Water Bottling Facility

Mid-Atlantic
United States

Mechanical Option | Spring 2013
Advised by Dr. William Bahnfleth

Justyne Neborak

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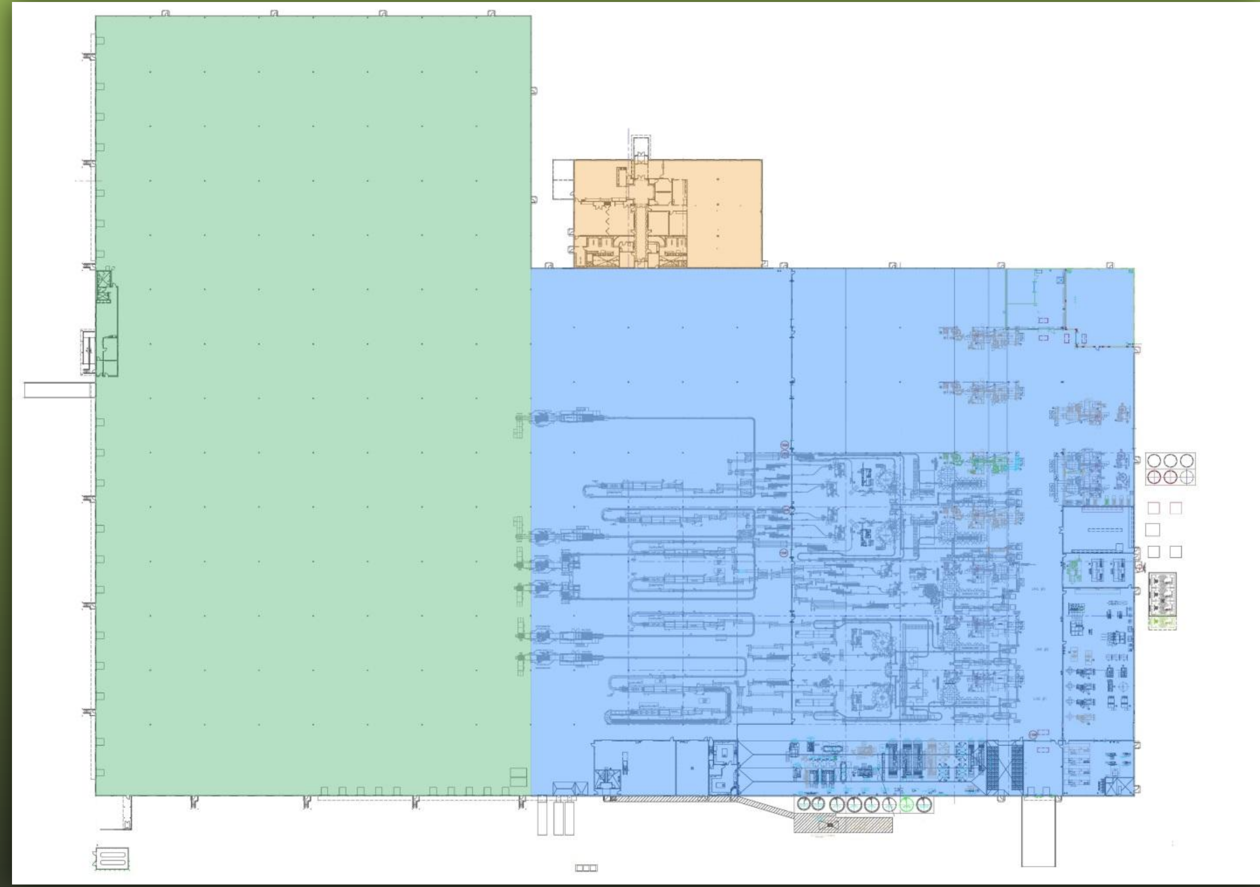

Introduction

- Water Bottling Facility
  - Production
  - Warehouse
  - Office
- Mid Atlantic Region
- 30 ft Ceiling Warehouse
- 23 ft 6 in Draft Curtain Production
- 8 – 30 ft Ceiling Office

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Introduction

Outdoor Design Conditions

	Summer Design Cooling (0.4%)	Winter Design Heating (99.6%)
OA Dry Bulb (°F)	88°F	5°F
OA Wet Bulb (°F)	72°F	-

Indoor Design Conditions

	Conditioned Process	Offices, QC Lab, & Parts Office	Warehouse & Packaging	Storage, Maintenance & Mechanical
Cooling Set Point	85°F	72°F	95°F	95°F
Heating Set Point	65°F	72°F	48°F	60°F
Relative Humidity	-	45%	-	-

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Existing Mechanical Systems

- Heating Water System
  - Only used for Manufacturing Purposes
- Chilled Water System
  - 3 Ammonia Chillers
  - 4 Cooling Towers
- Air Side
  - 5 Air Handing Units
  - 17 VAV Terminal Units
  - 8 Makeup Units

Space	Max Cooling Dry Bulb	Cooling Dew Point/Max	Relative Humidity	Min Heating Temperature
Warehouse	80°± 2°F	48°F/50°F	-	60°F
Shipping Office	74°F	-	45%	68°F
Main Office	74°F	-	45%	68°F
Production	80°± 2°F	48°F/50°F	-	60°F
Maintenance	104°± 2°F	-	45%	60°F
QC Lab	75°F	59°F/64°F	-	68°F
H-3 Essence	80°± 2°F	48°F/50°F	-	50°F
Mechanical	80°± 2°F	48°F/50°F	-	60°F

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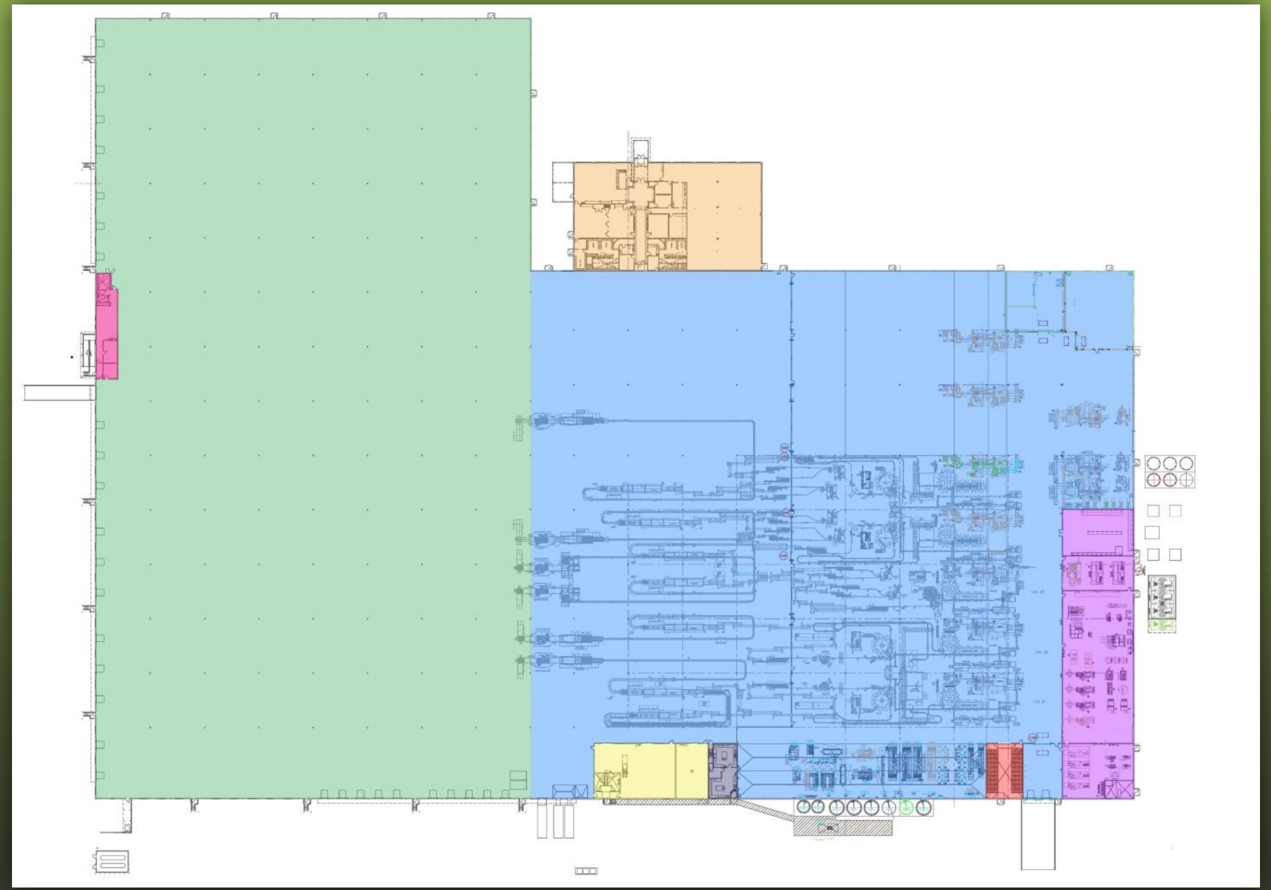
Existing Mechanical Systems



Warehouse	Shipping office	Main Office
Production Area	Maintenance	Quality Control Lab
H-3 Essence	Mechanical Rooms	

