SUPPORT SERVICES BUILDING

PENN STATE MILTON S. HERSHEY MEDICAL CENTER

PENN STATE AE SENIOR THESIS FINAL PRESENTATION

WILL LAZRATION

CONSTRUCTION MANAGEMENT - DR. RILEY

PRESENTATION OUTLINE

- I. **PROJECT BACKGROUND**
- II. **ANALYSIS #1: FOUNDATION RE-DESIGN**
  - I. Initial Conditions
  - II. Re-Design
- III. **ANALYSIS #2: ROOFING**
  - I. Part I: Roofing Type Comparison
  - II. Part II: Elimination of Offset Roof
- IV. **ANALYSIS #3: RENEWABLE ENERGY SOURCES**
  - I. Part I: Geothermal System
  - II. Part II: Installation of PV Array
    - I. Site Analysis
    - II. System Design (Electrical Breadth)
- V. LESSONS LEARNED
- VI. ACKNOWLEDGEMENTS

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OWNER:
- Pennsylvania State University
  - Hershey Medical Center

LOCATION:
- Hershey Medical Center – Hershey PA

BUILDING INFORMATION
- 42,796 SF
- 2 Stories + 1,000 SF Basement
- Built Atop Existing Utility Tunnel

PROJECT INFORMATION
- Delivery Method: Design-Bid-Build
- Contract Type: CM @ Risk
- Project Cost: $14,395,331.00 GMP
- Constriction Dates: 6-1-2010 – 8-31-2011

STRUCTURAL SYSTEM

- Micropiles
- Pile caps and gradebeams
- Rigid Structural Steel Frame

EXTERIOR ENCLOSURE:

- Arriscraft Masonry veneer with CMU backup
- Centria Metal Panels
- Glazed Aluminum Curtain Wall
- 3-ply Cold Applied Built-Up Roof

ANALYSIS I: FOUNDATION REDESIGN

PROBLEM IDENTIFICATION

- Micropile foundation recommendations based on significantly larger loads
- Micropiles are expensive
- Installation Issue arose on project

RESEARCH GOALS

- Perform preliminary foundation resign
- Reduce total project cost
- Reduce overall project schedule

