plenum
- Classroom & heat pump modeled in Odeon



- Option 2: mechanical room



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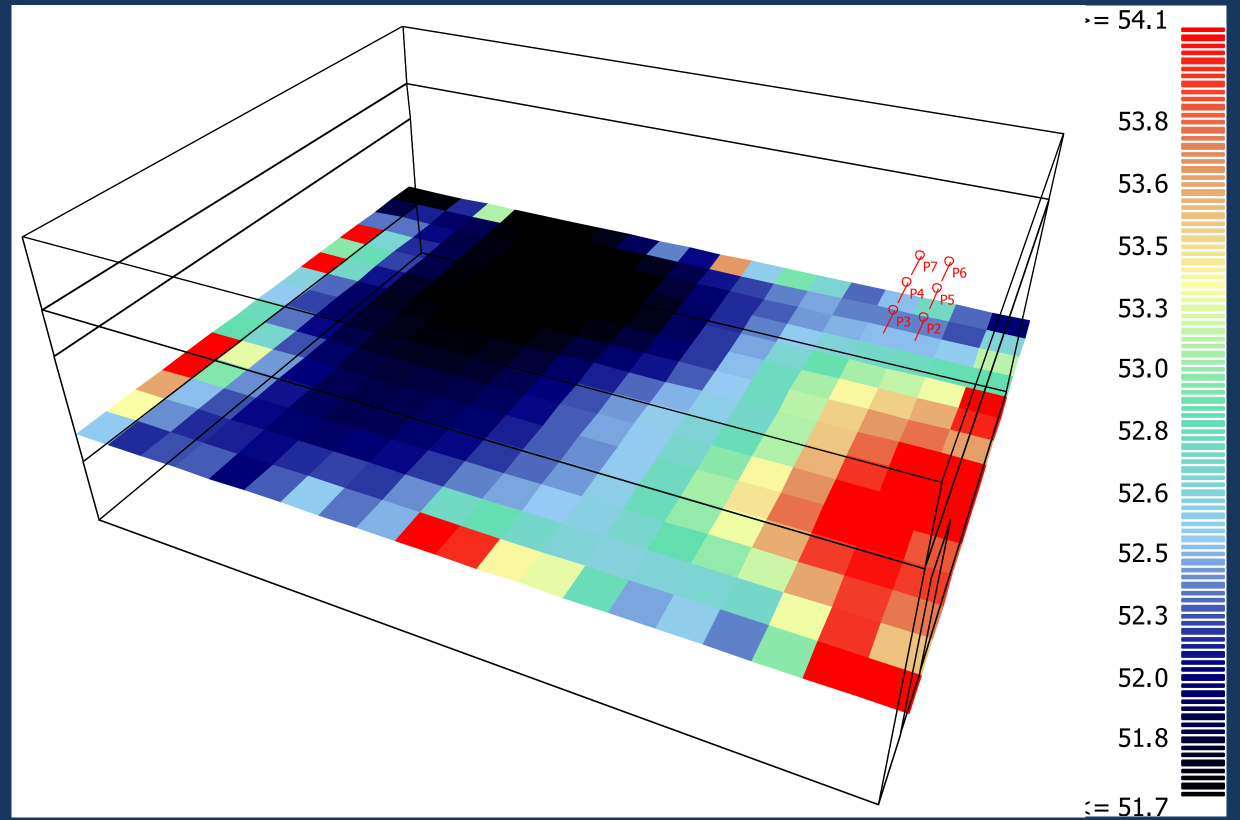
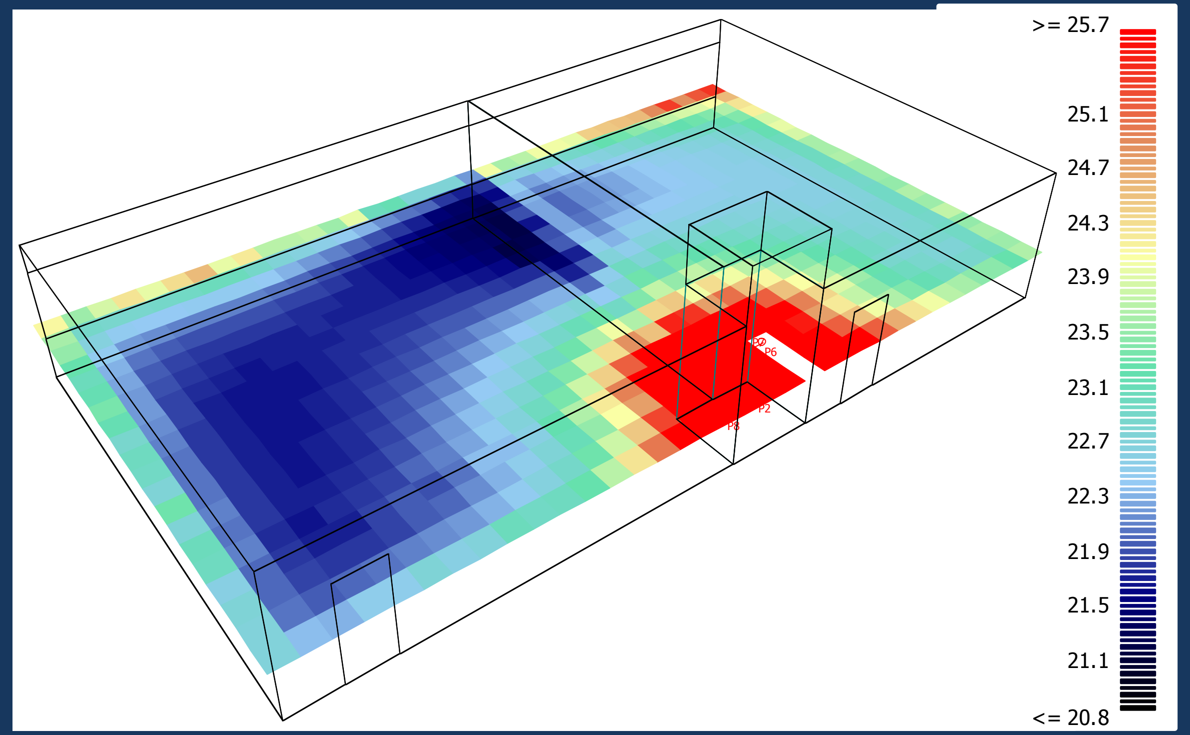
Acoustics Breadth

Heat Pump Sound Isolation

- Option 1: ceiling plenum
- Classroom & heat pump modeled in Odeon
  - Inadequate background noise level
  - ~ 50 to 55 dBA



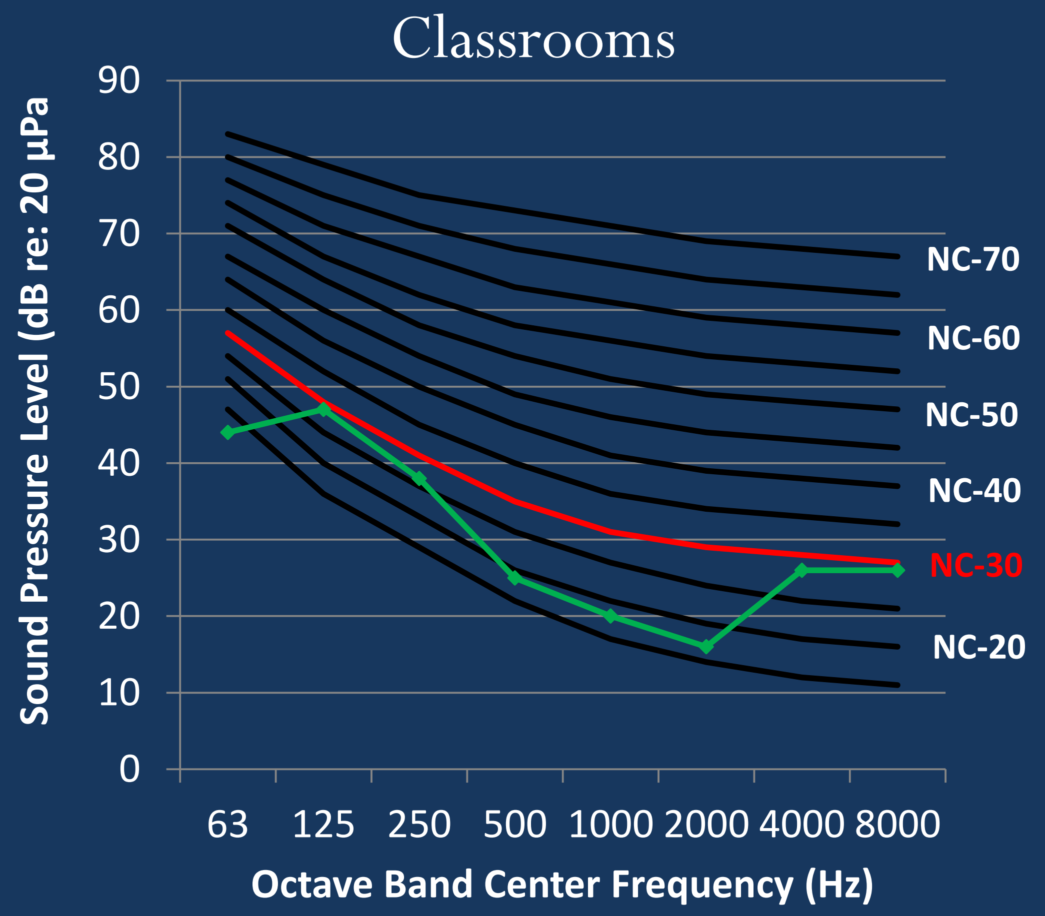
- Option 2: mechanical room
  - Meets 35 dBA criteria
  - ~ 20 to26 dBA