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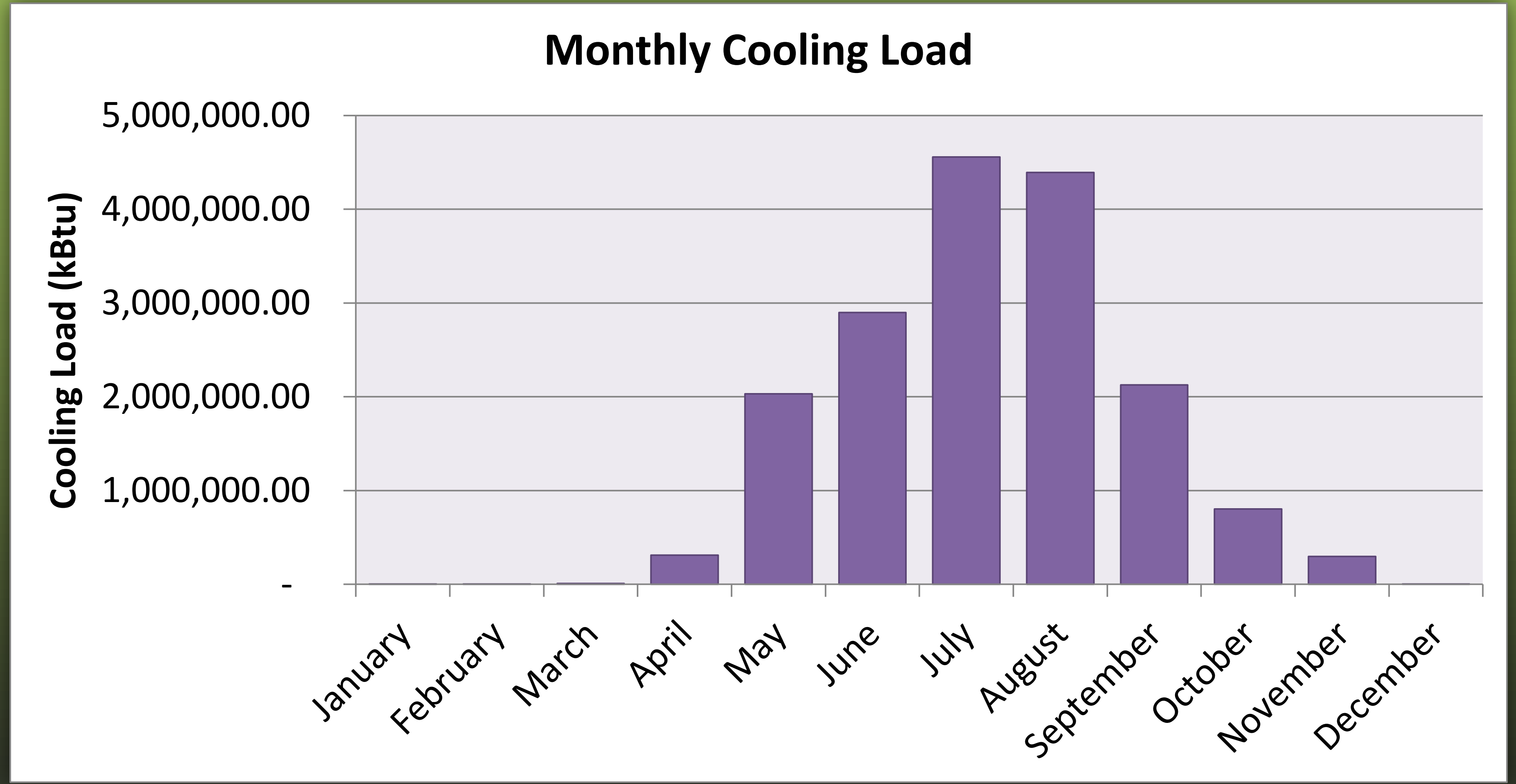
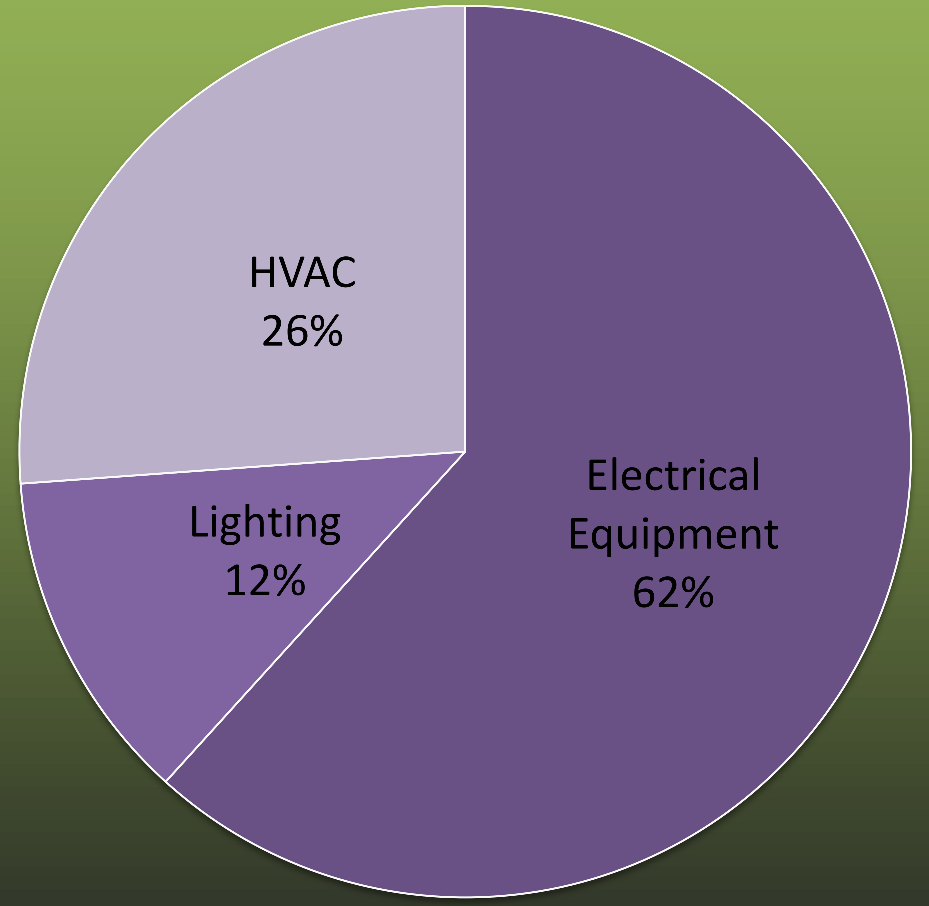
Existing Mechanical System





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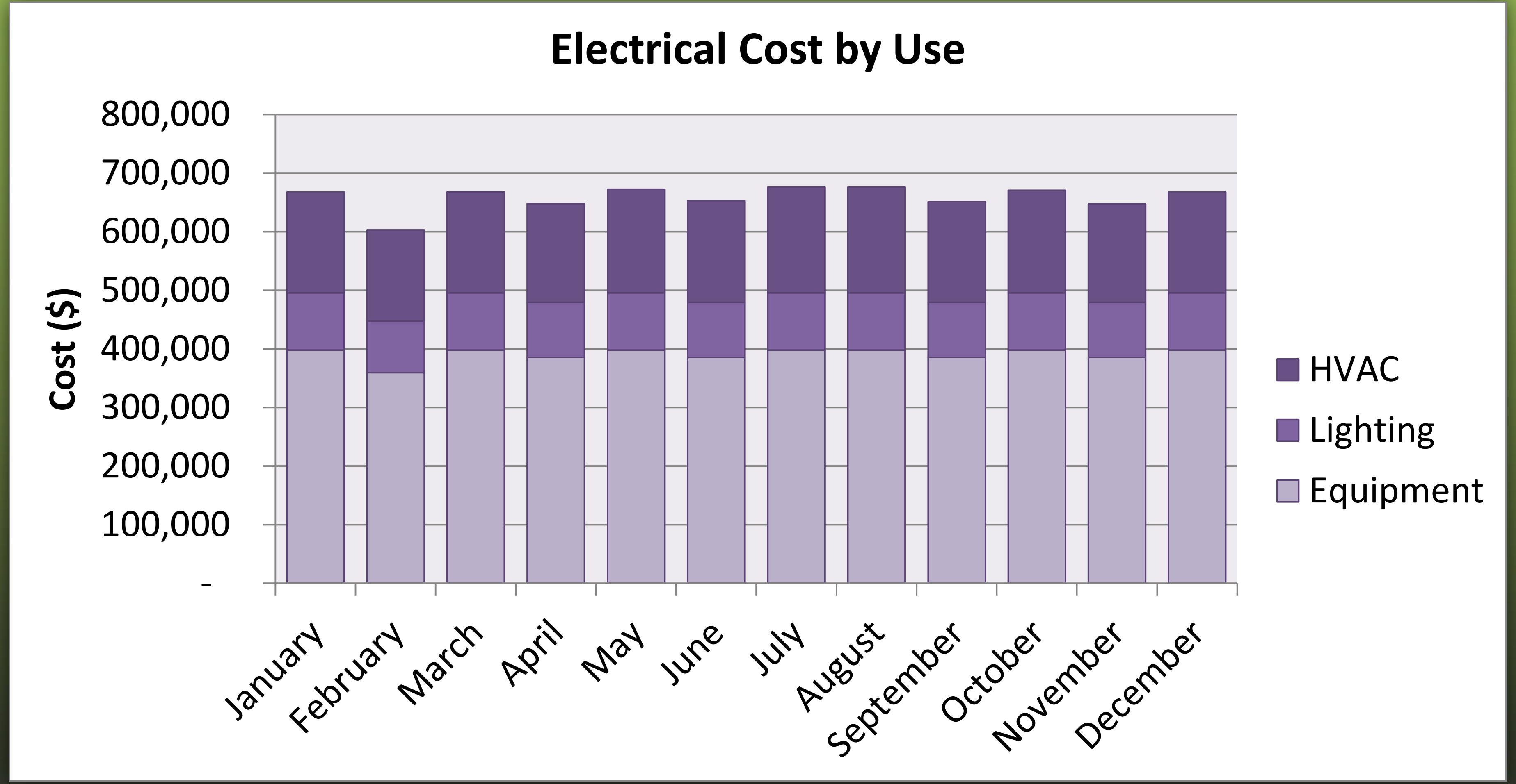
Existing Mechanical System

Function	Energy (kW)	Total Energy (%)
HVAC	27,354,233	28.1
Lighting	12,686,111	12.1
Electrical Equipment	64,583,837	61.7



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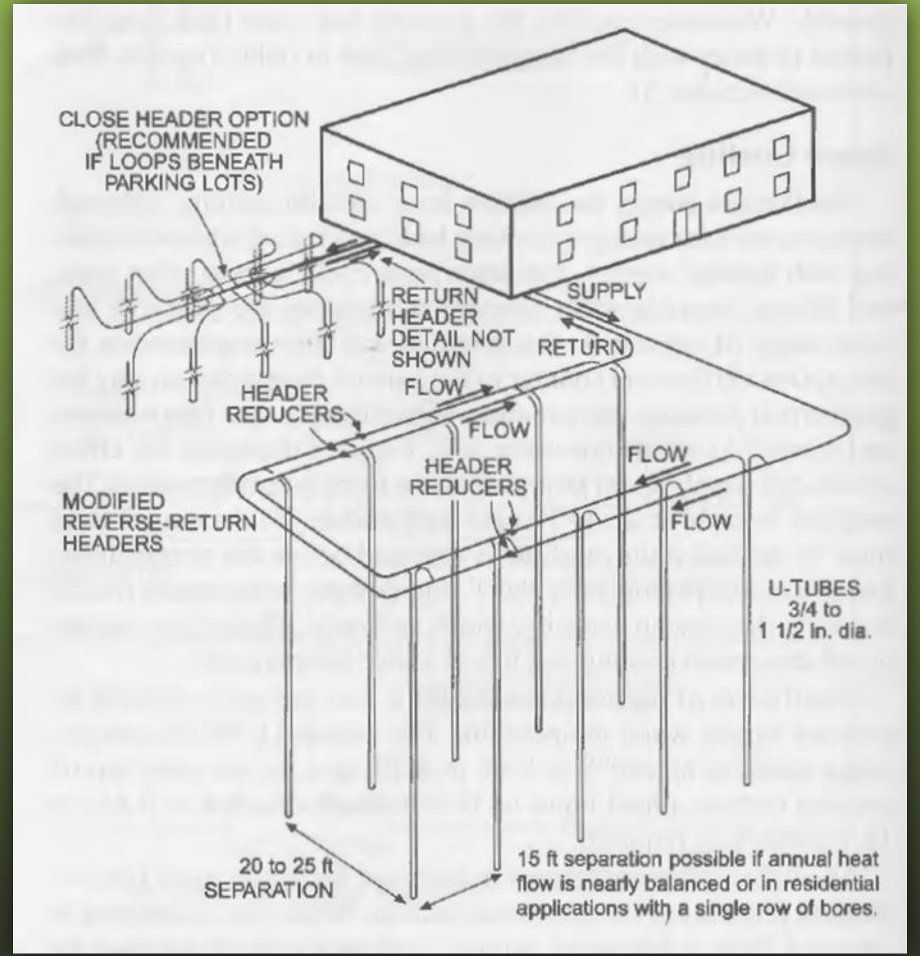
Ground Coupled Heat Pump