ANALYSIS I: FOUNDATION REDESIGN

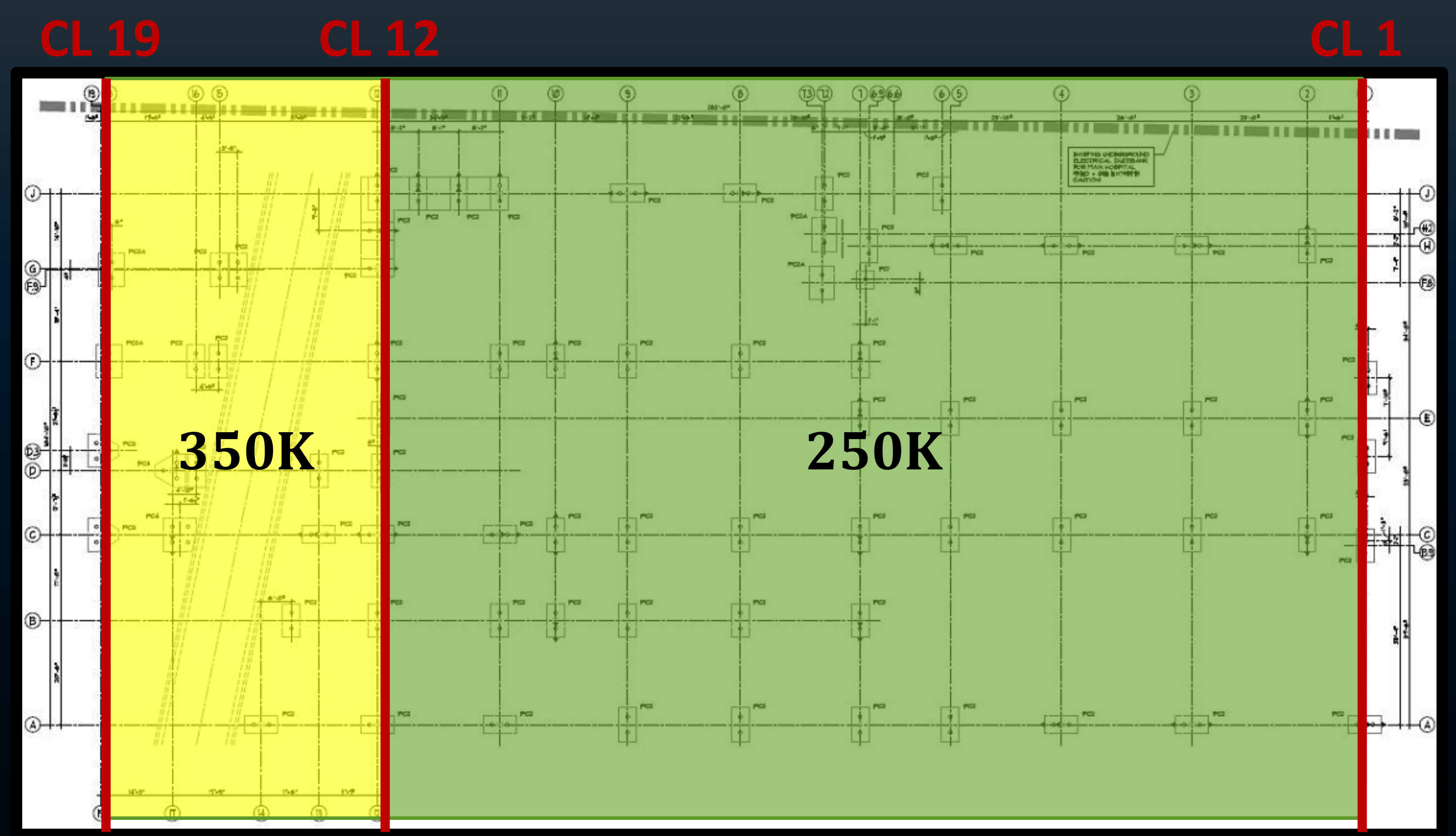
GEOTECHNICAL REPORT REVIEW

- Based on 350K and 250K Column Loads
- Karstic Bedrock (average depth: 40ft)
- Mostly moist & stiff Silts & Clays
- Bearing Capacity 2,000 PSF

ACTUAL COLUMN LOADS & ESTIMATED SETTLEMENTS

- 350K loads acceptable,
- 250K >> 98K Average (196K Max, 20K Min)
- Settlements still >1” (Column lines 1-12)

=> Soil Improvement Needed



PRESENTATION OUTLINE:

Image Taken from www.geopier.com

GEOPIER RAMMED AGGREGATE PIERS

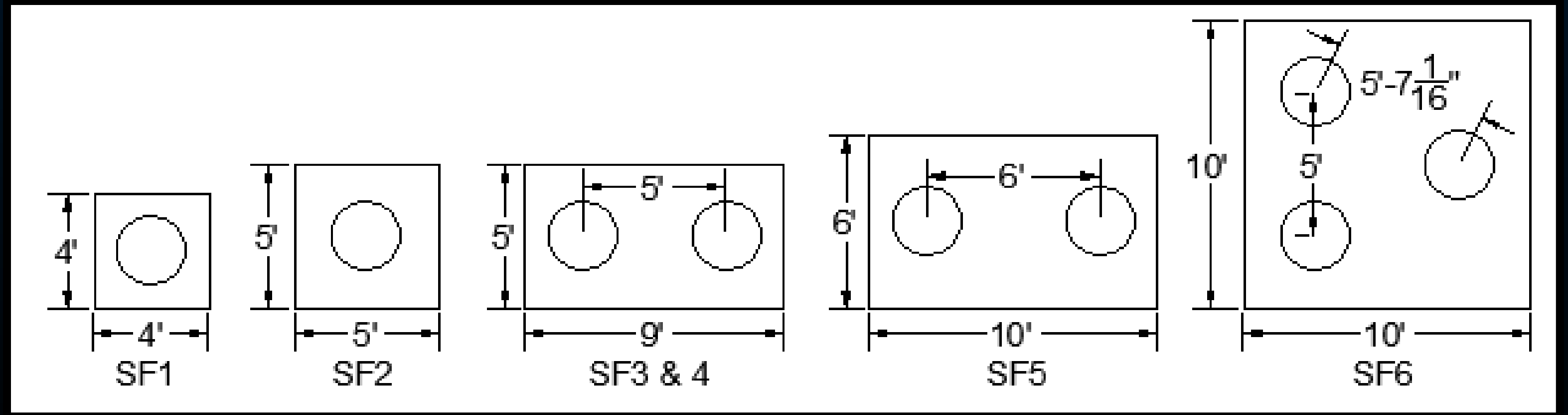
- Relatively Newer Technology
- 2-3' Drilled Hole filled with compacted aggregate in 1-2' lift
- Proven System on Medical Center's Campus (Centerview Parking Garage)

SPREAD FOOTING DESIGN WITH GEOPIERS (CL 1-12)

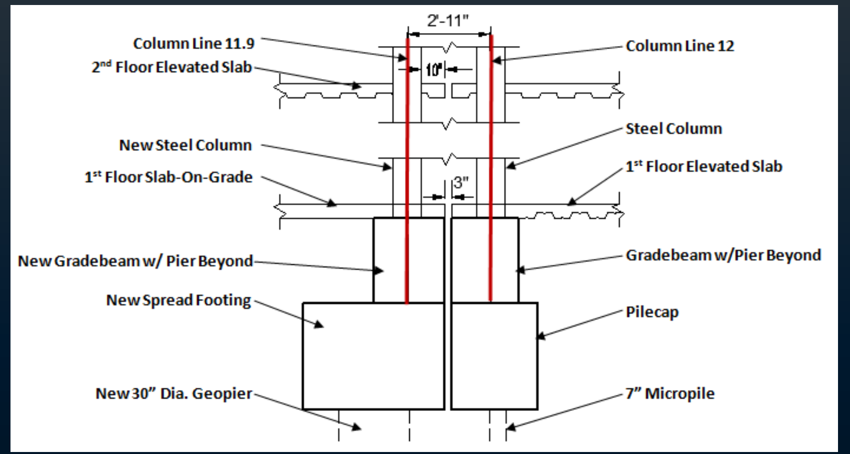
- 30" Diameter pier (S) increased Soil Bearing Capacity to 5,000 PSF
- Minimum Geopier Element Spacing (2x Diameter)Ruled Design
- Limited Settlement to under ¾"
- Limited Differential Settlement to under ½"