Acoustics Breadth

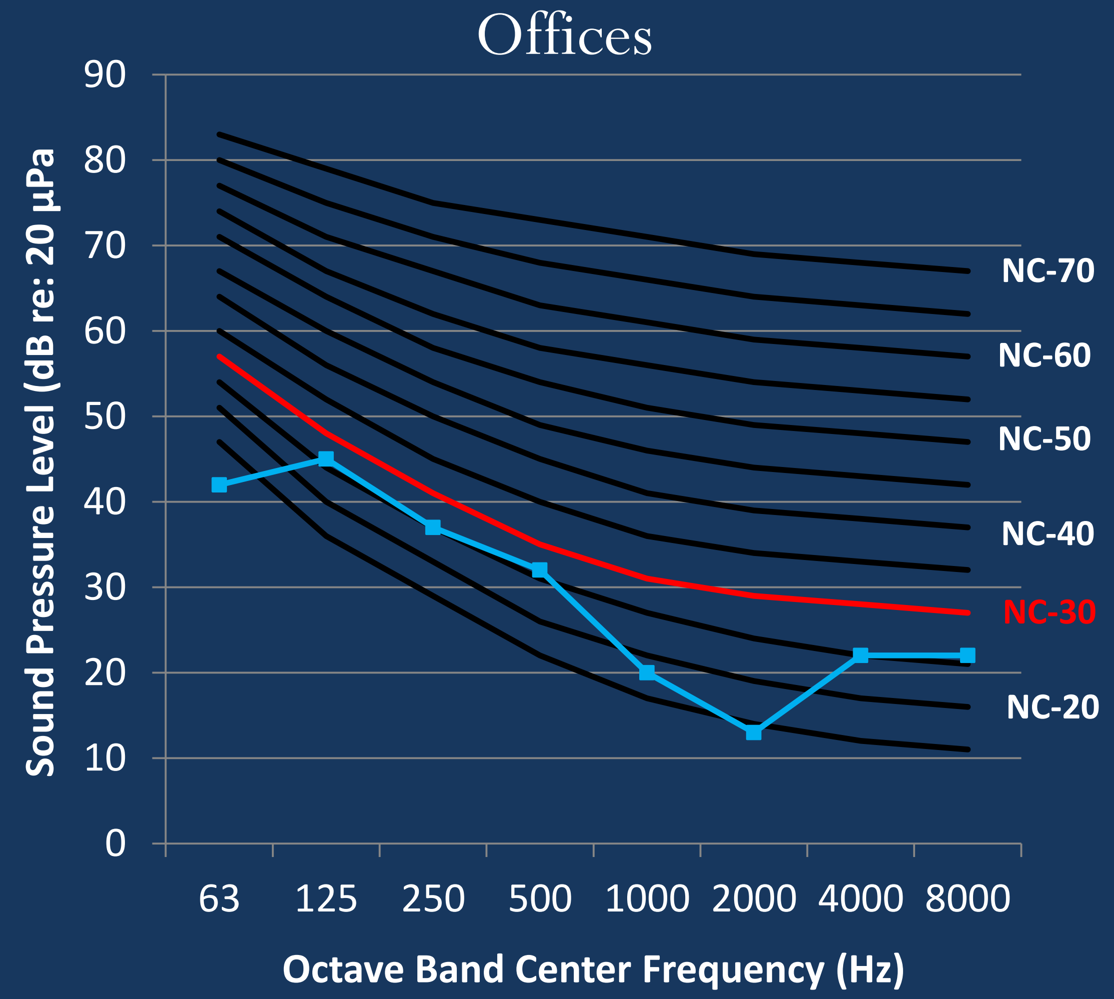
Heat Pump Ductwork Noise Control

- Private Offices & Classrooms
  - Specify minimum lengths of duct lining



Minimum Duct Lining Lengths

Path	Private Office	Classroom
Supply	2 feet	3 feet
Return	3 feet	5 feet



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Campus Geothermal

Initial Motivation

- Overview
- Existing Conditions
- Geothermal Depth
  - System Alternatives
  - Energy & Emissions
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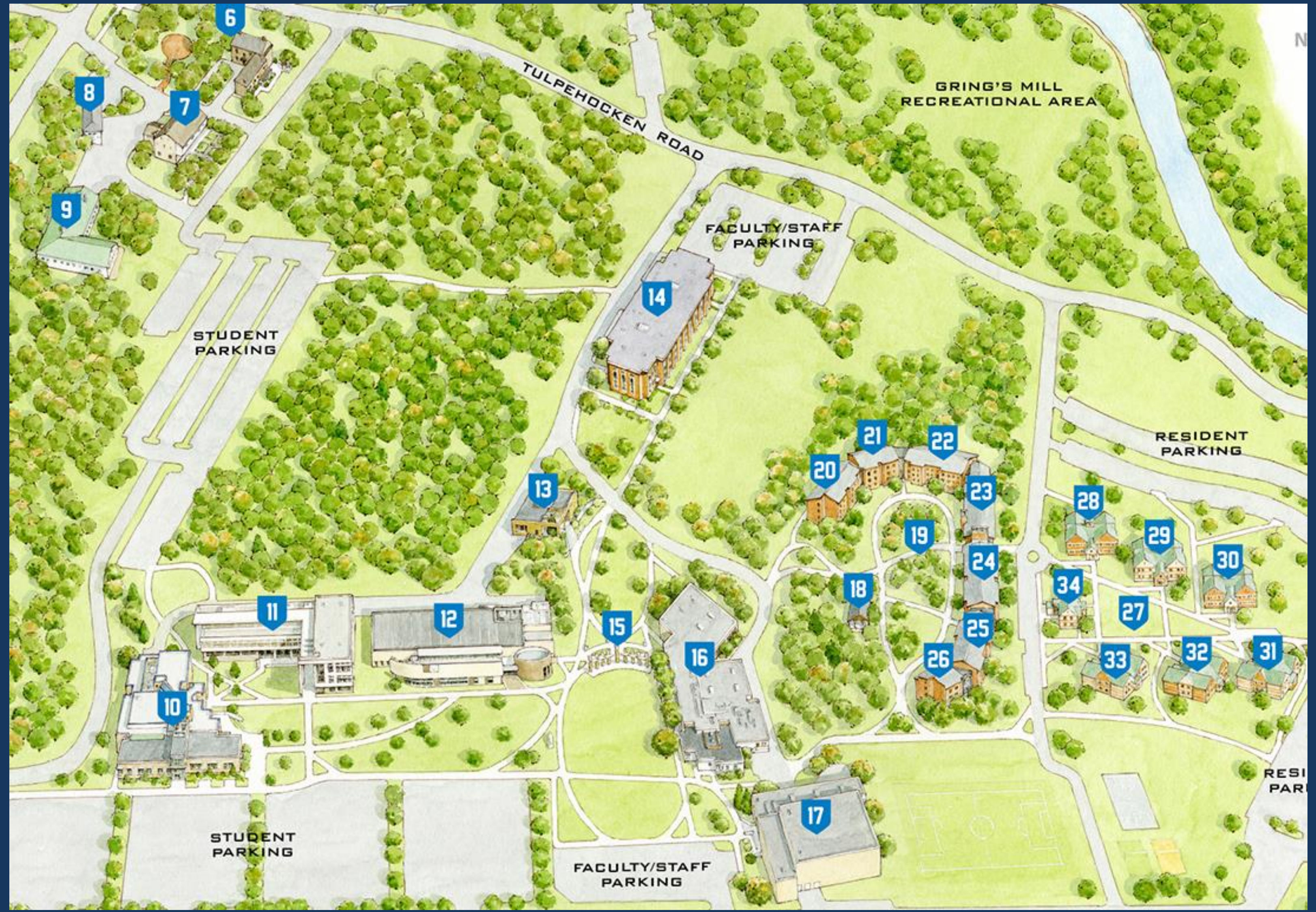
- Campus-wide Geothermal
- Conclusions



- Close proximity
- All same owner
- More space with vertical wells
- Potential diversity benefits
- Utility usage data known
  - Need to know: heating, cooling, and ventilation loads

Campus Geothermal

Model Validation

Model Validation Performance

Building Name	EIA Targets		Model Results		Percentage Deviations	
	Electricity (kWh)	Nat. Gas (therms)	Electricity (kWh)	Nat. Gas (therms)	Electricity (kWh)	Nat. Gas (therms)
The Franco Building	163007	7525	164693	7905	1.03%	5.04%
The Gaige Building	223701	11643	226577	11816	1.29%	1.49%
Thun Library	330557	7041	331394	7089	0.25%	0.69%
Luerssen Building	800746	0	800627	0	0.01%	n/a
Janssen Conference Center	101072	0	100504	0	0.56%	n/a
Perkins Student Center	593073	0	592461	0	0.10%	n/a
Beaver Community Center	176622	5607	177305	5338	0.39%	4.79%
Hintz Bookstore	31168	0	31800	0	2.03%	n/a
All Campus Residences	455342	0	458615	0	0.72%	n/a

- 2003 EIA building energy use survey used
- End use energy percentages estimated
- Trace model created for each building
- Validated to utility and EIA percentage estimates

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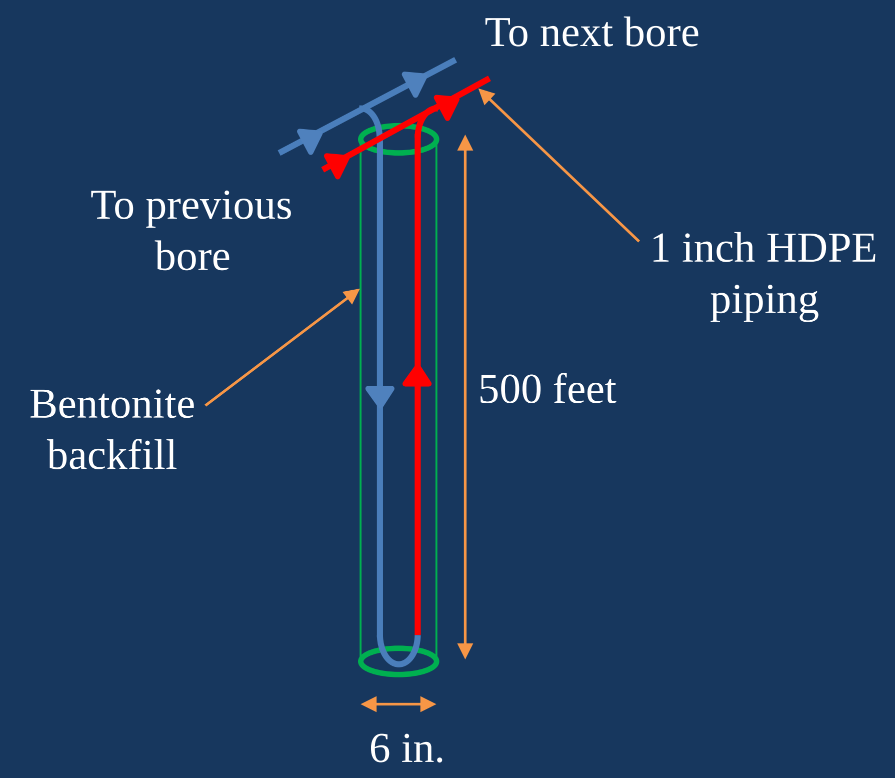
Campus Geothermal

Sizing and Layout

- 463,653 feet of wells required
- 500' well depth used
- 1020 wells minimum
  - 1050 wells chosen