- Vertical Layout
  - Pros
    - Less Space
    - Maintains Thermal Properties of Ground
    - Less Pipe
    - Less Pump Energy
  - Cons
    - Expensive
    - Specialized equipment



- Pipe Sizing
  - 6” Diameter Bores
  - 1” Diameter U-Tube
- Bore Fill
  - 15% Bentonite, 85% SiO_2

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Ground Coupled Heat Pump

$$L_c = \frac{q_a R_{ga} + (q_{lc} - 3.41W_c)(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p} \quad (1)$$

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

F_{sc}	Short-Circuit Heat Loss Factor
PLF_m	Part-Load Factor during Design Month
q_a	Net Annual Average Heat Transfer to Ground
q_l	Building Design Block Load
R_{ga}, R_{gd}, R_{gm}	Effective Thermal Resistance of Ground
R_b	Thermal Resistance of Bore
t_g	Undisturbed Ground Temperature
t_p	Temperature Penalty for Interference of Adjacent Bores
t_{wi}, t_{wo}	Liquid Temperature at Heat Pump
W	System Power Input at Design Load

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Ground Coupled Heat Pump

- Short-Circuit Heat Loss Factor, F_{sc}
  - 1 bore/loop + 3 gpm/loop = 1.04 short-circuit heat loss factor
- Part-Load Factor during Design Month, PLF_{m}
  - Unknown therefore use maximum of 1.0
- Building Design Block Load, q_{lc}(Cooling), q_{lh} (Heating)
  - Found using block load analysis, 6,125,519 Btu/hr & 0 Btu/hr
- Net Annual Average Heat Transfer to Ground, q_a
  - Difference between heating and cooling, 6,125,519 Btu/hr

- Undisturbed Ground Temperature, t_g

Average Ground Temperature
53°

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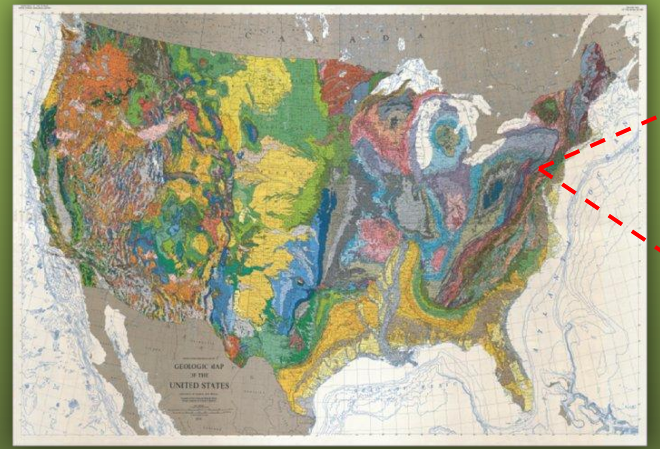
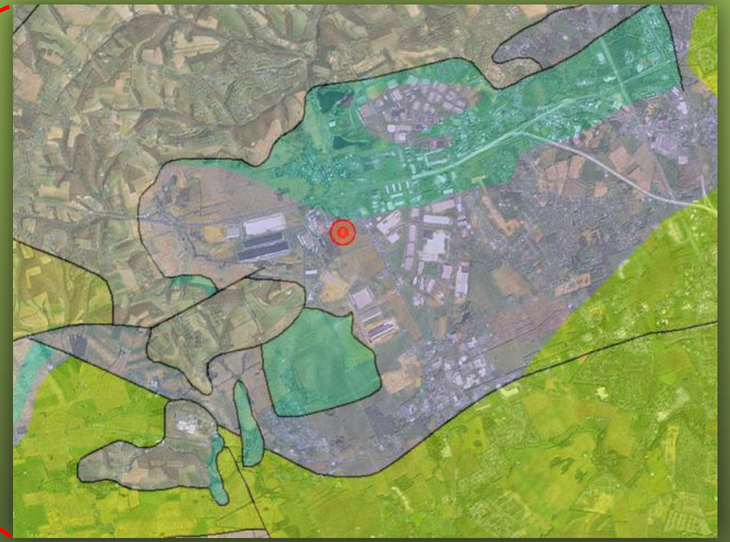
Ground Coupled Heat Pump

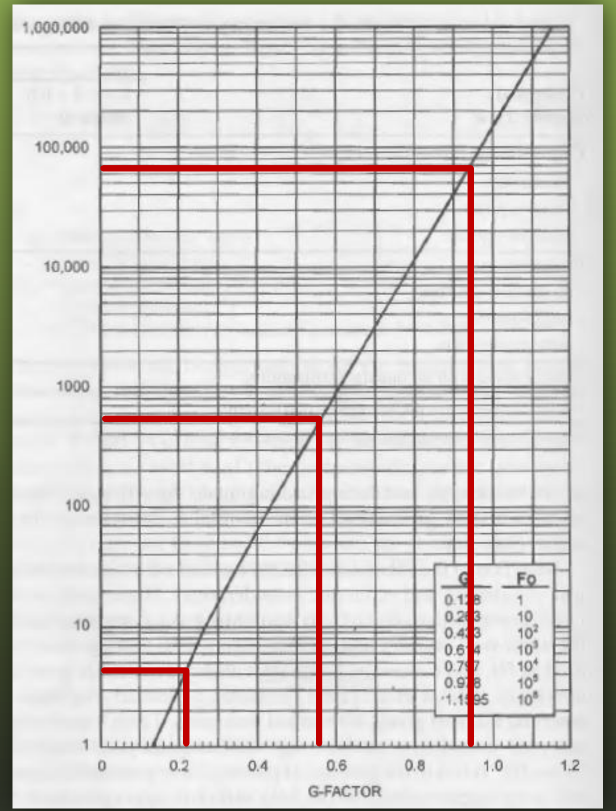




Rock Type	Dry Density (lb/ft³)	Conductivity (Btu/h·ft·°F)	Diffusivity (ft²/day)
Limestone	150 to 175	1.4 to 2.2	0.9 to 1.4
Average Value	162.5	1.8	1.15

- Effective Thermal Resistance of Ground, R_{ga} (Annual), R_{gd} (Daily), R_{gm} (Monthly)
  - Calculate Fourier number
  - Use table to find G-Factor
  - Calculate Thermal Resistance

Time Pulse	Fourier Number	G-Factor	Thermal Resistance (ft·h·°F/Btu)
Annual	67,716.6	0.94	0.211
Monthly	556.6	0.56	0.183
Daily Peak	4.6	0.22	0.122



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Ground Coupled Heat Pump

- Thermal Resistance of Bore, R_b
  - 15% Bentonite 85% SiO_2, 0.10 Btu/h·ft·°F
- Temperature Penalty for Interference of Adjacent Bores, t_p
  - 20 ft spacing results in a penalty of 1.8°F
- System Power Input at Design Load, W_c (Cooling), W_h (Heating)
  - Based on pump selection, 112,000 W

- Liquid Temperature at Heat Pump, t_{wi} (Inlet), t_{wo} (Outlet)
  - Inlet 20 to 30°F higher for heating, 10 to 20°F lower for cooling
    - 68°F Cooling
    - 38°F Heating
  - Outlet 10°F increase from inlet
    - 78°FCooling
    - 48°F Heating

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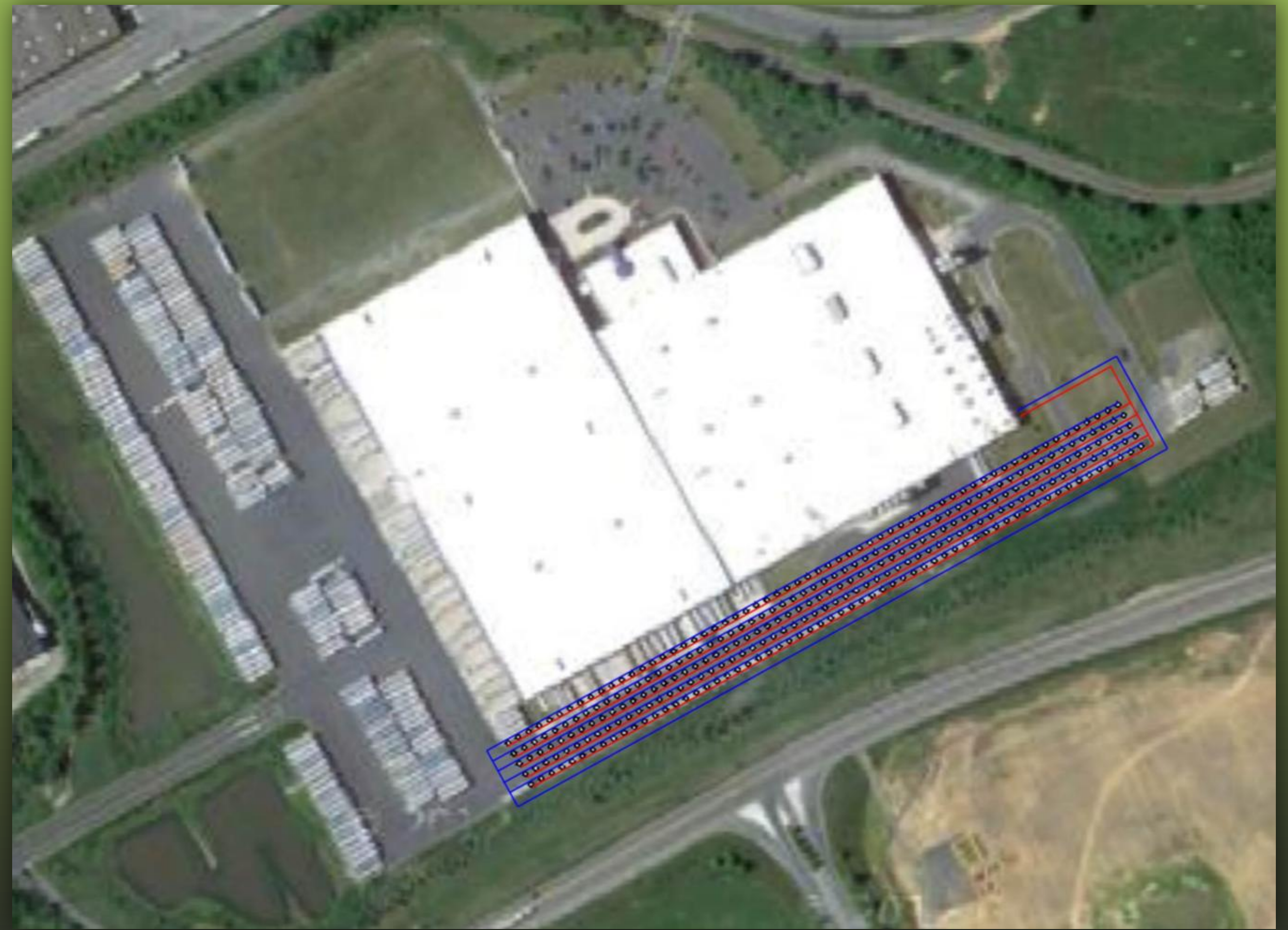
Ground Coupled Heat Pump