FOOTING SCHEDULE

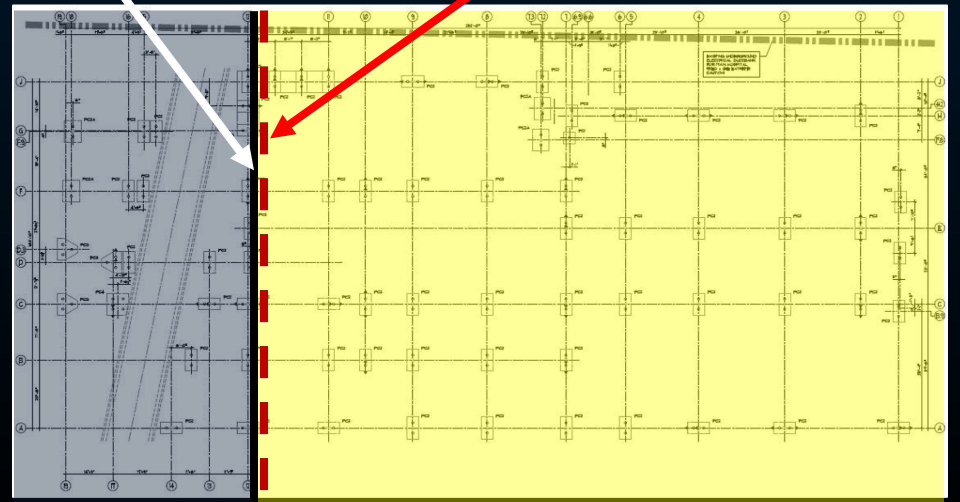
ID	Footing Size	Depth (ft)	# of Geopier® Elements	Depth of Geopier®(s) (ft)
SF1	4'-0" x 4'-0"	3'-9"	1	14
SF2	5'-0" x 5'-0"	3'-9"	1	16
SF3	5'-0" x 9'-0"	3'-9"	2	18
SF4	5'-0" x 9'-0"	5'-0"	2	20
SF5	6'-0" x 10'-0"	3'-9"	2	20
SF6	10'-0" x 10'-0"	3'-9"	3	20



ANALYSIS I: FOUNDATION REDESIGN



Column Line 12 Added Column Line 11.9



ADDED COLUMN LINE 11.9

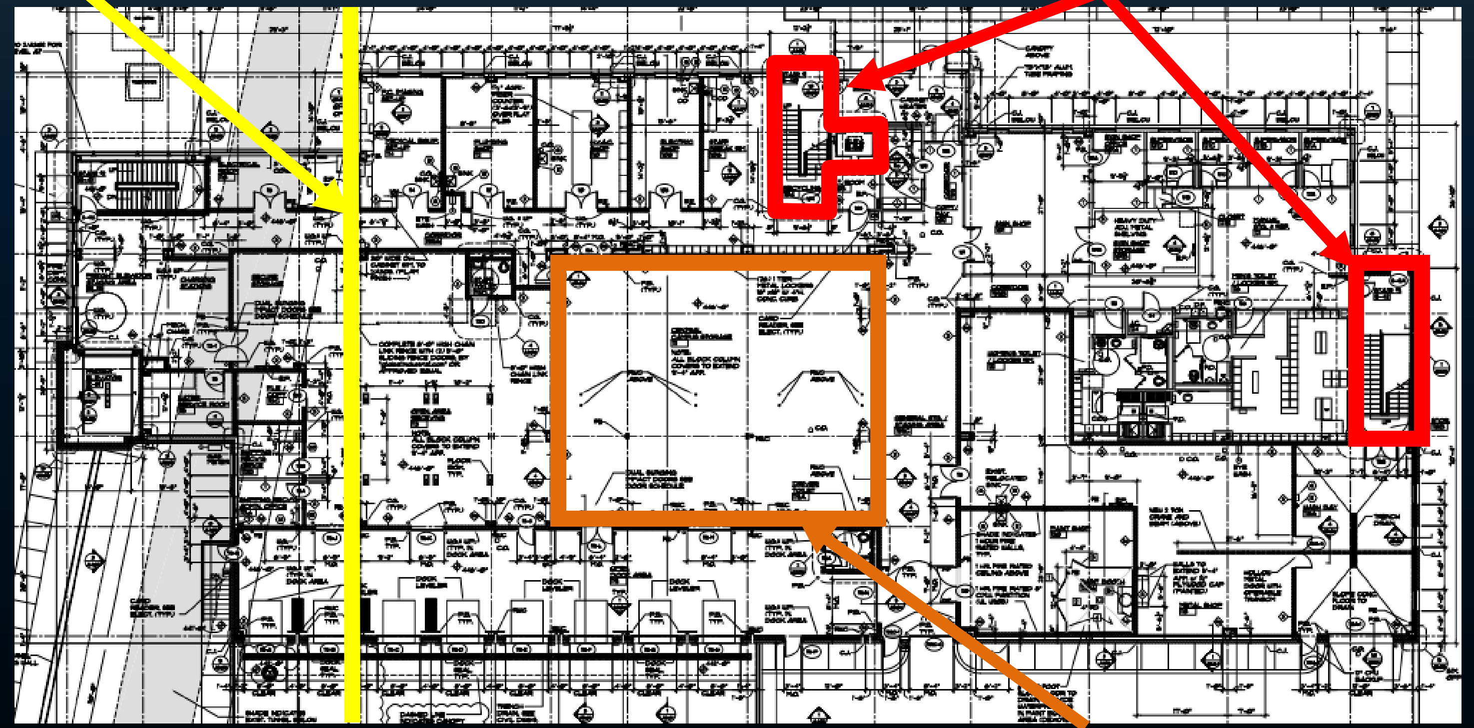
- Isolated the two foundation types
- Able to withstand vertical movements
- Separates SOG from 1st floor elevated deck