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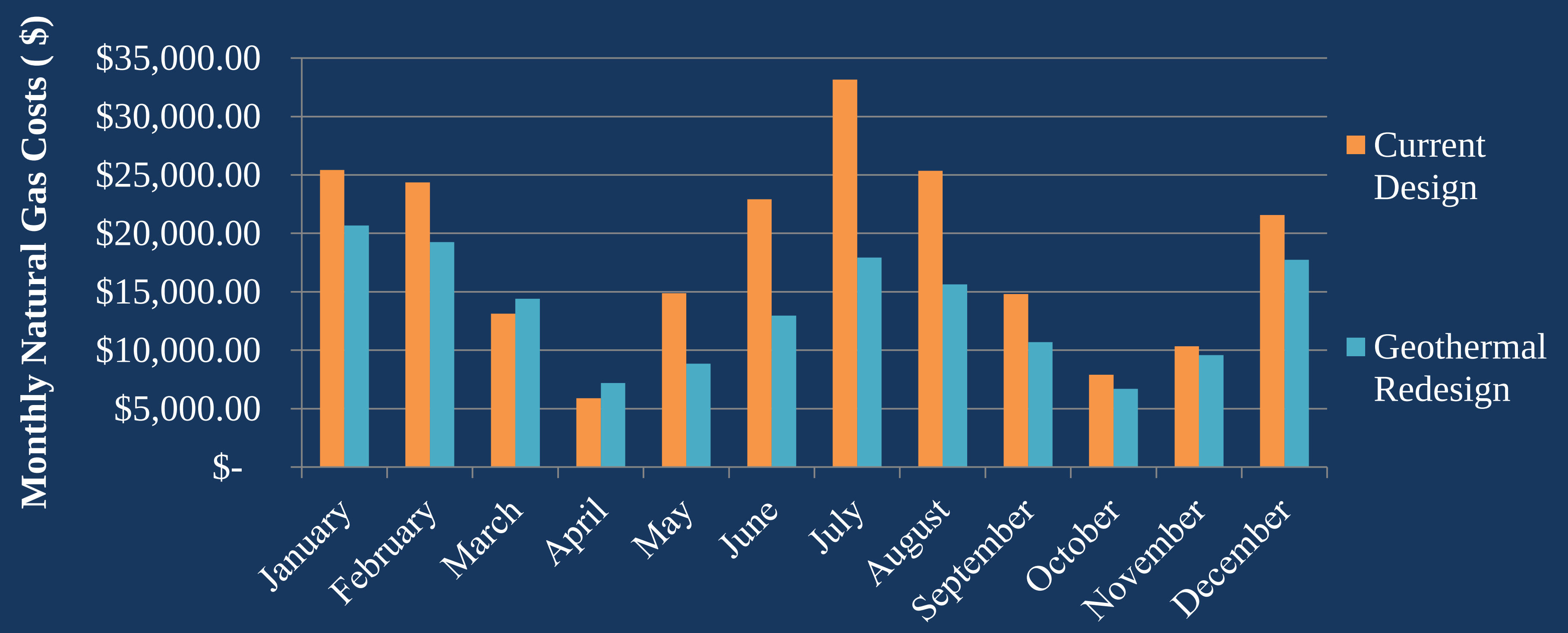
Campus Geothermal

Annual Energy Savings

- Baseline and geothermal models created
  - **Annual Energy Savings: $58,166.00**
- ~ 27.2 % reduction in emissions



Difference in Total Annual Emissions

Pollutant	Original Design Total Emissions (lb/yr)	Geothermal Design Total Emissions (lb/yr)	Percent Decrease %
CO2e	15258985.5	11108037.4	27.20%
CO_2	14405155.4	10489303.8	27.18%
CH4	30525.2	22104.3	27.59%
N_2O	338.5	246.3	27.24%
NO_x	25923.5	18824.4	27.38%
SO_x	72849.1	52749.9	27.59%
CO	7614.6	5558.6	27.00%
PM10	819.1	597.2	27.10%
Solid Waste	1742541.0	1261763.3	27.59%

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Campus Geothermal

Life Cycle Cost Analysis

Campus - Increased First-Costs	
Cost Item	Amount
Increased First Cost - Building Costs	$ 1,252,778.74
Increased First Cost – Well Field Costs	$ 5,734,520.38
Location Multiplier - Reading PA	0.988
Increased First Cost - Reading	$ 6,903,451.53
Savings from Original Design - 2009	$ 484,710.00
Time Multiplier - 2014 to 2009	0.889
Savings from Original Design - 2014	$ 545,230.60
Overall First Cost Increase:	$ 6,358,220.94

- Increased first costs estimated
  - $6,358,220.94 increase
- No reasonable payback period was found
  - Very high increased first costs
  - No savings realized from other buildings

Campus Geothermal

Life Cycle Cost Analysis

- Overview
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Building	Required Bores
The Gaige Building	48
The Franco Building	109
The Thun Library	173
The Hintz Bookstore	4
The Beaver Community Commons	122
The Perkins Student Center	202
The Janneson Conference Center	37
The Luerssen Building	284
All Campus Residences	58
Total Bores for Campus, separate	1038
Total Bores for Campus, together	928
Diversity Realized	89.4%

- Increased first costs estimated
  - **$6,358,220.94 increase**
- No reasonable payback period was found
  - Very high increased first costs
  - No savings realized from other buildings
- Relatively small amount of diversity
  - ~ 89.4% overall

The Gaige Building

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Campus Geothermal

Life Cycle Cost Analysis

Simple Payback with 10% Safety Factor

Load Diversity	Bores: 10% Safety	First Cost Increase	Simple Payback
100%	1142	$ 6,185,478.68	82.64
95%	1085	$ 5,906,080.61	78.90
90%	1028	$ 5,626,682.53	75.17
85%	971	$ 5,347,284.45	71.44
80%	914	$ 5,067,886.37	67.70
75%	857	$ 4,788,488.30	63.97
70%	800	$ 4,509,090.22	60.24
65%	743	$ 4,229,692.14	56.51
60%	686	$ 3,950,294.06	52.77
55%	628	$ 3,665,994.26	48.98
50%	571	$ 3,386,596.19	45.24
Actual Building	1050	$ 5,734,520.38	76.61

- Effect of increased diversity
  - Poor payback period with high diversity
  - Not justifiable

Campus Geothermal

Life Cycle Cost Analysis

Savings Comparison – With Current Safety Factor			
Increased Savings ($)	New First Cost	Simple Payback	Discounted Payback
Current Design	$ 5,734,520.38	76.61	> 40 years
$ 1,000,000.00	$ 4,734,520.38	63.25	> 40 years
$ 3,000,000.00	$ 2,734,520.38	36.53	> 40 years
$ 4,000,000.00	$ 1,734,520.38	23.17	> 40 years
$ 4,400,000.00	$ 1,334,520.38	17.83	30.11
$ 4,500,000.00	$ 1,234,520.38	16.49	25.02
$ 4,600,000.00	$ 1,134,520.38	15.16	21.56
$ 4,800,000.00	$ 934,520.38	12.48	16.34
$ 5,000,000.00	$ 734,520.38	9.81	12.21
$ 5,200,000.00	$ 534,520.38	7.14	8.68
$ 5,500,000.00	$ 234,520.38	3.13	4.10

- Effect of increased diversity
  - Poor payback period with high diversity
  - Not justifiable
- Effect of increased initial savings
  - Feasible payback with $4.5 million initial savings
  - Savings from new buildings
  - Savings from renovation alternatives for buildings

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Final Conclusions

Gaige Building and Campus Geothermal

- Both vertical and horizontal designs feasible
  - Horizontal system cheaper – 6.1 years
  - Vertical system less space constraints – 12.7 years
- Heat pump noise control
  - Isolated through partition design
  - Isolated from minimum duct lining lengths
- Gaige Building compared with ANSI S12.60
  - Meets requirements for RT and BNL
  - Some partitions do not meet STC requirements

- Campus-wide geothermal
  - Not reasonable payback
  - Less diversity found in campus load
  - Initial savings are needed

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Final Conclusions

Acknowledgements

- Special thanks to:
  - Scott Mack & Justin Kalanesh, H. F. Lenz
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  - Dr. Stephen Treado, adviser
  - Dr. Richard Mistrick, honors adviser
  - Moses Ling
  - Dr. Michelle Vigeant
  - Aaron King and Cory Clippinger
  - Photos courtesy of Penn Sate Berks and Illumination Arts

H.F. LENZ COMPANY

PENNSTATE Berks 1855

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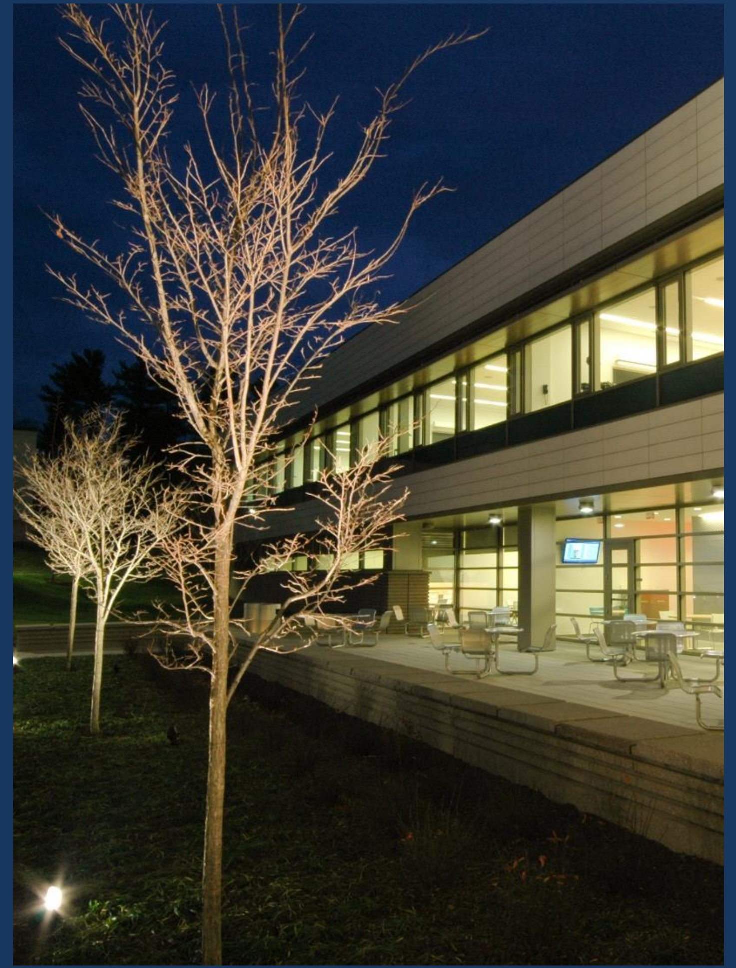
Thank You!