Variable	Cooling Value	Heating Value	Units
F_{sc}	1.04		-
PLF_m	1.0		-
q_a	6,125,519		Btu/h
q_l	6,125,519	0	Btu/h
R_{ga}	0.211		ft·h·°F/Btu
R_{gd}	0.183		ft·h·°F/Btu
R_{gm}	0.122		ft·h·°F/Btu
R_b	0.10		ft·h·°F/Btu
t_g	53		°F
t_p	1.8		°F
t_{wi}	78	38	°F
t_{wo}	88	48	°F
W	112,000	112,000	W
L	125,020	0	ft



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Ground Coupled Heat Pump

- Head Loss Calculations

	Length (ft)	Multiplicity	Total Length (ft)	Head Loss (ft/100 ft)	Total Head Loss (ft)
Bore	400	2	800	2.5	20
Longest Branch	20	60	1200	2.5	30
Tee-Fittings	7	2	14	2.5	0.35
Elbows	3.5	4	14	2.5	0.35
Total					50.7

	Length (ft)	Flow Rate (gpm)	Fittings	Equivalent Length (ft)	Head Loss (ft/100ft)	Total Head Loss (ft)
Header	2800	1531	6 90° elbows	66	3.5	100.31
1	100	1505	2 Tees	14	3.5	3.99
2	100	1480	2 Tees	14	3.5	3.99
3	100	1455	2 Tees	14	3.5	3.99
4	100	1430	2 Tees	14	3.5	3.99
5	100	1405	2 Tees	14	3	3.42
6	100	1380	2 Tees	14	2.5	2.85
⋮	⋮	⋮	⋮	⋮	⋮	⋮
60	100	25	2 Tees	14	0.7	0.798
Total						203.252

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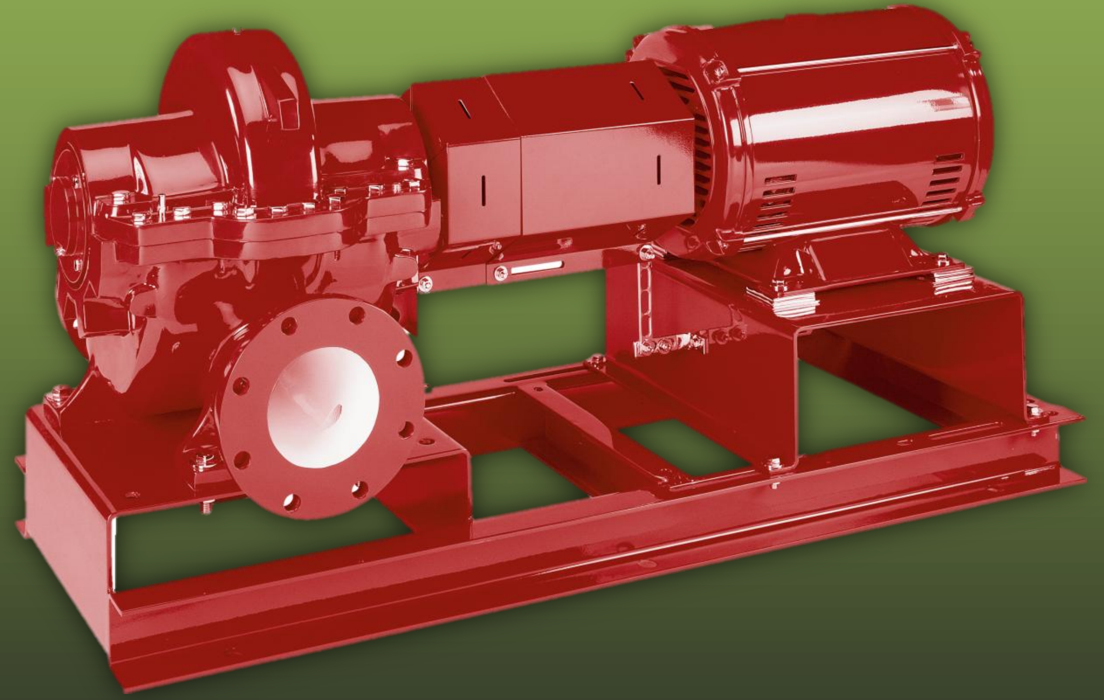
Ground Coupled Heat Pump

Pump

Manufacturer	Bell & Gossett
Model	4x6x10M HSC3
Flow Rate (gpm)	1531
Head (ft)	254
Impeller Diameter (in)	8.3
RPM	3565
HP	150



Heat Pump

- 21 Rooftop Units
  - Twenty 25 ton
  - One 10 ton

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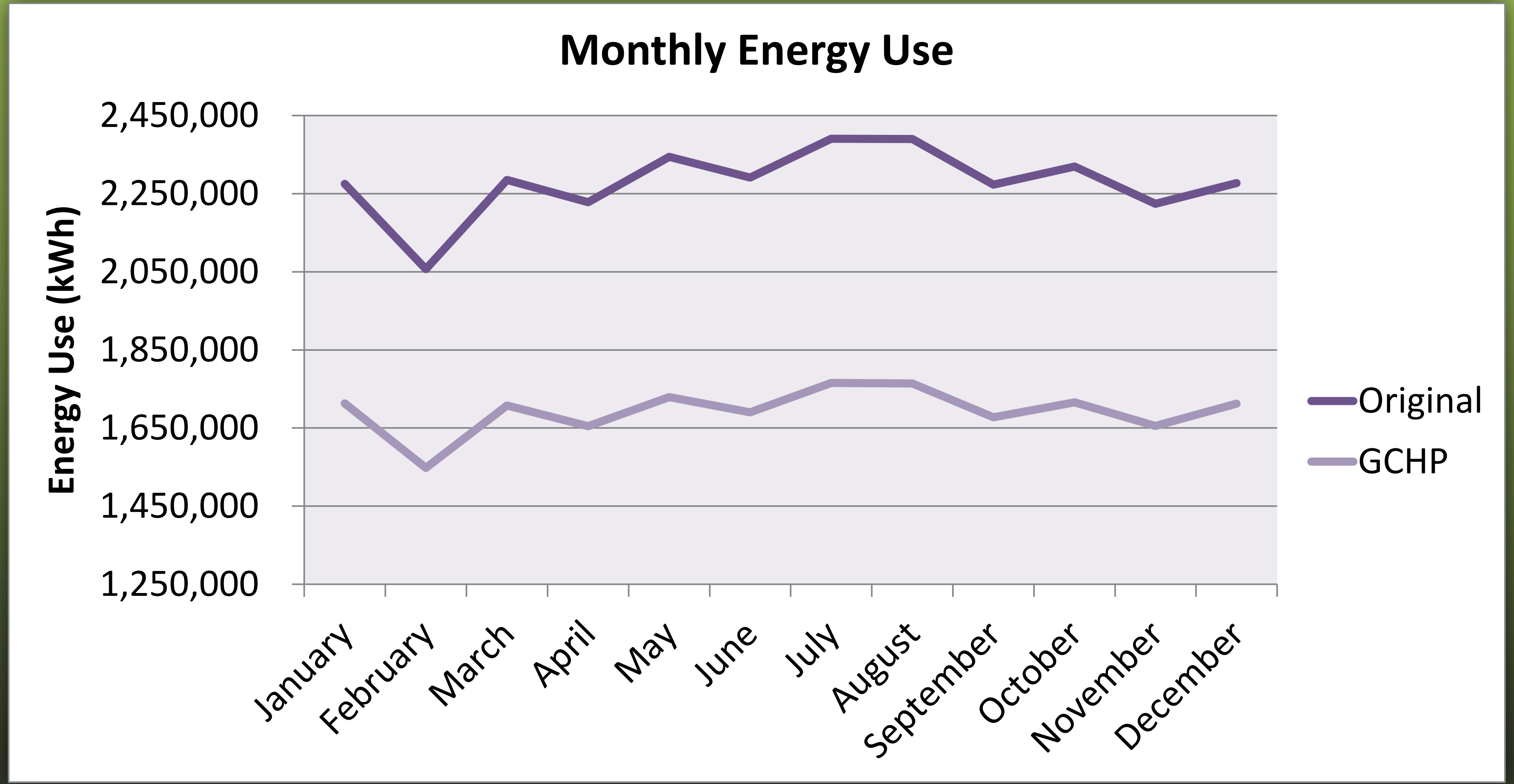
Cost Analysis



Month	Original Energy (kWh)	GCHP Energy (kWh)	Difference (kWh)
January	2,275,032	1,713,184	561,848
February	2,056,716	1,547,770	508,946
March	2,285,022	1,707,854	577,168
April	2,228,204	1,654,628	573,576
May	2,344,024	1,729,509	614,515
June	2,291,104	1,690,252	600,852
July	2,390,752	1,765,344	625,408
August	2,389,709	1,764,376	625,333
September	2,273,169	1,677,335	595,834
October	2,319,265	1,715,919	603,346
November	2,223,874	1,655,288	568,586
December	2,277,362	1,712,482	564,880
Largest Difference			116,462
Average Value			585,024

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Cost Analysis

Design	Energy Usage (kWh)	Electric Cost
Original	27,354,230	$ 2,065,428
Ground Source Heat Pump	19,201,080	$ 1,449,730
Difference	8,153,150	$ 615,698