LATERAL LOADS

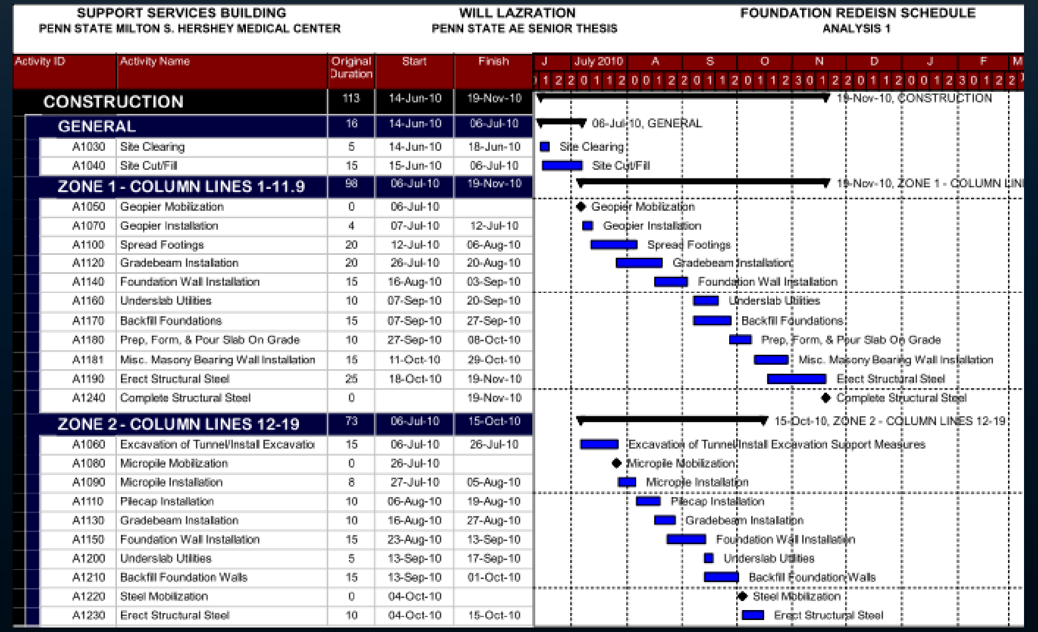
- Utilize elevator & stair tower CMU shafts
- Extend 1st floor CMU @ Central Campus Storage to roof