Matthew Neal
Mechanical Option
Dr. Stephen Treado, Adviser

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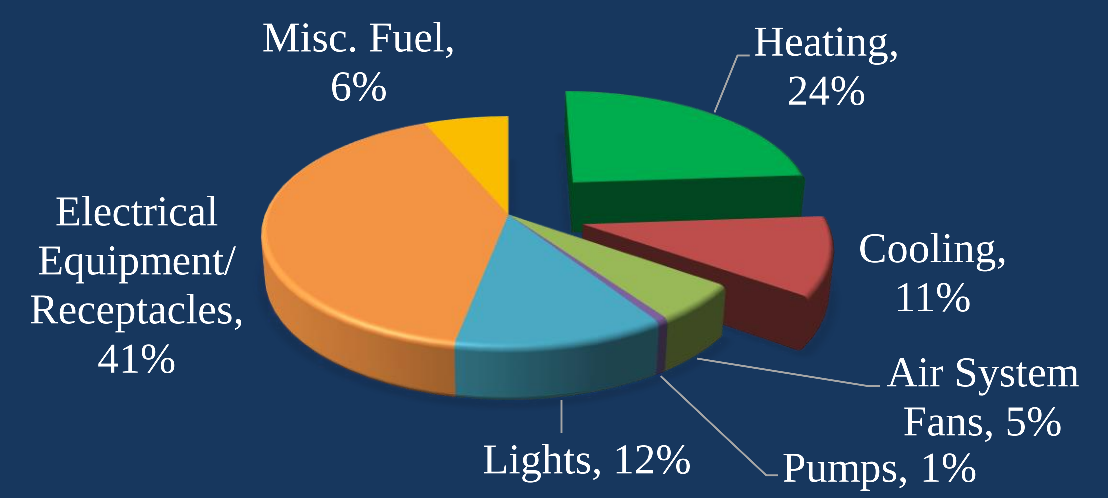
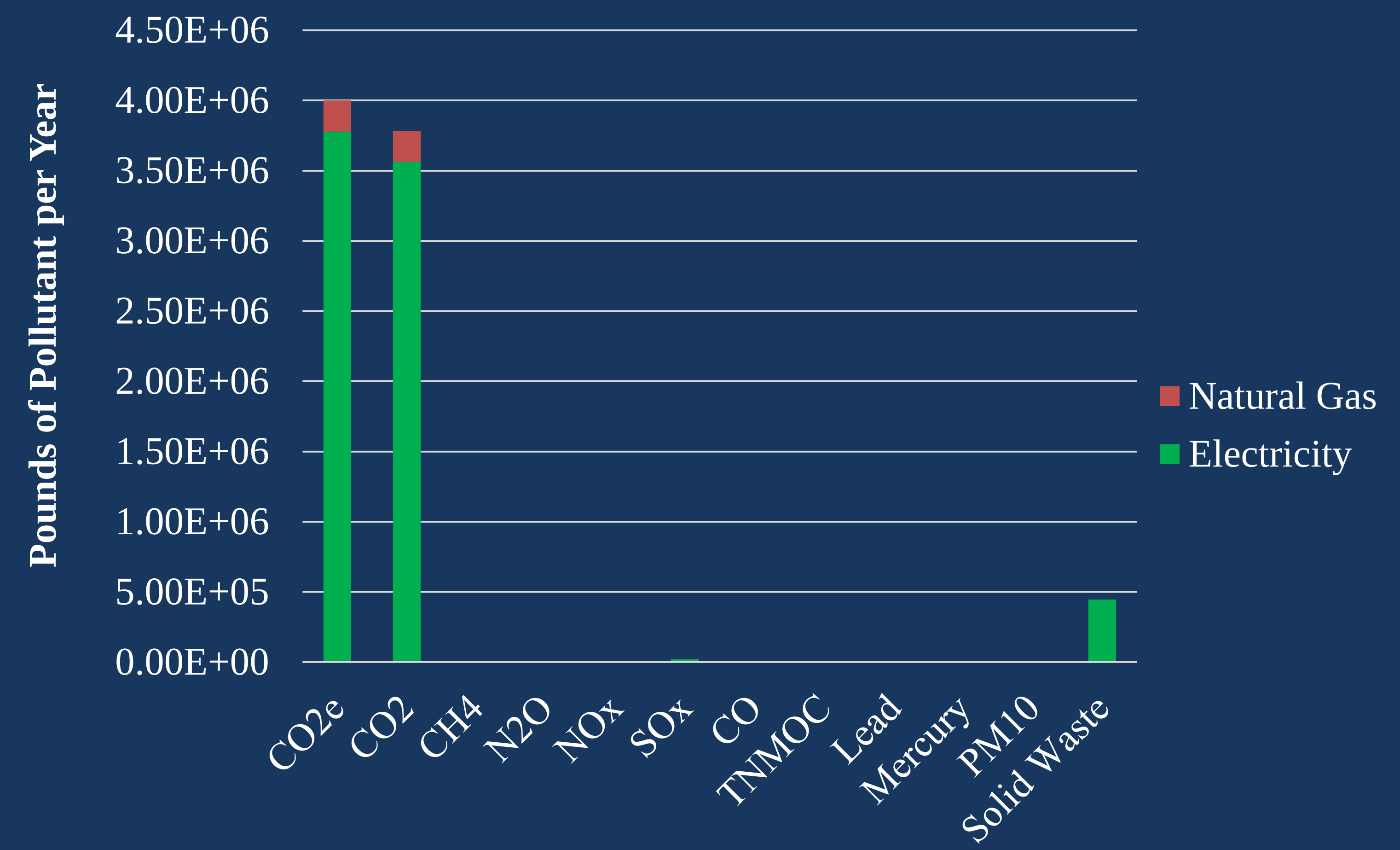
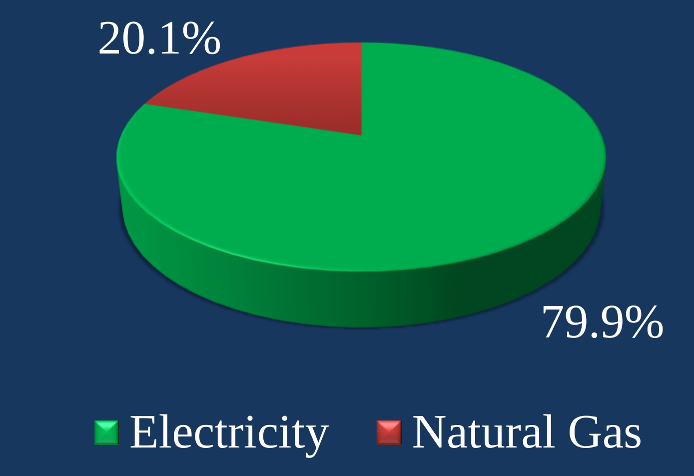
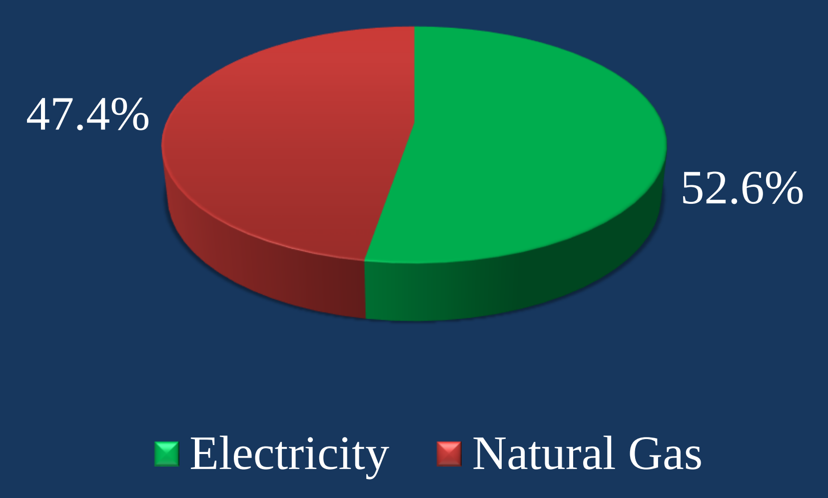
Existing Conditions









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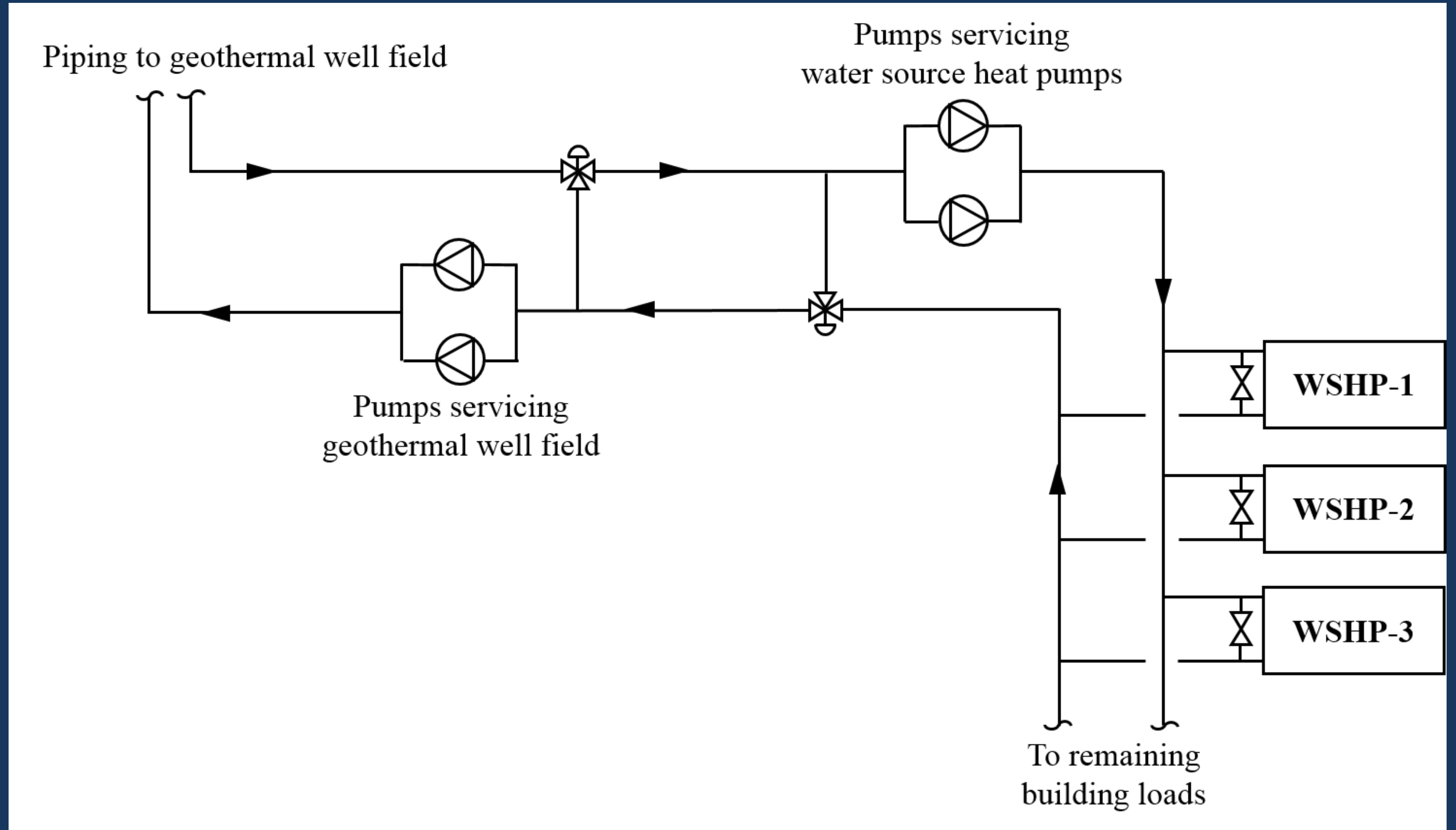
Gaige Geothermal

$$L_c = \frac{q_a R_{ga} + (q_{lc} - 3.41W_c)(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p}$$

$$L_h = \frac{q_a R_{ga} + (q_{lh} - 3.41W_h)(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p}$$

Geothermal Design		
Parameter	Heating	Cooling
Short-Circuit Factor (F_{sc})	1.04	1.04
Part-Load Factor (PLF_m)	1	1
Average Heat Transfer to Ground (q_a)	387000	387000
Block Loads (q_{lc} and q_{lh})	679400	1066400
Resistance of Ground, Annual pulse (R_{ga})	0.215	0.215
Resistance of Ground, Daily pulse (R_{gd})	0.129	0.129
Resistance of Ground, Monthly pulse (R_{gm})	0.207	0.207
Resistance of Bore (R_b)	0.09	0.09
Undisturbed Ground Temperature (tg)	53	53
Temperature Penalty for Bore Spacing (t_p)	1.8	1.8
Heat Pump Inlet Temperature (t_{wi})	38	78
Heat Pump Outlet Temperature (t_{wo})	33	85
System Power Input (W_c and W_h)	3728.5	3728.5
Required Bore Length (L_c and L_h)	23636.4	17760.4