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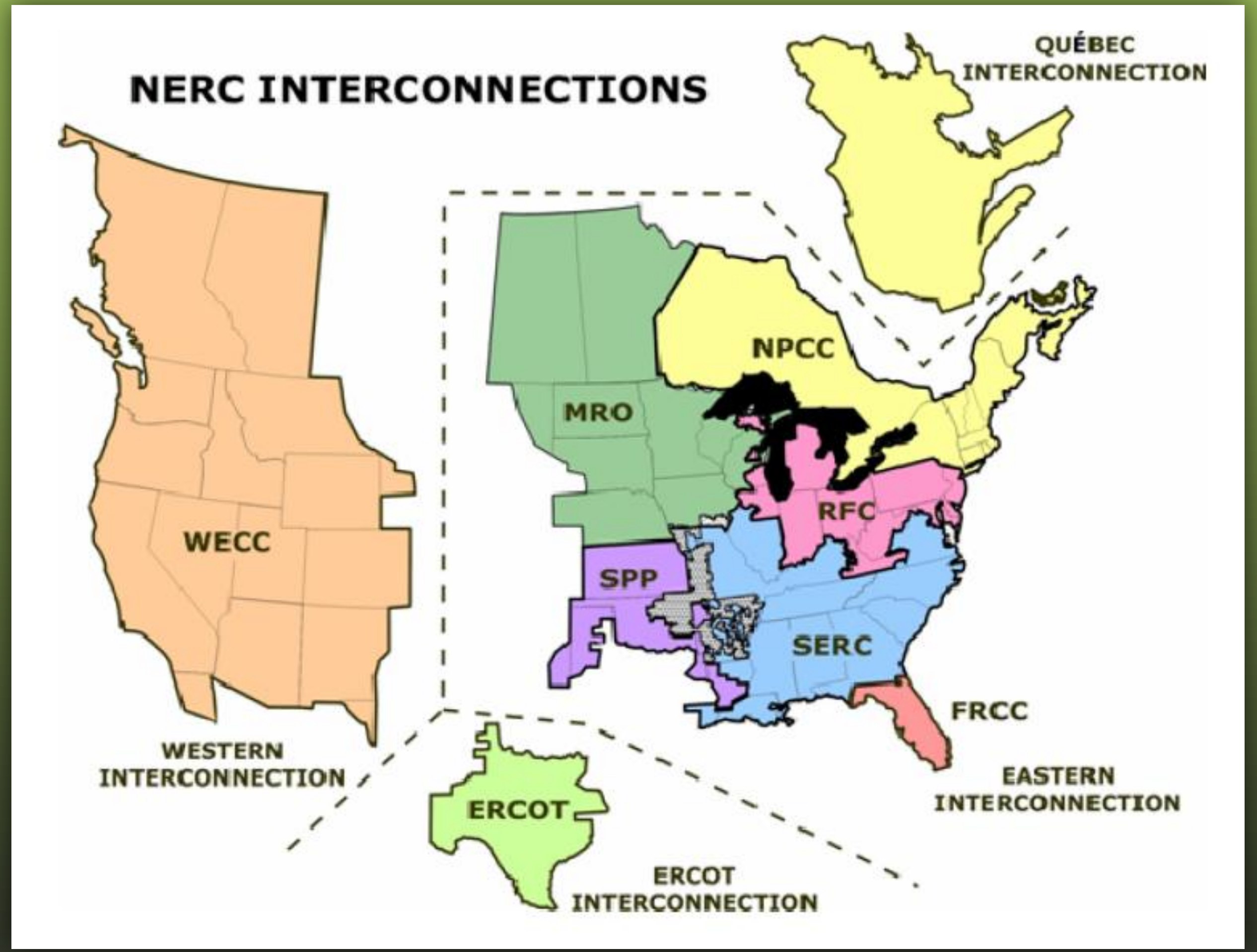
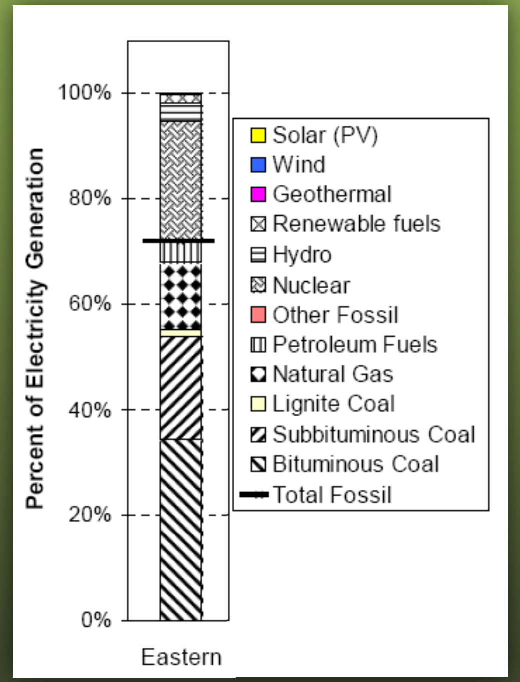
Emissions Analysis

Pollutant	Regional Grid Emission Factors 2007 (lb/kWh)	Calculated Emissions (lb/year)		Reduction in Emissions
		Original	GCHP	
$CO2_e$	1.74E+00	3.96E+06	2.98E+06	25%
CO_2	1.64E+00	3.37E+06	2.54E+06	25%
CH_4	3.59E-03	8.20E+03	6.13E+03	25%
N_2O	3.87E-05	8.62E+01	6.40E+01	26%
NO_X	3.00E-03	7.03E+03	5.19E+03	26%
SO_X	8.57E-03	1.96E+04	1.45E+04	26%
CO	8.54E-04	2.04E+03	1.51E+03	26%
TNMOC	7.26E-05	1.73E+02	1.28E+02	26%
Lead	1.39E-07	3.16E-01	2.33E-01	26%
Mercury	3.36E-08	7.79E-02	5.77E-02	26%
PM10	9.26E-05	2.06E+02	1.53E+02	26%
Solid Waste	2.05E-01	4.67E+05	3.51E+05	25%





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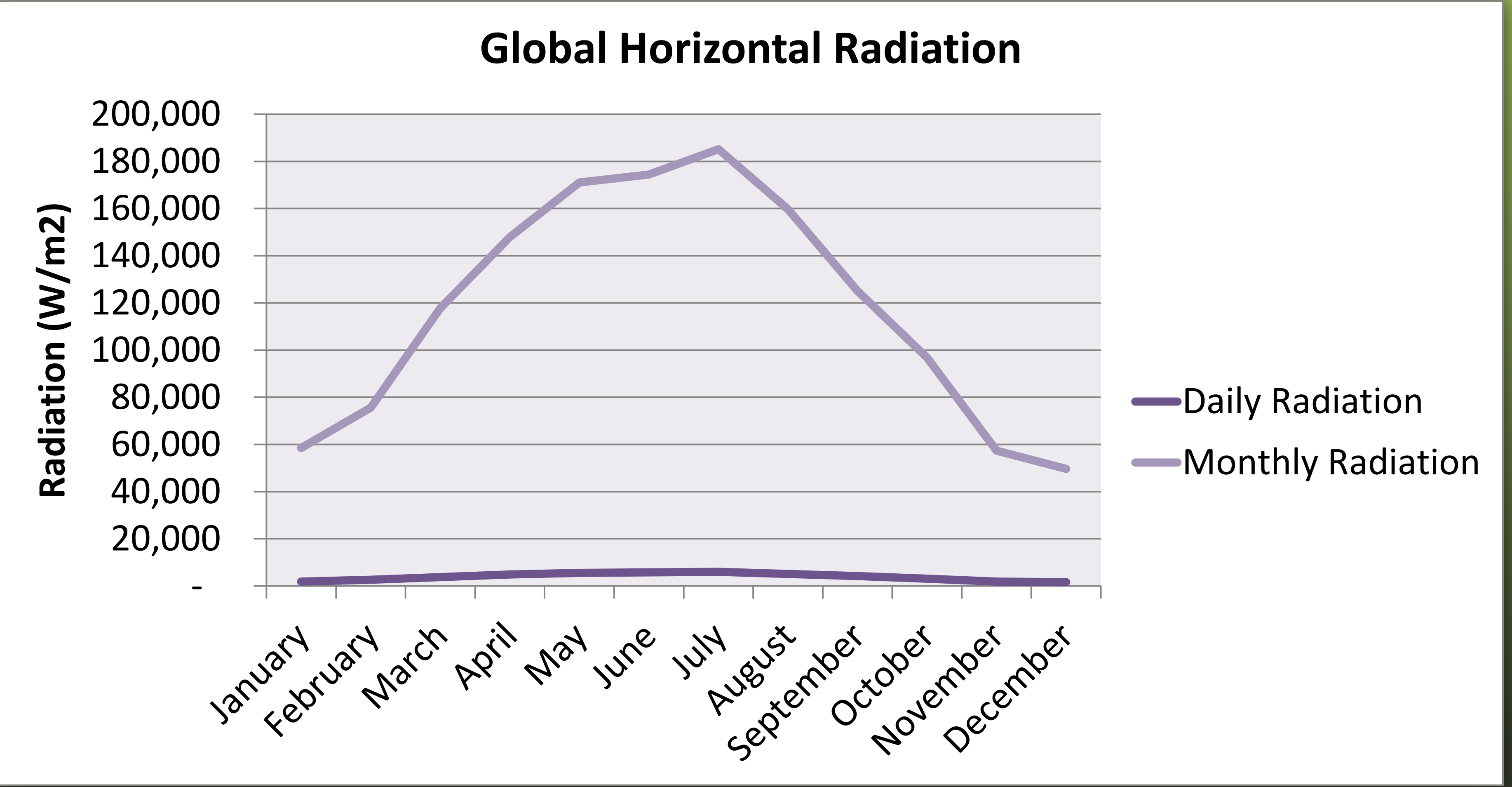
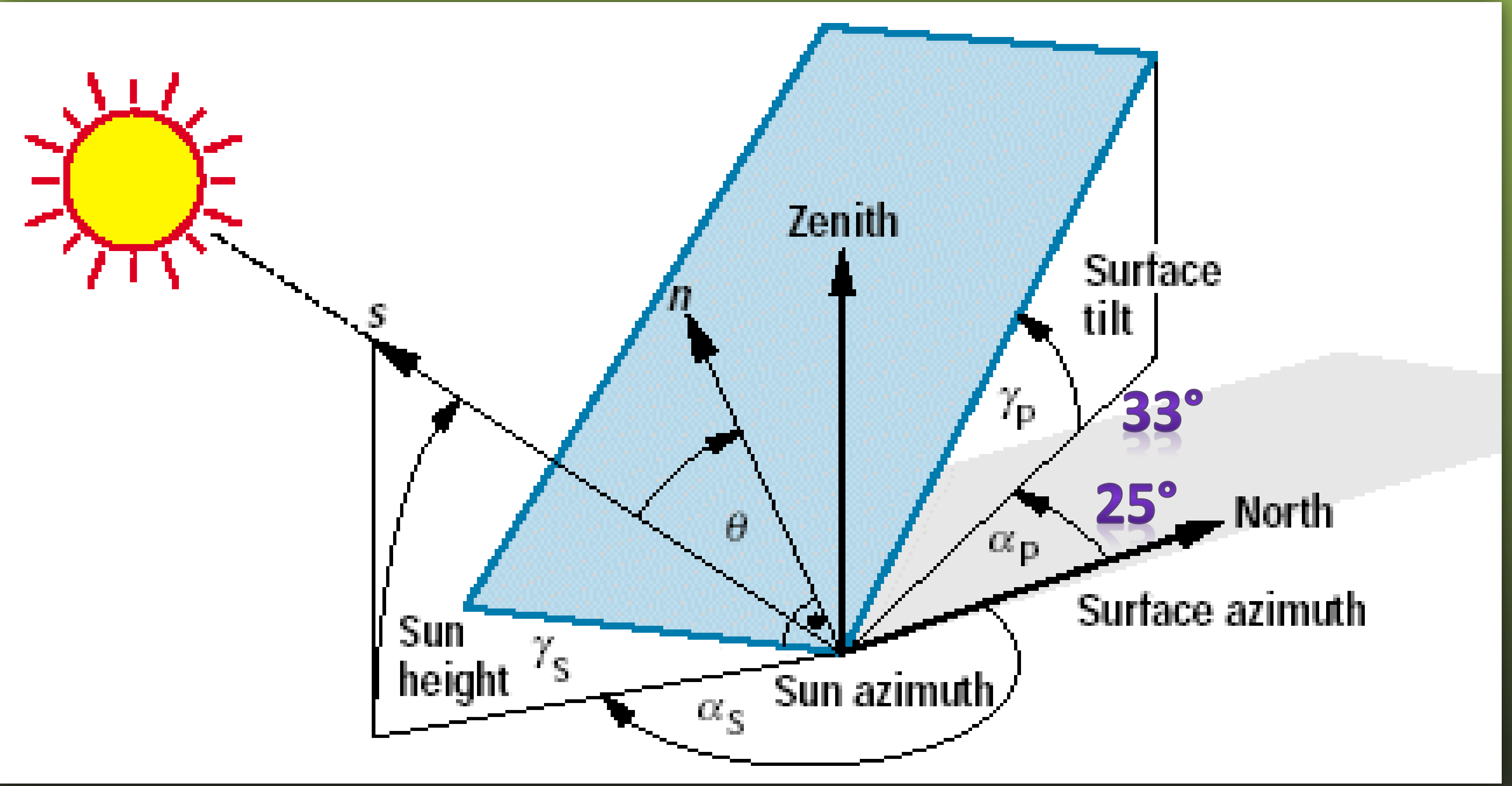
Photovoltaic Design