Column Line 11.9

CMU Shafts that extend from 1st floor to the roof



1st floor CMU walls to be extended to the roof



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PENN STATE MILTON S. HERSHEY MEDICAL CENTER

WILL LAZRATION
PENN STATE AE SENIOR THESIS

FOUNDATION REDEISN SCHEDULE
ANALYSIS 1

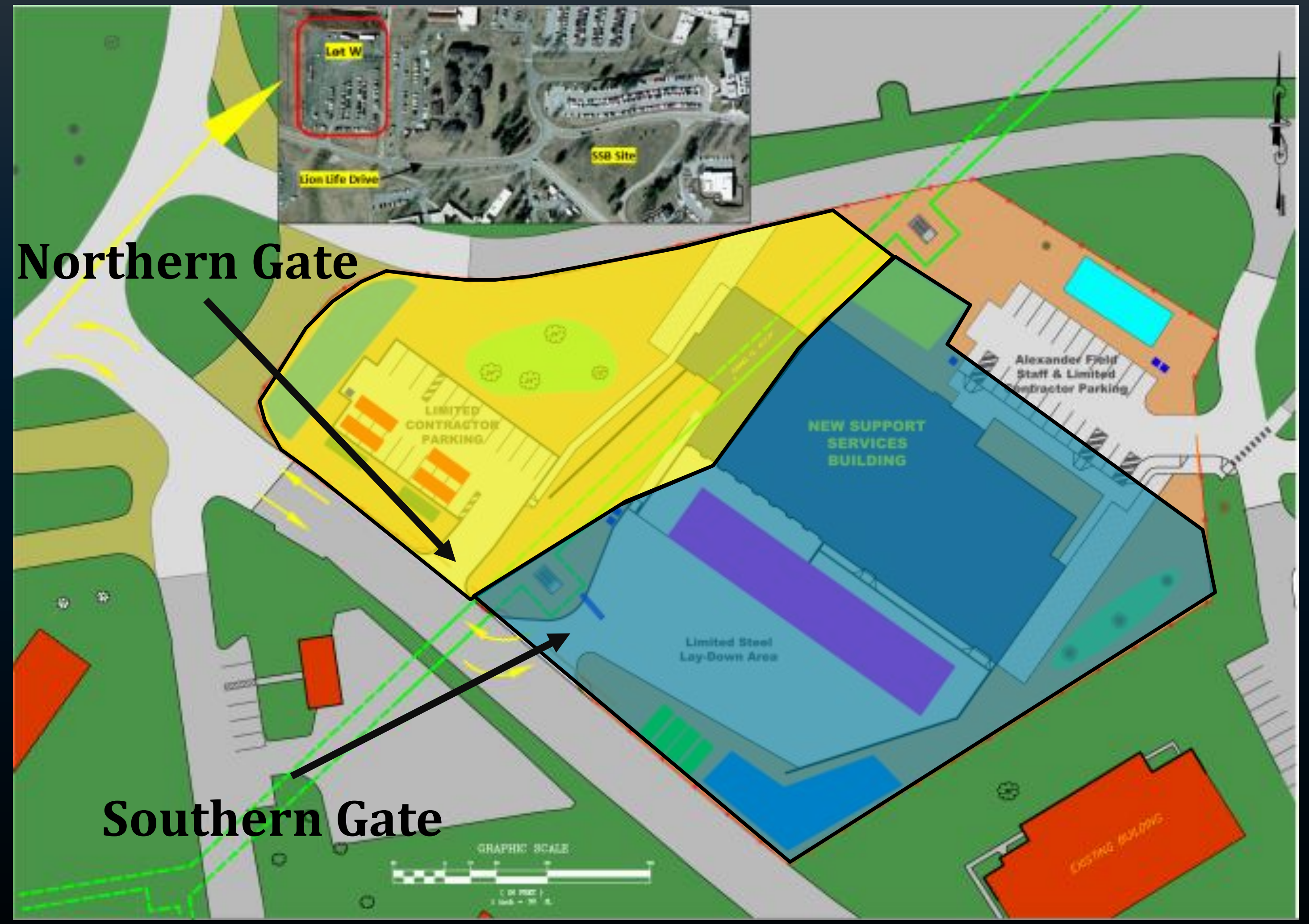
Activity ID	Activity Name	Original Duration	Start	Finish
	CONSTRUCTION	113	14-Jun-10	19-Nov-10
	GENERAL	16	14-Jun-10	06-Jul-10
A1030	Site Clearing	5	14-Jun-10	18-Jun-10
A1040	Site Cut/Fill	15	15-Jun-10	06-Jul-10
	ZONE 1 - COLUMN LINES 1-11.9	98	06-Jul-10	19-Nov-10
A1050	Geopier Mobilization	0	06-Jul-10	
A1070	Geopier Installation	4	07-Jul-10	12-Jul-10
A1100	Spread Footings	20	12-Jul-10	06-Aug-10
A1120	Gradebeam Installation	20	26-Jul-10	20-Aug-10
A1140	Foundation Wall Installation	15	16-Aug-10	03-Sep-10
A1160	Underslab Utilities	10	07-Sep-10	20-Sep-10
A1170	Backfill Foundations	15	07-Sep-10	27-Sep-10
A1180	Prep, Form, & Pour Slab On Grade	10	27-Sep-10	08-Oct-10
A1181	Misc. Masony Bearing Wall Installation	15	11-Oct-10	29-Oct-10
A1190	Erect Structural Steel	25	18-Oct-10	19-Nov-10
A1240	Complete Structural Steel	0		19-Nov-10
	ZONE 2 - COLUMN LINES 12-19	73	06-Jul-10	15-Oct-10
A1060	Excavation of Tunnel/Install Excavatio	15	06-Jul-10	26-Jul-10
A1080	Micropile Mobilization	0	26-Jul-10	
A1090	Micropile Installation	8	27-Jul-10	05-Aug-10
A1110	Pilecap Installation	10	06-Aug-10	19-Aug-10
A1130	Gradebeam Installation	10	16-Aug-10	27-Aug-10
A1150	Foundation Wall Installation	15	23-Aug-10	13-Sep-10
A1200	Underslab Utilities	5	13-Sep-10	17-Sep-10
A1210	Backfill Foundation Walls	15	13-Sep-10	01-Oct-10
A1220	Steel Mobilization	0	04-Oct-10	
A1230	Erect Structural Steel	10	04-Oct-10	15-Oct-10