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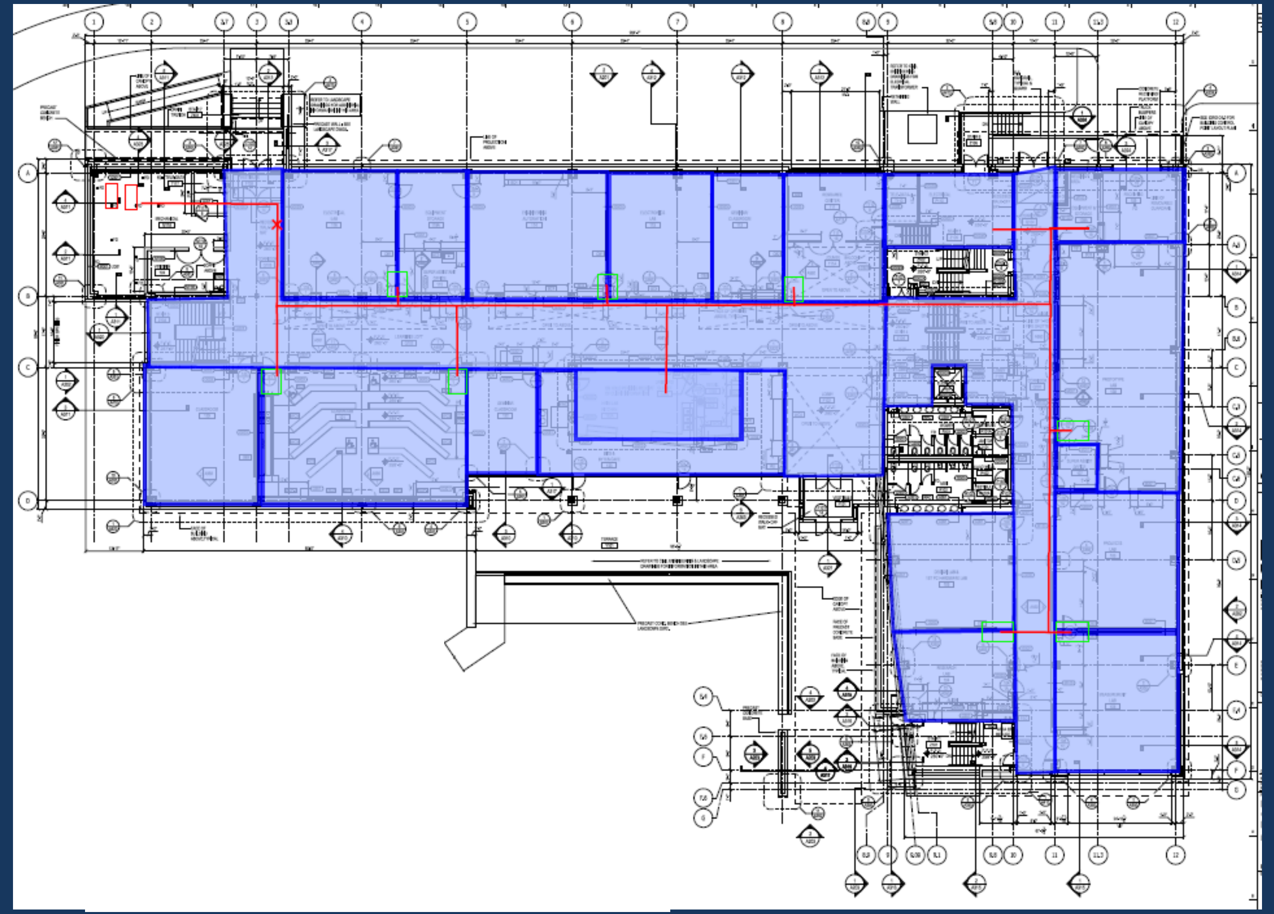
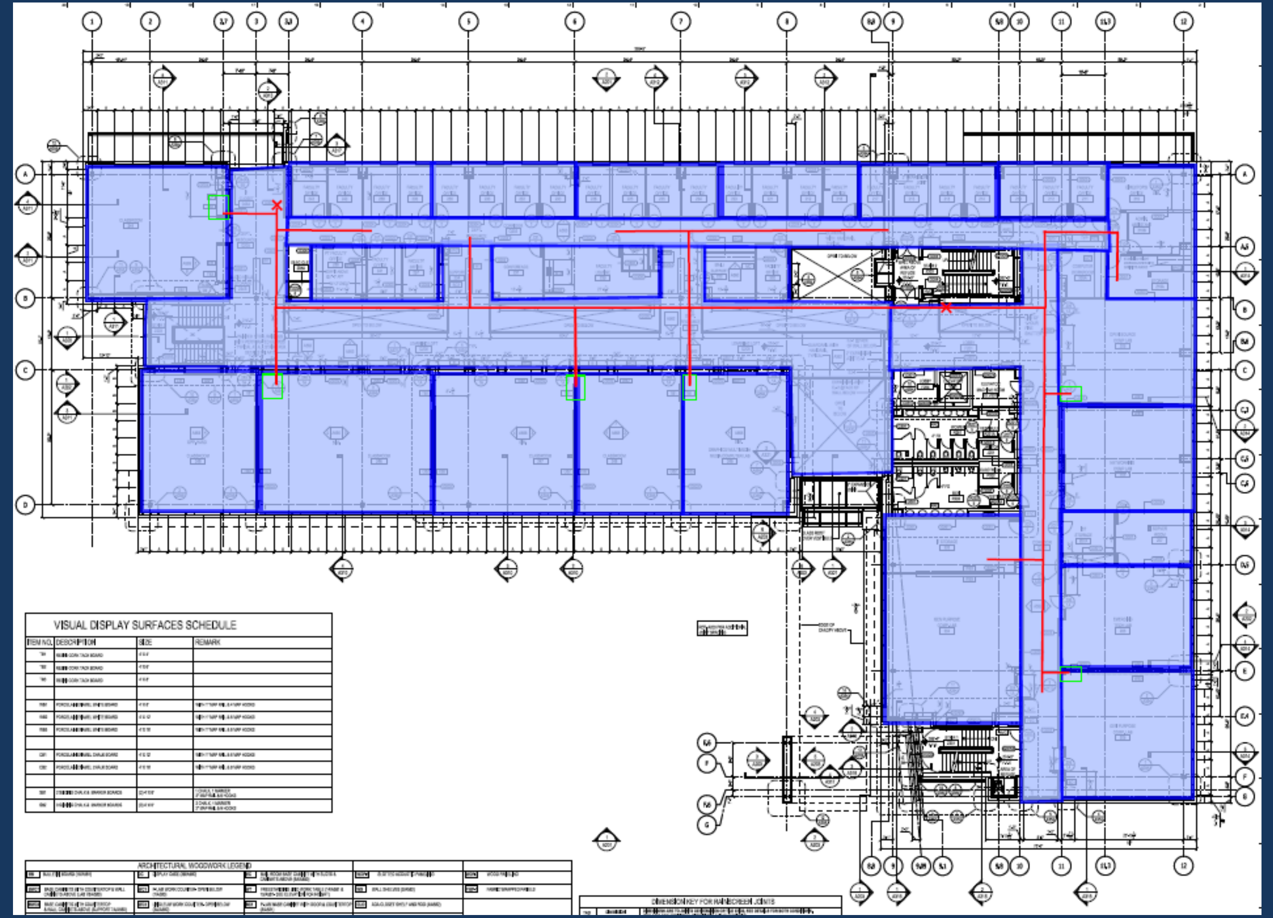
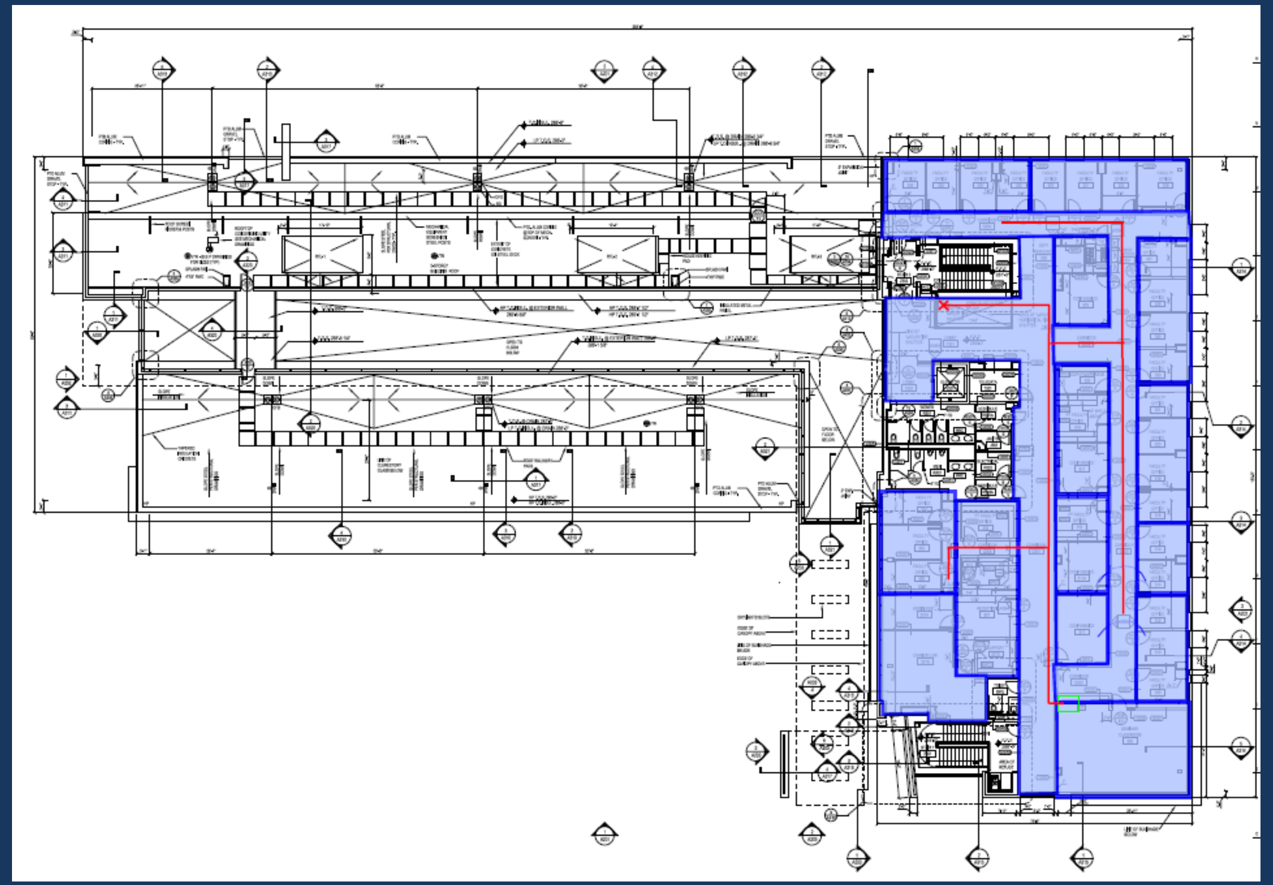
Gaige Geothermal