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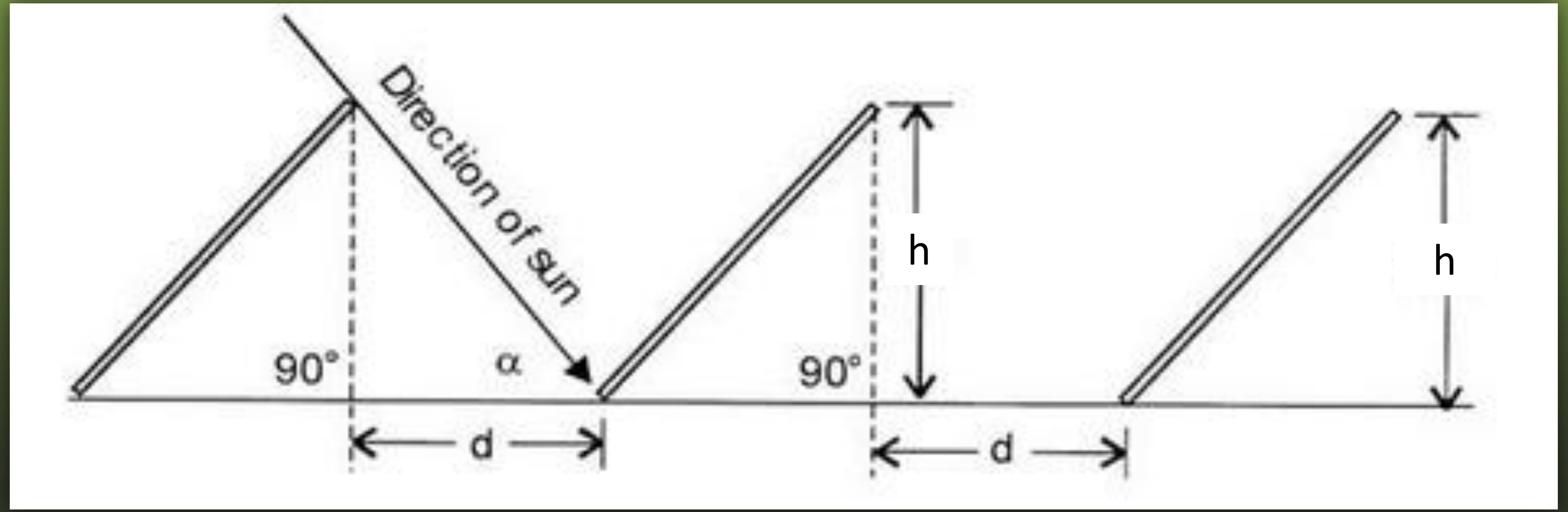
Photovoltaic Design

Sharp ND-F4Q300 Electrical Characteristics	
Maximum Power (P_{max})	300 W
Open Circuit Voltage (V_{oc})	45.1 V
Maximum Power Voltage (V_{pm})	35.2 V
Short Circuit Current (I_{sc})	8.94 A
Maximum Power Current (I_{pm})	8.52 A
Module Efficiency (%)	15.3%
Maximum System (DC) Voltage	1000 V
Temperature Coefficient (P_{max})	-0.439%/°C
Temperature Coefficient (V_{oc})	-0.321%/°C
Temperature Coefficient (I_{sc})	0.050%/°C

Panel Length	Panel Width	Array Tilt Angle	Height From Ground	Horizontal Length	Distance Between Panels	Row Spacing
39.1 in	77.6 in	33°	21.3 in	32.8 in	63.9 in	96.7 in



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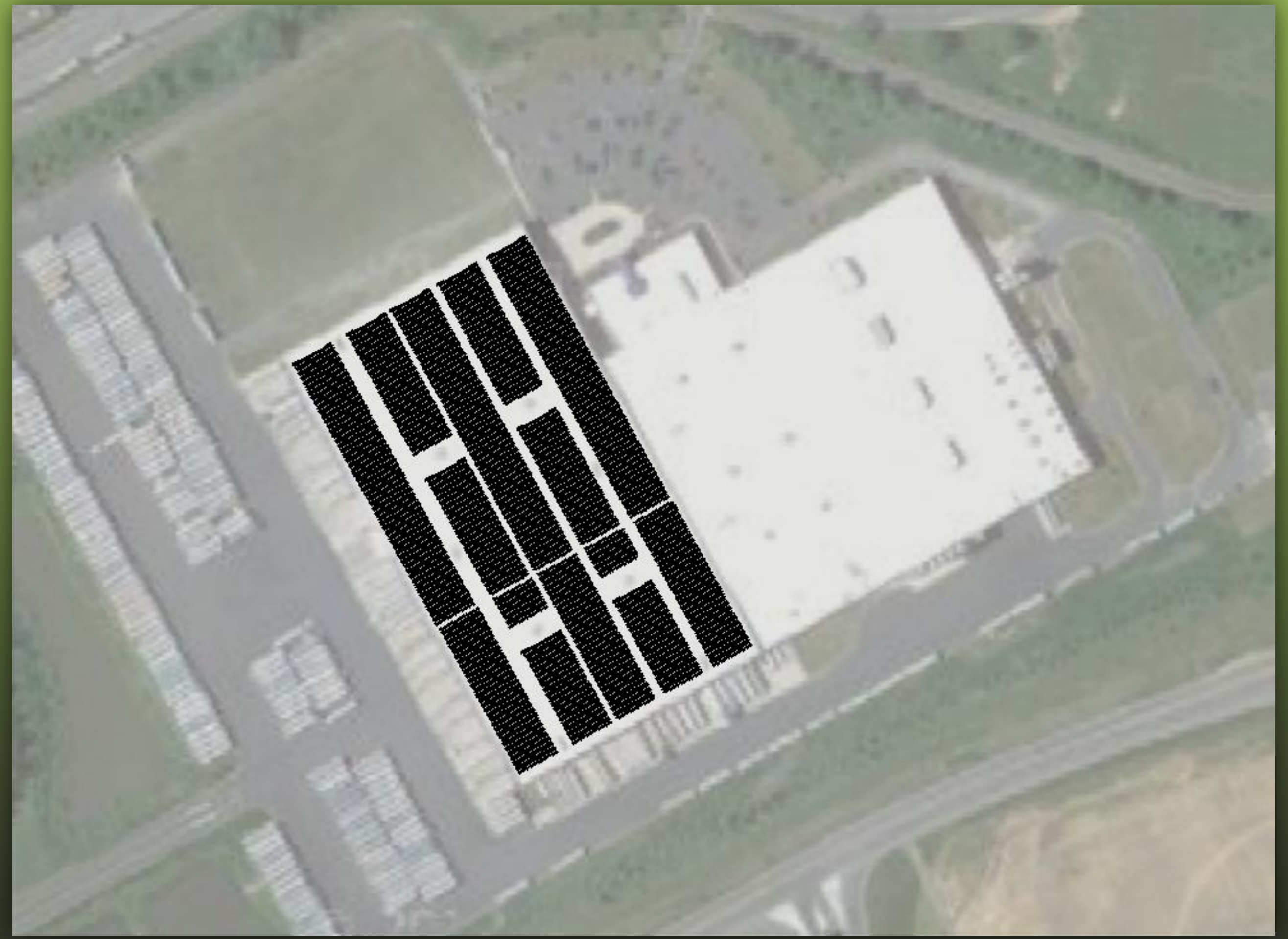
Photovoltaic Design

Month	Beam Incident Radiation (kWh/m2)	Total Incident Radiation (kWh/m2)	Net DC Output (kWh)	Net AC Output (kWh)
January	55.95	90.61	50,402	41,602
February	50.55	97.46	84,698	75,567
March	76.06	134.88	154,112	142,010
April	79.07	146.97	226,988	212,703
May	77.37	153.18	274,686	258,784
June	69.07	151.30	275,015	259,367
July	83.74	163.15	295,087	278,953
August	80.86	152.08	237,668	223,063
September	74.28	134.93	165,337	153,409
October	76.37	124.04	93,685	83,602
November	43.55	80.11	55,004	46,542
December	50.17	79.11	42,569	34,245



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Photovoltaic Design

	# of units	kW/unit	kW	$/W	Total
Module	7695	0.3	2307.76	2.05	$ 4,730,910.62
Inverter	5	500	2500	0.37	$ 925,000.00
Balancing	-	-	-	0.43	$ 992,337.3
Installation Labor	-	-	-	0.48	$ 1,107,725.41
Margin And Overhead	-	-	-	0.81	$ 1,869,286.64
Permitting	-	-	-	0.23	$ 530,785.09
Grid Interconnection	-	-	-	0.01	$ 23,077.61
Total				$ 4.62	$ 10,660,385.73