SCHEDULE IMPLICATIONS

- Original structural steel completion date: **November 29th**
- Work on both foundation systems (zones) simultaneously
- New structural steel completion date: **November 19th**
- 2 week reduction in overall project schedule

SITE LOGISTICS IMPLICATIONS

- Zone 2 utilize northernmost gate & northern side of site
- Zone 1 utilize southernmost gate & southern side of site



ANALYSIS I: FOUNDATION REDESIGN

ESTIMATED COSTS

ELIMINATED ITEMS	
Micropiles	$460,500.86
Pilecaps	$27,214.29
Moment Connections	$15,000.00
Total of Deleted Items:	**$502,715.05**

GENERAL CONDITIONS	
Weekly	$14,283.62
Total for 2 Weeks:	**$28,567.25**

Eliminated Items

- 101 Micropiles
- 51 Pilecaps

General Conditions Savings

- 2 Weeks

Added Items

- 93 Geopiers
- 259 CY of Concrete
- 5.69 Ton of Reinforcing
- 8.5 Ton of Structural Steel

Cost of New Foundation Design	$408,410.03
Cost of Deleted Elements	-$502,715.05
General Conditions Savings (2 weeks)	-$28,567.25
Total Cost Savings:	**-$122,872.27**

NEW DESIGN	
Geopiers®	$199,796.70
Spread Footings	$93,820.78
Added Gradebeam & Piers	$20,467.06
Expansion Joint	$14,240.45
Structural Steel	$32,065.51
CMU Lateral Load Walls	$30,000.00
Contingency	$18,171.11
Total Cost of New Design:	**$408,410.03**

CONCLUSION

- Foundation design based on significantly higher loading conditions
- Redesigned foundation system reduced both cost and schedule

RECOMMENDATIONS

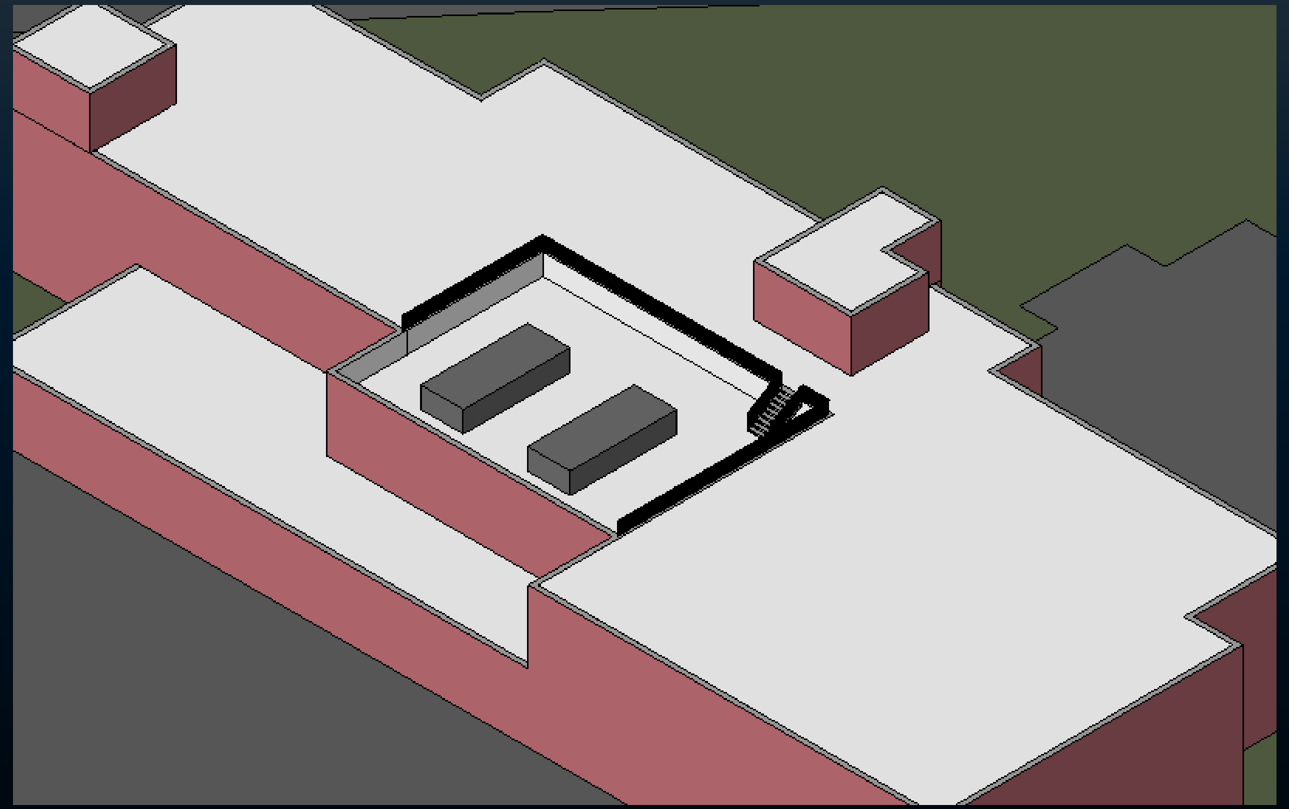
- Architects/Engineers should strongly consider Geopier foundation elements vs. micropiles
- Consider actual loading conditions before making final determination on proper foundation system