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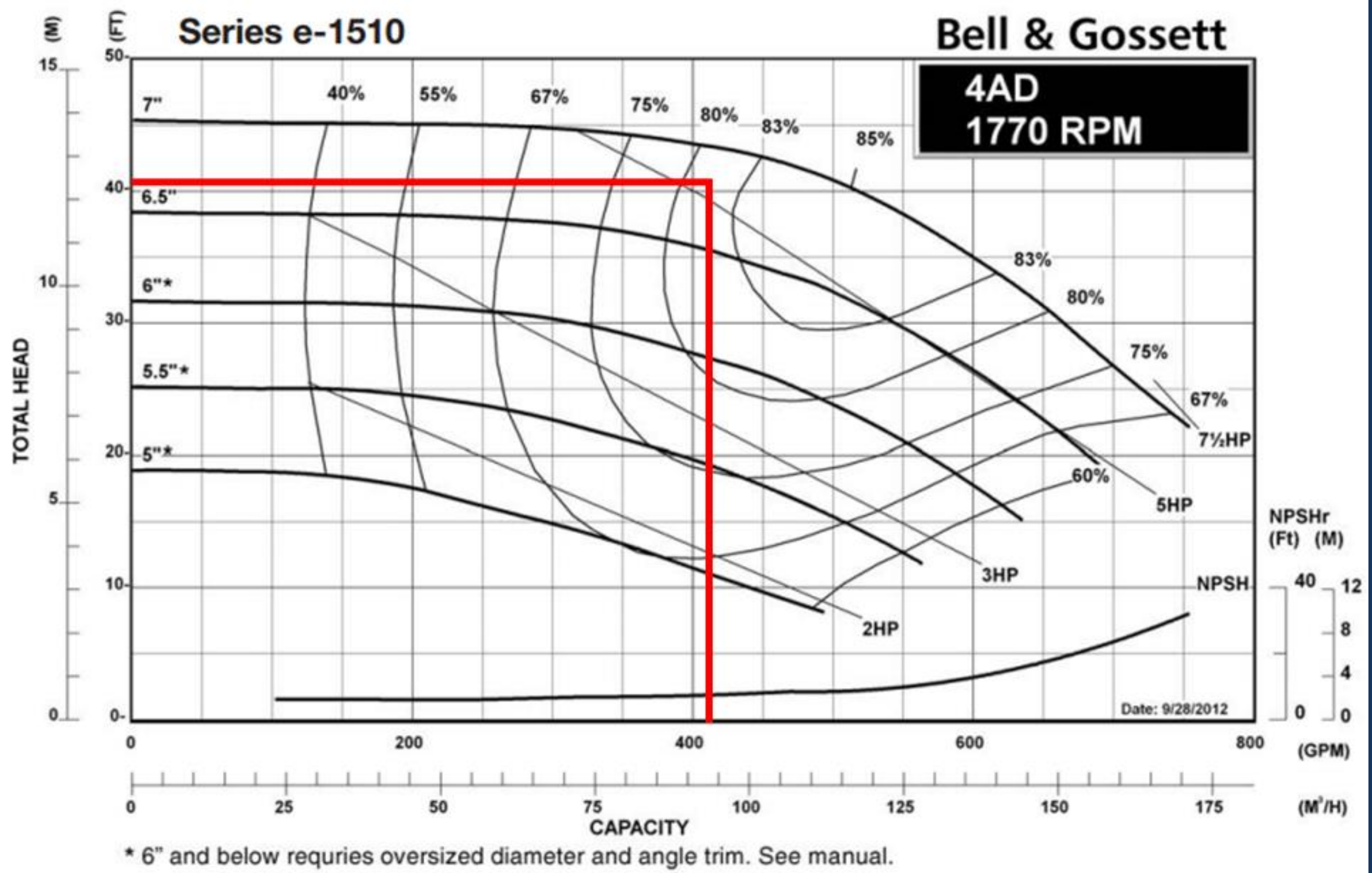
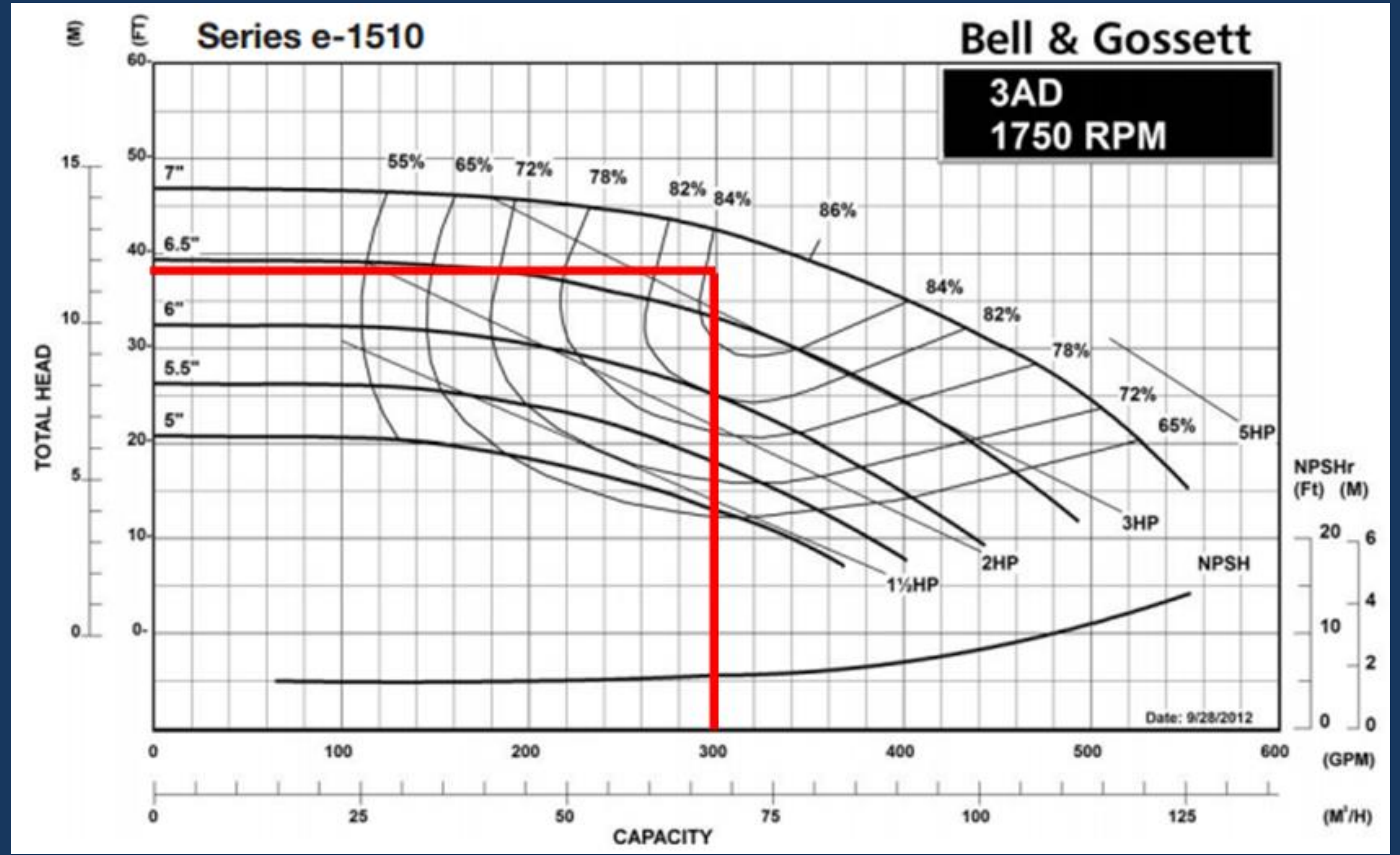
Gaige Geothermal