- Payback Period
  - Infinite

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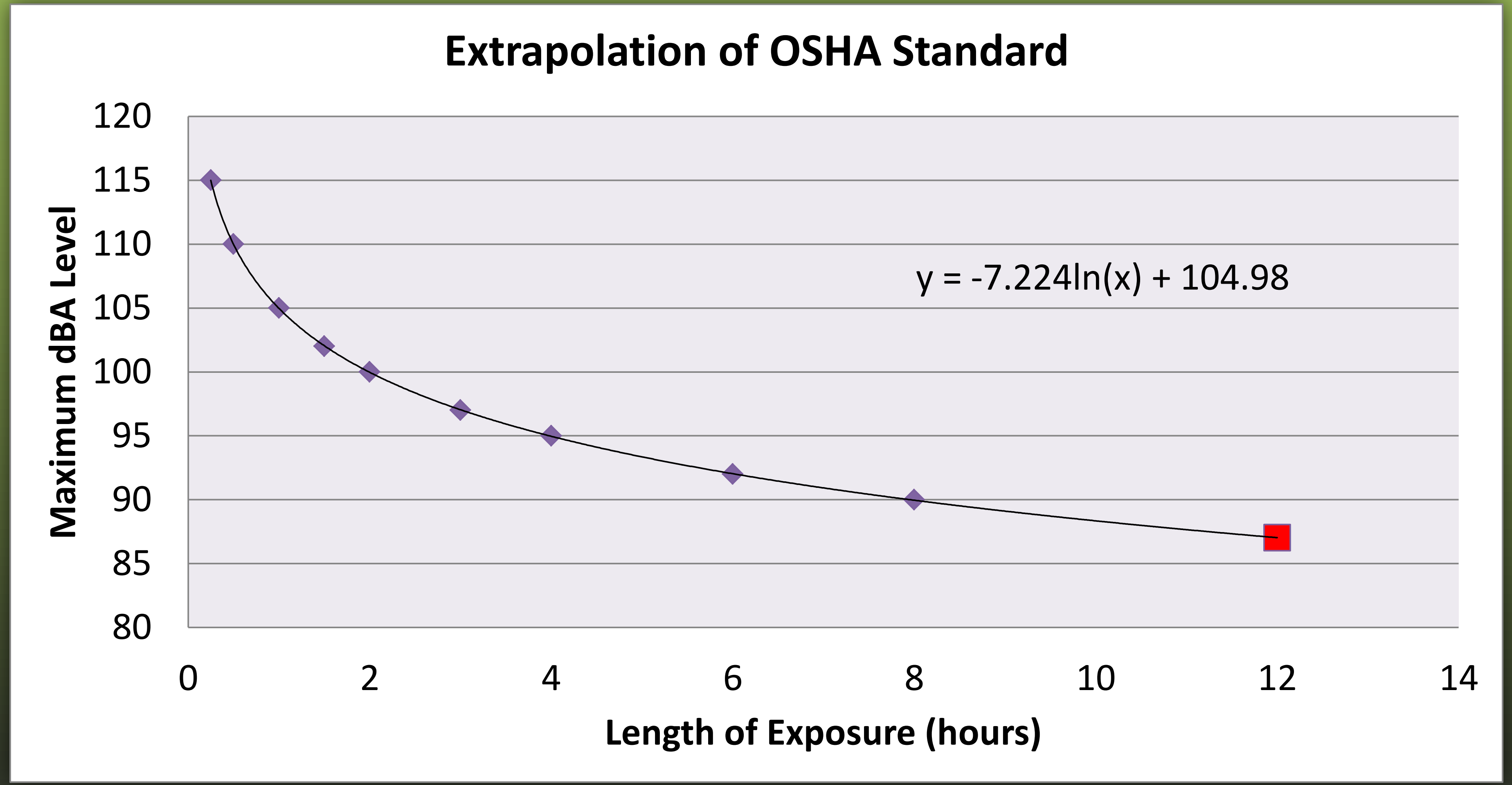
Acoustical Design

Duration Per Day (h)	Sound Level (dBA)
8	90
6	92
4	95
3	97
2	100
1 ½	102
1	105
½	110
¼ or less	115



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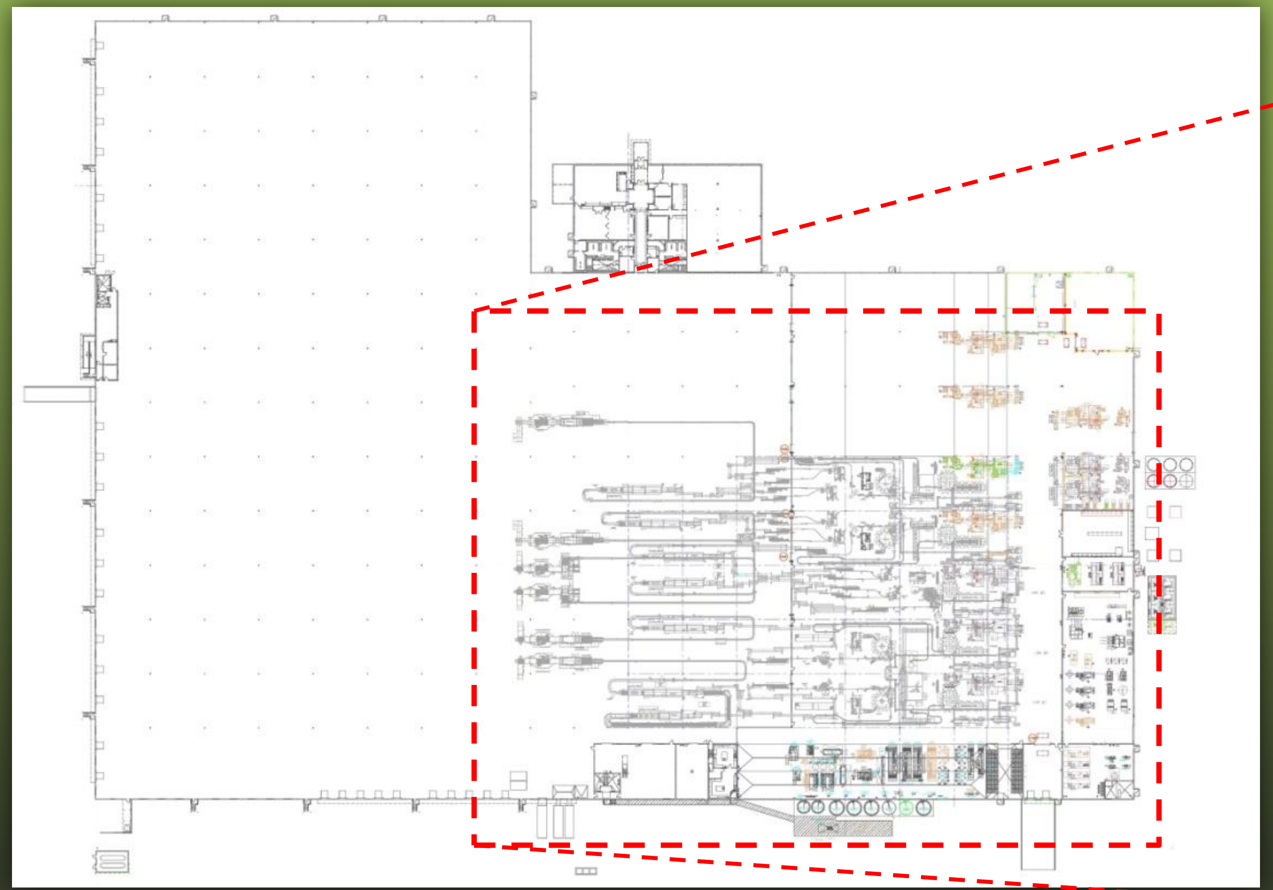
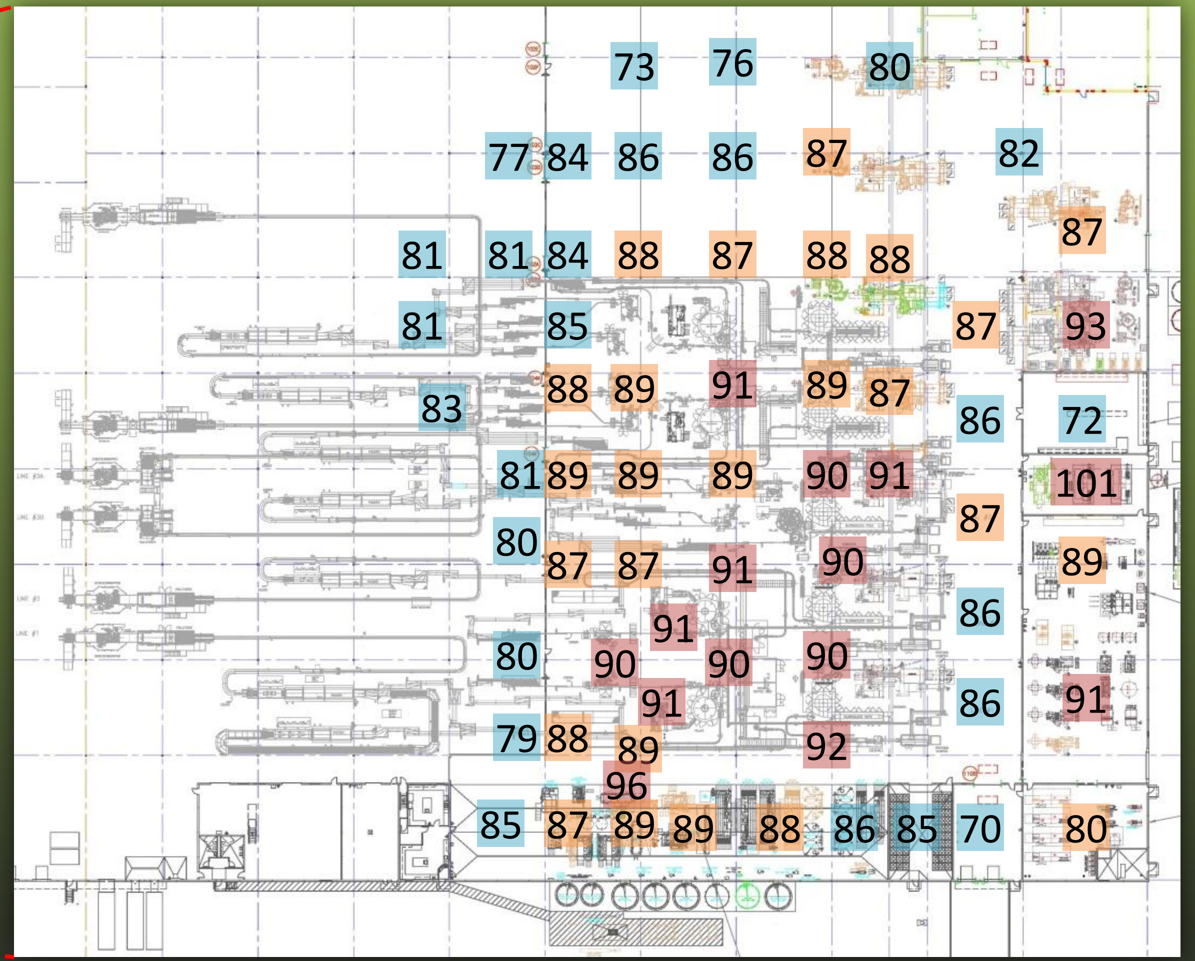
Acoustical Design





SL < 87 dBA

87dBA ≤ SL <90 dBA

SL ≥ 90 dBA

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Acoustical Design

Step 1: Determine Surface Area

Surface	Dimensions (ft)	Number of Surfaces	Area (ft^2)
Walls	23.5 x 315 23.5 x 439	2 2	14,805 20,633
Floor	315 x 439	1	138,285
Ceiling	315 x 439	1	138,285
Total			312,008

Step 2: Determine Overall Acoustical Character

Surface	Acoustical Characteristic
Walls:	Hard x 5 (Concrete) Medium x 1 (Stacked Pallets)
Floor:	Hard (Concrete)
Ceiling:	Hard (Steel)
Combined Characteristic:	Medium Hard