PROBLEM IDENTIFICATION

- Cold Applied BUR is both expensive and has slow installation rate
- Cold Applied BUR is not often considered the most sustainable roof
- 3,600SF Offset Roof required additional time and material all to hide rooftop RTU's

RESEARCH GOALS

- Compare several roofing types on sustainability, cost, & schedule
- Determine both cost and schedules savings with elimination of offset roof



SSB with Offset Roof

ANALYSIS II: ROOFING TYPE COMPARISON

PRESENTATION OUTLINE:

RoofPoint Logo Taken From:
www.roofpoint.wikispaces.com/roofpoint

ROOFPOINT RATING SYSTEM

- Center for Environmental Innovation in Roofing
- Rates only roofs for their sustainability
- Places emphasis on importance of the roof to a buildings integrity

ROOFPOINT COMPARISON

- Virtually all similar => not limited to 1 or 2 roofing types
- Shows that roofing industry has embraced sustainability

ROOFPOINT RATING

Built-Up Bitumen		Single Ply			Modified Membranes		Vegetated
Hot Applied	Cold Applied	EPDM	TPO	PVC	APP	SBS	Extensive
15	15	14	14	14	13	13	15

SYSTEM	Built-Up Bitumen		Single Ply			Modified Membranes		Vegetated
TYPE	Hot Applied	Cold Applied	EPDM	TPO	PVC	APP	SBS	Extensive
Credit								
SECTION 1: ENERGY MANAGEMENT								
E1 - High R Roof Systems	x	x	x	x	x	x	x	x
E2 - Best Thermal Practices	x	x	x	x	x	x	x	x
E3 - Roof Surface Thermal Contribution	x	x	x	x	x	x	x	x
E4 - Roof Air Barrier	x	x	x	x	x	x	x	x
E5 - Rooftop Energy Systems								
E6 - Rooftop Daylighting								
SECTION 2: MATERIAL MANAGEMENT								
M1 - Recycled Content	x	x	x	x	x	x	x	x
M2 - Materials Reuse								
M3 - Roofing Waste Management	x	x	x	x	x	x	x	x
M4 - Low-VOC Materials	x	x	x	x	x	x	x	x
SECTION 3: WATER MANAGEMENT								
W1 - Roof Storm Water Retention								x
W2 - Roof-Related Water Use Reduction								
SECTION 4: DURABILITY / LIFE CYCLE MANAGEMENT								
D1 - Durable Roof Insulation System	x	x	x	x	x	x	x	x
D2 - Roof Drainage Design	x	x	x	x	x	x	x	
D3 - Roof Traffic Protection	x	x						x
D4 - Increased Wind Uplift Resistance								
D5 - Hygrothermal Analysis	x	x	x	x	x	x	x	x
D6 - Construction Moisture Management	x	x	x	x	x	x	x	x
D7 - Roof System Durability Enhancement	x	x	x	x	x			x
L1 - Roof Maintenance Program	x	x	x	x	x	x	x	x
L2 - Project Installation Quality Management	x	x	x	x	x	x	x	x
SECTION 5: ENVIRONMENTAL INNOVATION IN ROOFING								
IR 1 - Innovation in Design								
IR 2 - Exemplary Performance								
IR 3 - RoofPoint Roofing Professional								
Total Points	15	15	14	14	14	13	13	15

ANALYSIS II: ROOFING TYPE COMPARISON

COST & SCHEDULE COMPARISON

- Single Ply most cost effective and shortest install rate
- Vegetated significantly more

System	Type	Approx. Cost (SF)	Typical Installation Rate	Typical Warranty Period
Built-Up Bitumen	Hot Applied	$13-$15	20-25 square/day	15- 20 year
	Cold Applied	$13-$15	20-25 square/day	15- 20 year
Single Ply	EPDM	$9-$11	30-35 square/day	15- 20 year
	TPO	$10-$12	30-35 square/day	15- 20 year
	PVC	$9-$11	30-35 square/day	15- 20 year
Modified Membranes	APP	$12-S14	25-30 square/day	15- 20 year
	SBS	$13-S15	25-30 square/day	15- 20 year
Vegetated	Extensive	$20-S25	5 square/day	10-15 year

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ANALYSIS II: ELIMINATION OF OFFSET ROOF