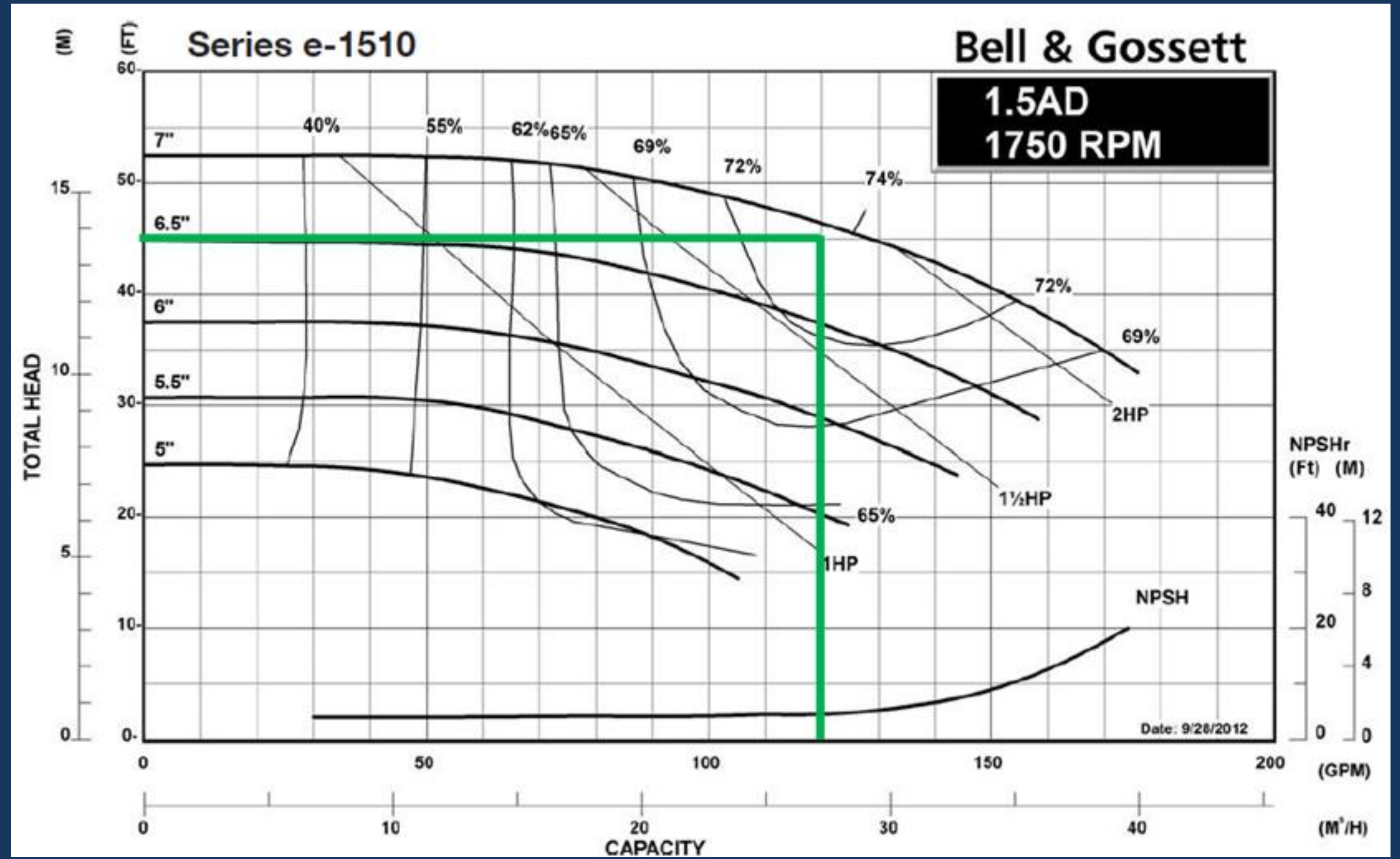
Building Pump



Vertical Pump



Horizontal Pump



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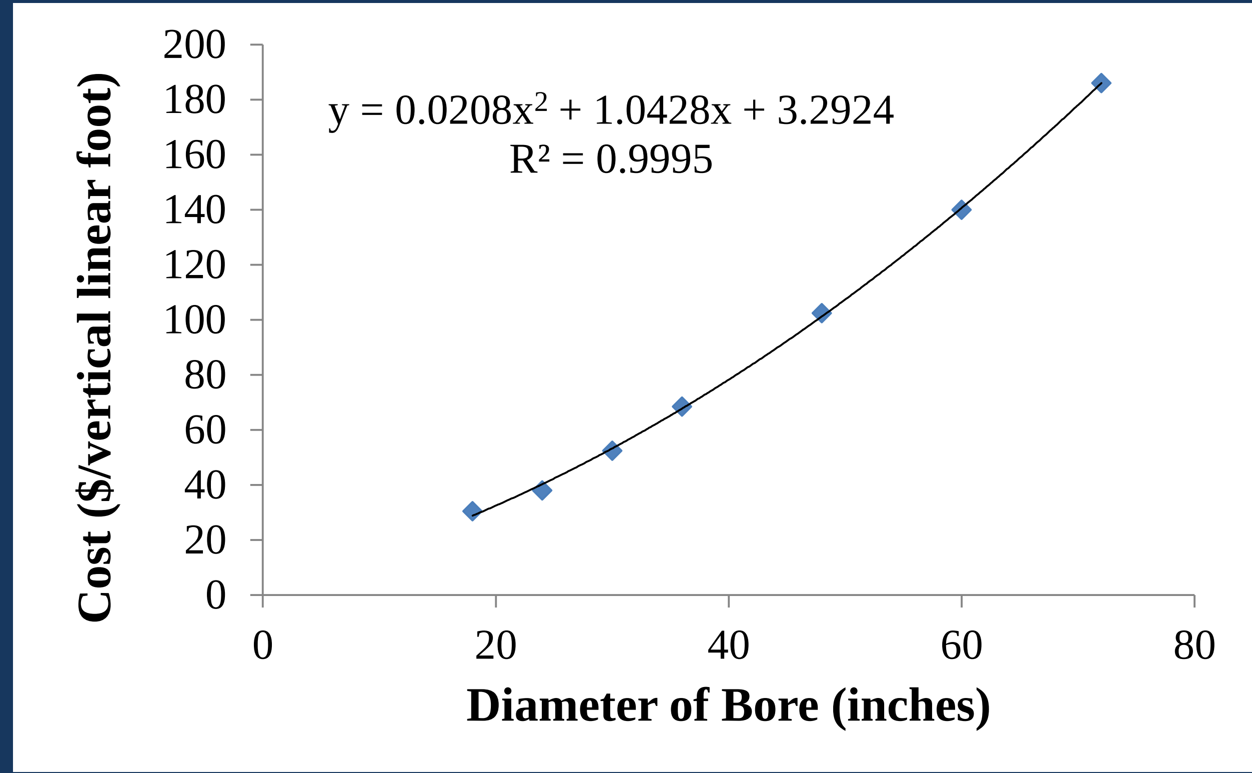
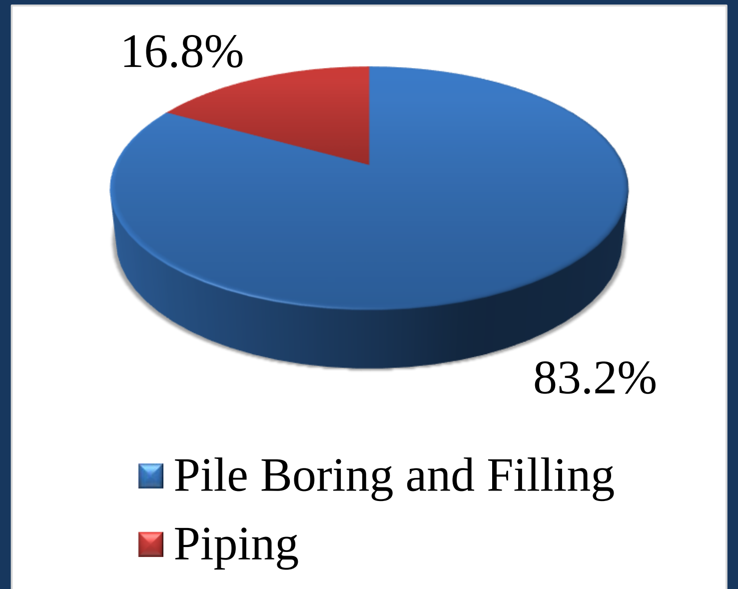


Vertical Geothermal Additional First Costs-Cost Per Pile

Item	Unit Cost				Amount	Units	Expense
	Materials	Labor	Equipment	Total			
Pile Boring and Filling	$ 1.09	$ 5.28	$ 3.92	$ 10.29	300	VLF	$ 3,088.41
1" HDP Pipe	$ 0.79	$ -	$ -	$ 0.79	600	LF	$ 474.00
1" HDP Elbow	$ 5.60	$ -	$ -	$ 5.60	4	Each	$ 22.40
1" HDP Joints	$ -	$ 5.55	$ -	$ 5.55	10	Each	$ 55.50
1" HDP Tee	$ 7.30	$ -	$ -	$ 7.30	2	Each	$ 14.60
Welding Machine	$ -	$ -	$ 40.50	$ 40.50	1.47	Each	$ 59.34
						Total	**$ 3,714.25**



Life Cycle Rate Assumptions

Discount Rate	8.00%
Escalation Rates	
Electricity	3.75%
Natural Gas	5.00%
Materials	1.73%
Main. & Labor	1.73%
Study Period	20 years

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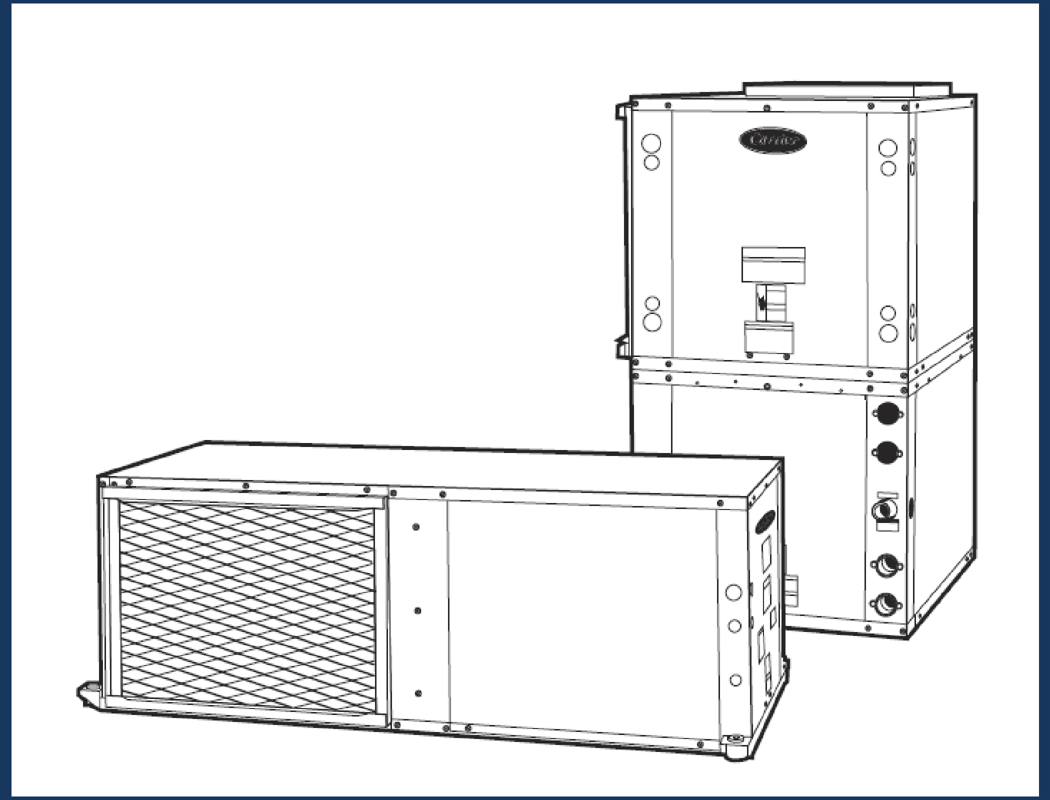
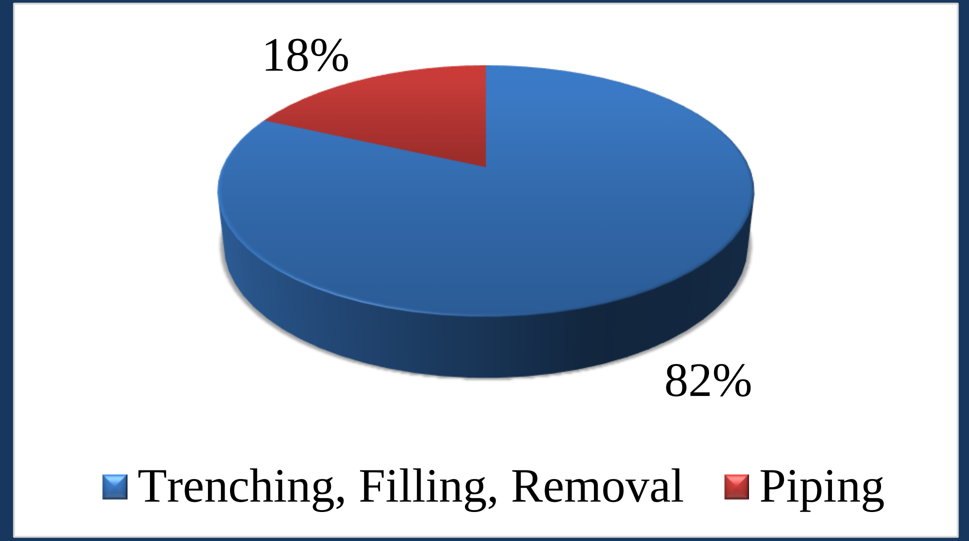
Gaige Geothermal



Horizontal Geothermal Additional First Costs-Cost Per Pile							
Item	Unit Cost				Amount	Units	Expense
	Materials	Labor	Equipment	Total			
Trenching for piles	$ -	$ 0.59	$ 0.75	$ 1.34	800	LF	$ 1,073.24
Fill for Trenches	$ 4.85	$ 1.09	$ 0.41	$ 6.35	800	LF	$ 5,079.17
Backfill for Trenches	$ -	$ 0.61	$ 0.21	$ 0.82	800	LF	$ 655.64
Hauling Dirt	$ -	$ 0.27	$ 0.37	$ 0.63	800	LF	$ 507.37
1" HDP Pipe	$ 0.79	$ -	$ -	$ 0.79	1600	LF	$ 1,264.00
1" HDP Elbow	$ 5.60	$ -	$ -	$ 5.60	2	Each	$ 11.20
1" HDP Joints	$ -	$ 5.55	$ -	$ 5.55	49	Each	$ 271.95
1" HDP Tee	$ 7.30	$ -	$ -	$ 7.30	2	Each	$ 14.60
Welding Machine	$ -	$ -	$ 40.50	$ 40.50	1.47	Days	$ 59.34
						Total	$ 8,936.51