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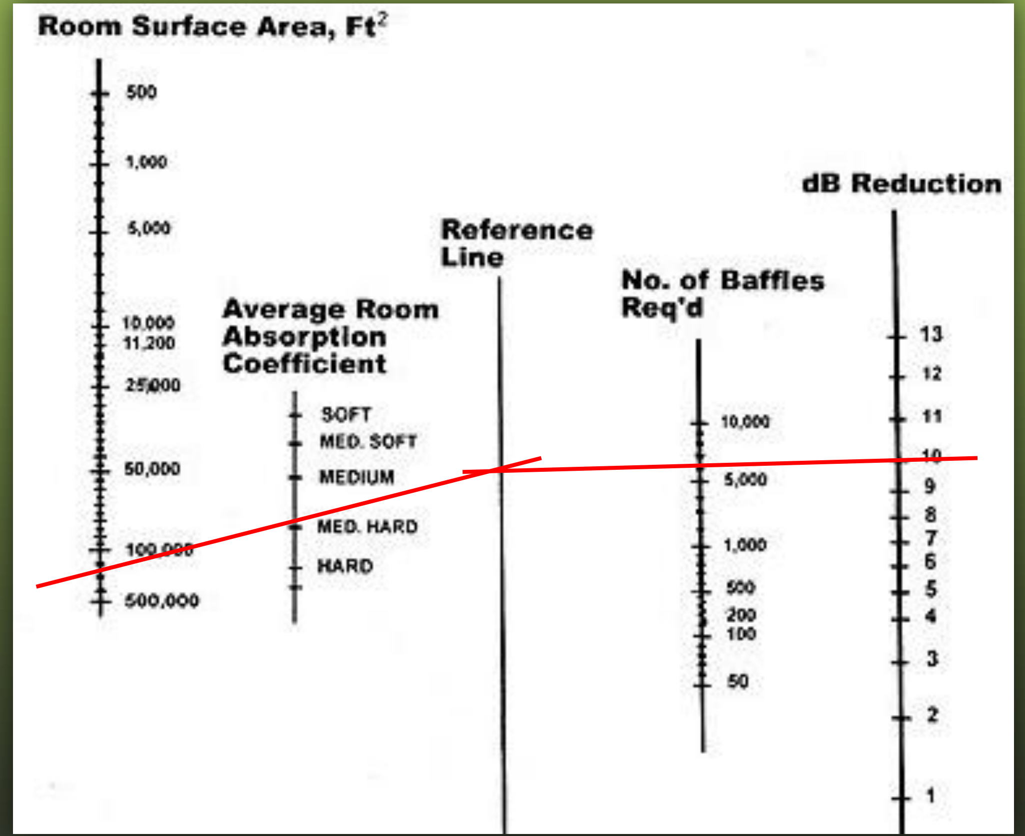
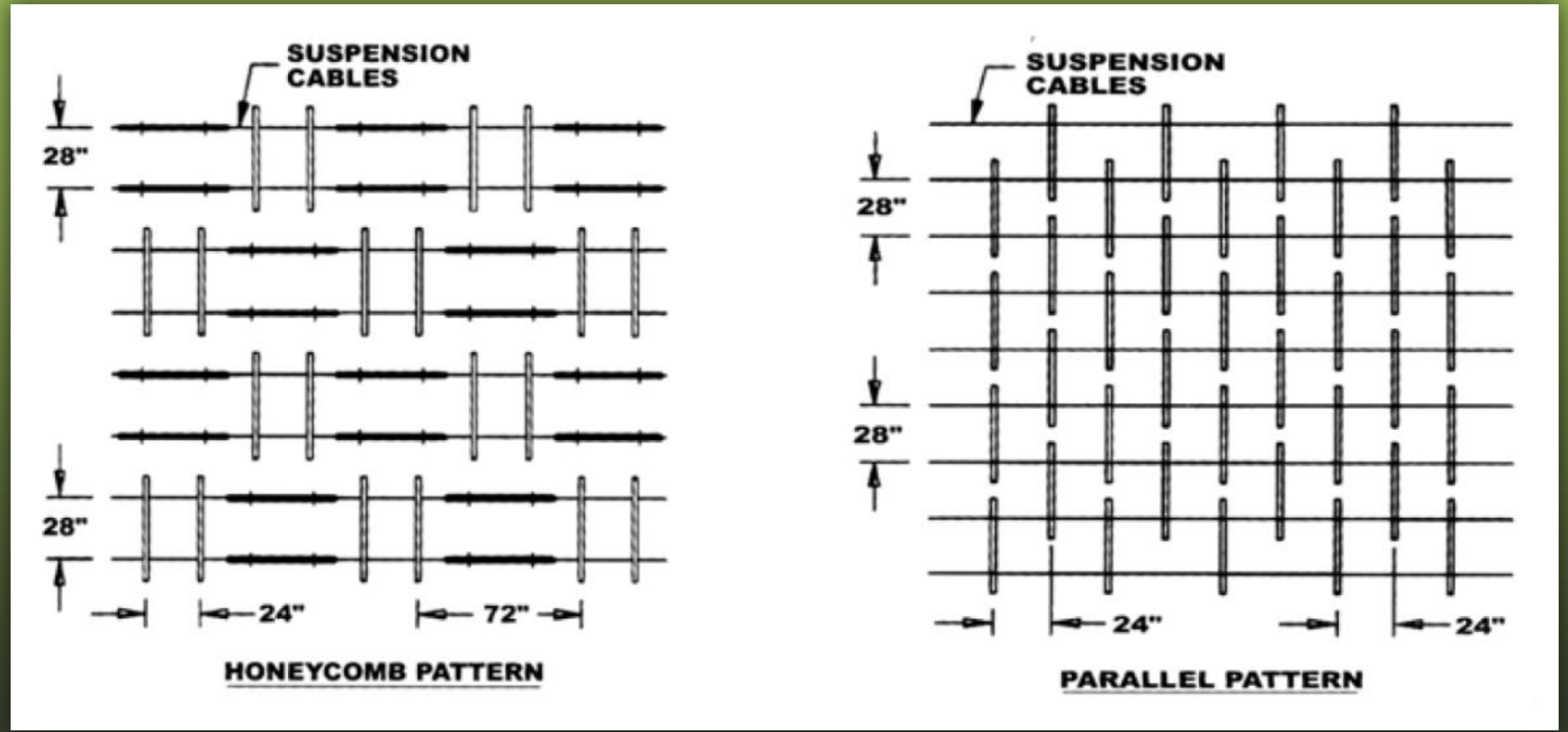
Acoustical Design

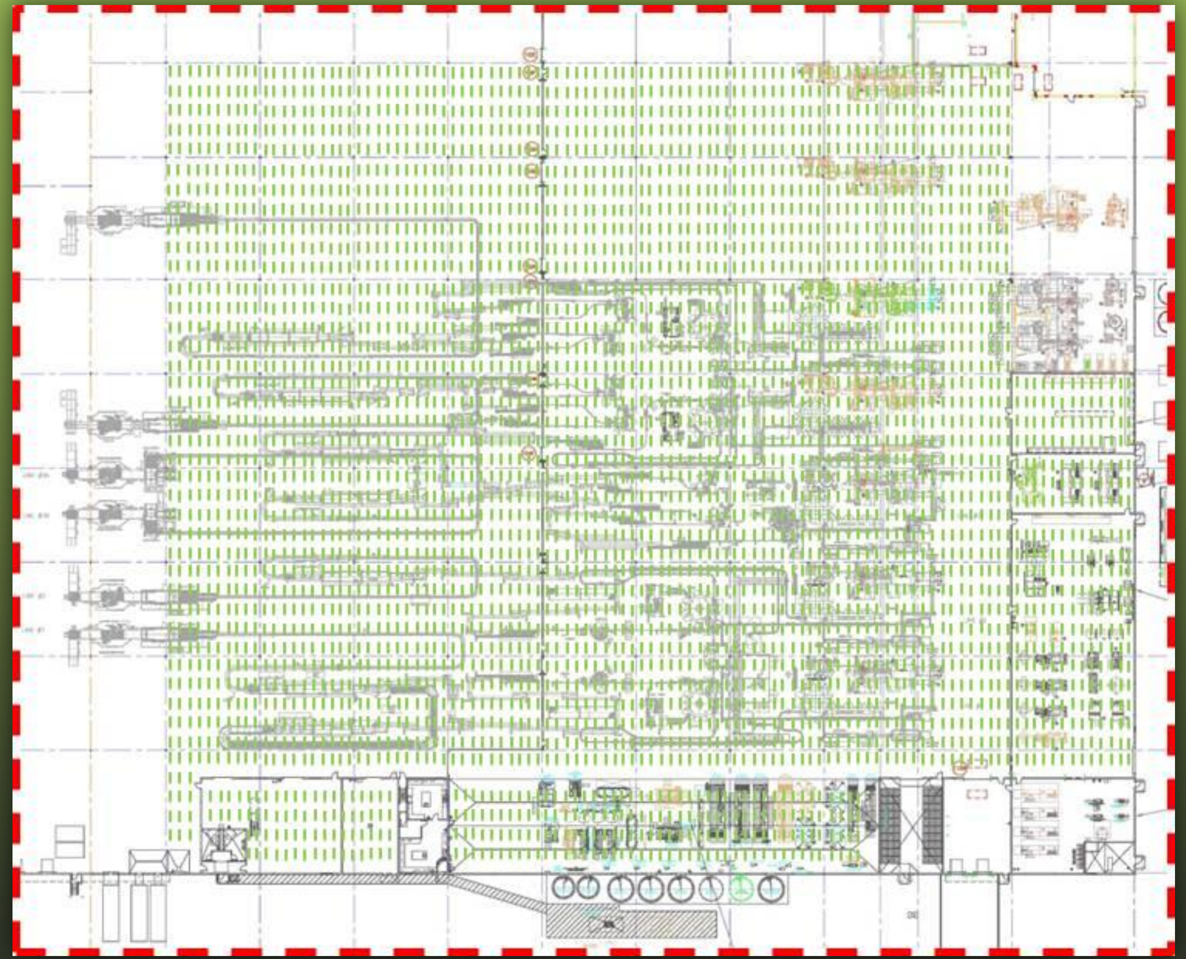
Steps 3-5: Plot Information from Previous Steps on Nomogram



Quality	Results
Room Surface Area (ft^2)	312,008
Average Room Absorption Coefficient	Medium Hard
dB Reduction (dBA)	10
Number of Baffles Required	6,000

Acoustical Design





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Conclusion

- Ground Coupled Heat Pump
  - Save Money
  - Reduce Emissions
- Photovoltaics
  - Not Feasible
- Acoustics
  - Able to reduce the Sound Level by 10 dBA

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Acknowledgements

Thank You!

AE Professors, Advisors, & Staff
The Water Bottling Facility
Jack, Ron, & Chris
My Parents & Family
My Friends & Classmates

Water Bottling Facility

Mid-Atlantic United States

Mechanical Option | Spring 2013

Advised by Dr. William Bahnfleth

Justyne Neborak

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QUESTIONS?