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Campus Geothermal

$$\# \; of \; Bores = 1.1 * \frac{463653.1}{500} = 1020 \; wells$$

Energy Multipliers for Electric - Natural Gas Energy Source Buildings

Building Type	Heating		Cooling		Ventilation
	Electricity	Nat. Gas	Electricity	Nat. Gas	
Office - Mid Atlantic	5.88%	54.94%	9.52%	4.01%	9.83%
Classroom - Mid Atlantic	4.93%	68.61%	11.20%	0.00%	30.28%
Public Assembly - Mid Atlantic	1.63%	54.90%	4.96%	38.78%	51.11%
Classroom / Office Averaged	5.40%	61.77%	10.36%	2.00%	20.05%
Public Assembly/Classroom/Office	4.15%	59.48%	8.56%	14.26%	30.40%
Public Assembly/Office	3.75%	54.92%	7.24%	21.39%	30.47%

Campus-wide Geothermal Design

Parameter	Heating	Cooling
Short-Circuit Factor (F_{sc})	1.04	1.04
Part-Load Factor (PLF_m)	1	1
Average Heat Transfer to Ground (q_a)	-1390309	-1390309
Block Loads (q_{lc} and q_{lh})	17939009	16548700
Resistance of Ground, Annual pulse (R_{ga})	0.215	0.215
Resistance of Ground, Daily pulse (R_{gd})	0.129	0.129
Resistance of Ground, Monthly pulse (R_{gm})	0.207	0.207
Resistance of Bore (R_b)	0.09	0.09
Undisturbed Ground Temperature (t_g)	53	53
Temperature Penalty for Bore Spacing (t_p)	1.8	1.8
Heat Pump Inlet Temperature (t_{wi})	38	78
Heat Pump Outlet Temperature (t_{wo})	33	85
System Power Input (W_c and W_h)	111855	111855
Required Bore Length (L_c and L_h)	463653.1	220436.7

Energy Multipliers for Electric only Buildings

Building Type	Heating	Cooling	Ventilation
Office - Mid Atlantic	27.99%	7.21%	6.18%
Public Assembly - Mid Atlantic	39.95%	19.08%	20.98%
Classroom - Mid Atlantic	50.72%	4.91%	13.26%
Lodging - Mid Atlantic	12.46%	5.43%	2.18%
Food Service - Mid Atlantic	17.51%	2.98%	3.69%
Retail - Mid Atlantic	31.24%	6.24%	8.06%
Classroom / Office Averaged	39.36%	6.06%	9.72%
Office/Food Service/Public Assembly	28.48%	9.76%	10.28%

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Campus Geothermal

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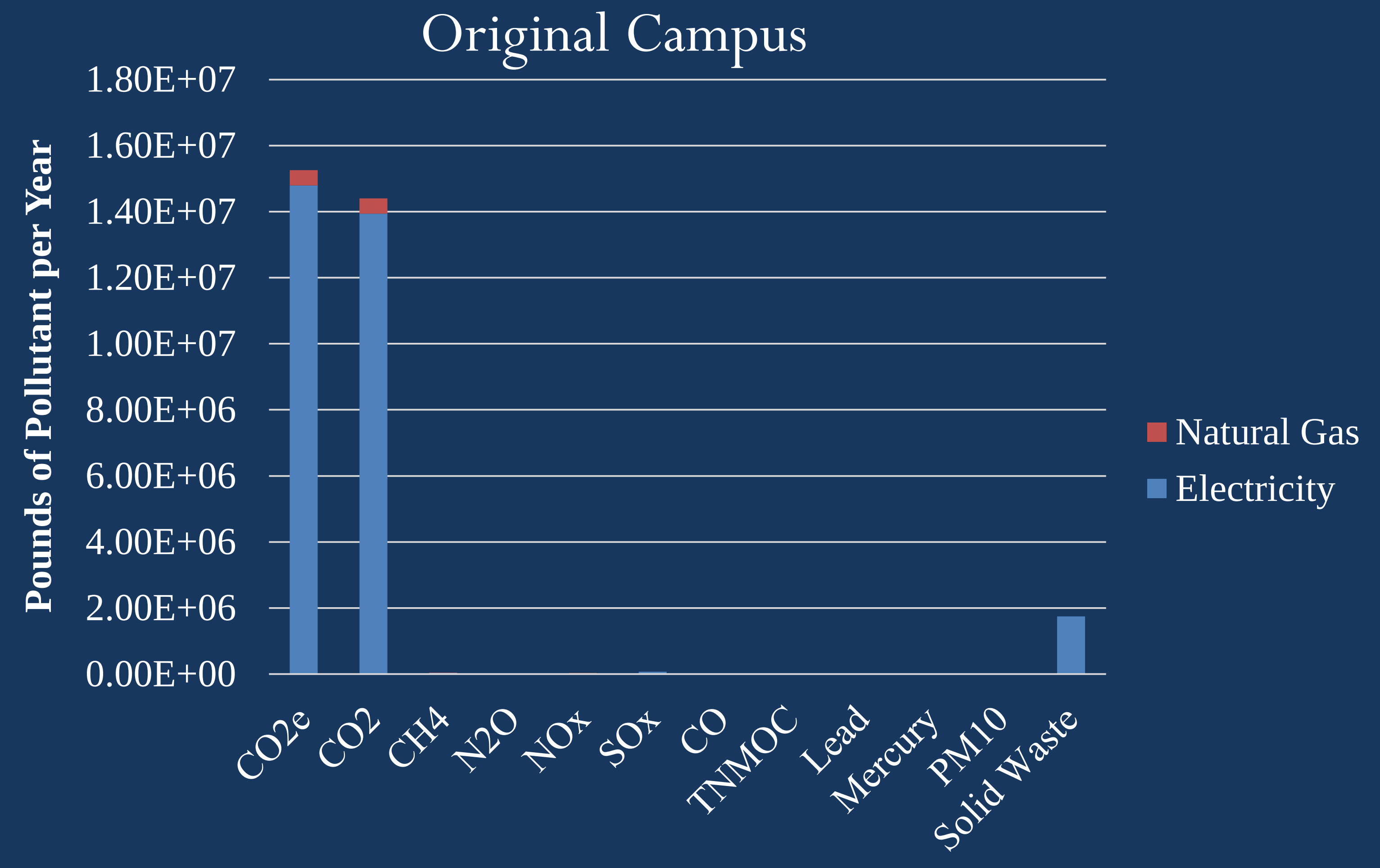
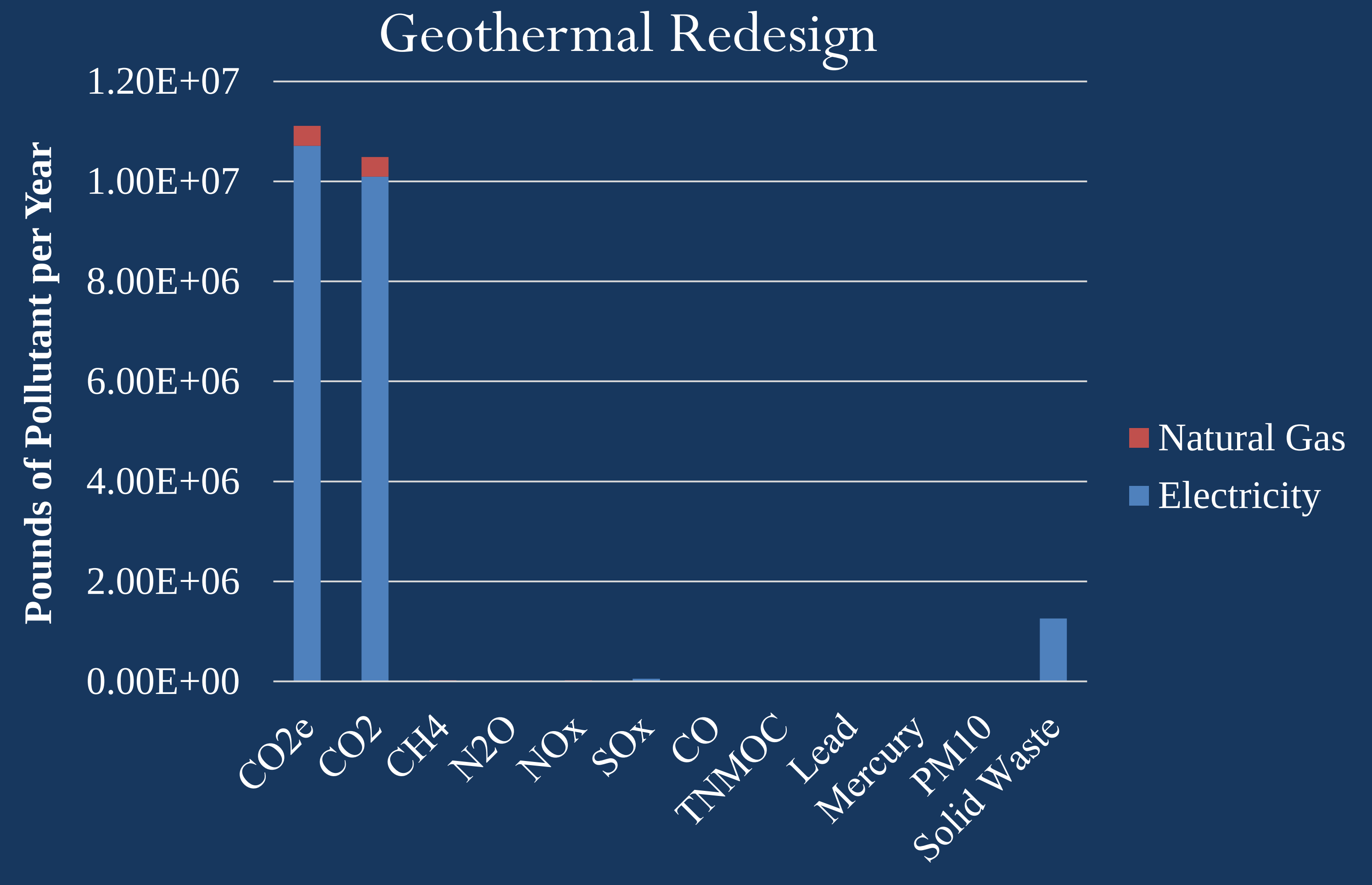
Background Noise Levels	
Room	Overall dBA
Classroom 120	32 dBA
Classroom 121	31 dBA
Classroom 122	29 dBA
Classroom 246	32 dBA
Classroom 247	31 dBA
Classroom 248	28 dBA





Geothermal Cost Savings				
Item	Unit Cost	Amount	Units	Savings
RTU's - Quote (20,500, 14,000, 10,725 CFM's)	$ 300,000.00	1	All	$ 300,000.00
RTU Installation	$ 2.00	45,230	CFM	$ 90,460.00
Fin Tubes	$ 75.00	1150	LF	$ 86,250.00
Radiant Heat Panels	$ 100.00	80	Each	$ 8,000.00
				$ 484,710.00