WILL LAZRATION
CONSTRUCTION MANAGEMENT

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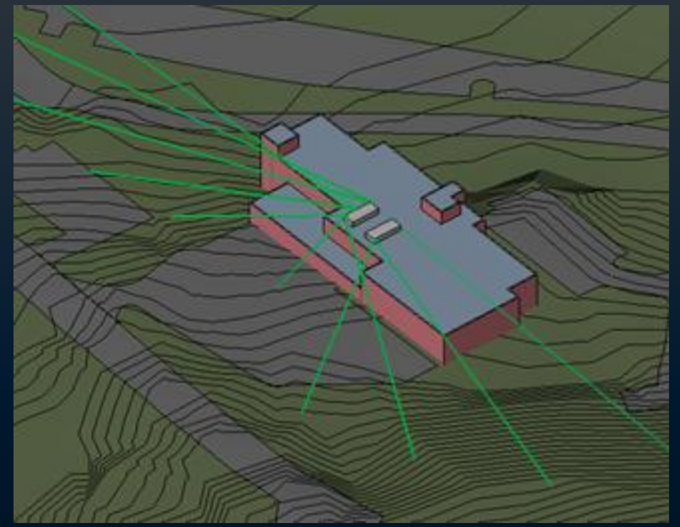
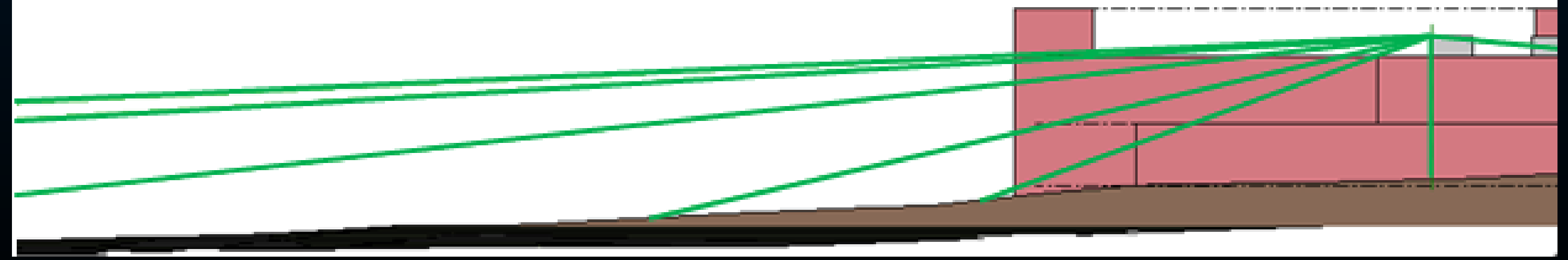
MATERIAL COST SAVINGS
- $41,030.00

SCHEDULE SAVINGS
- 1 week

TOTAL COST SAVINGS
- $55,314.00

LINE OF SIGHT STUDY





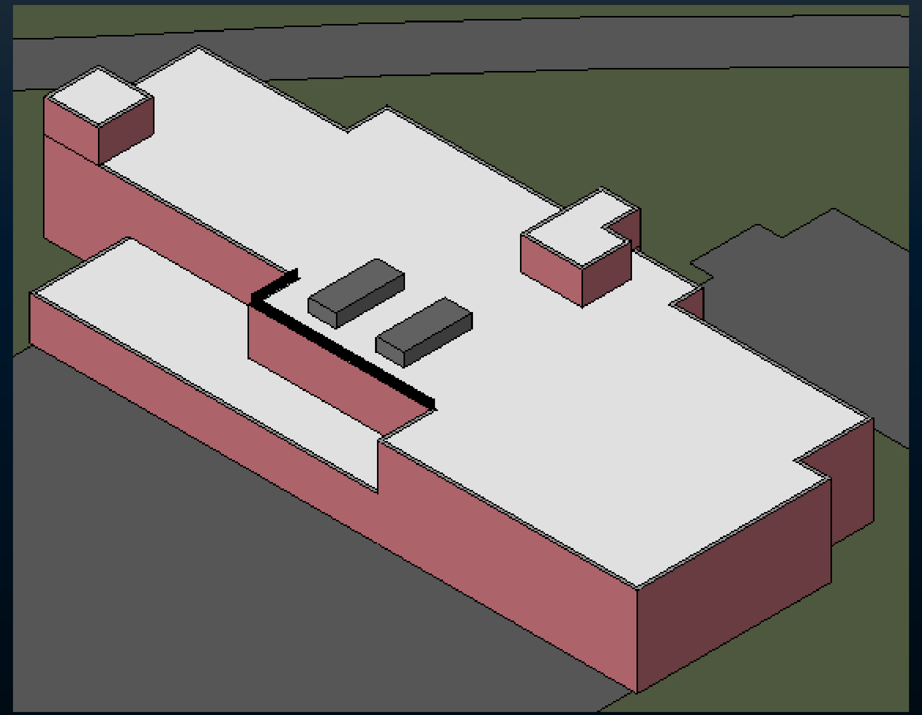
PRESENTATION OUTLINE:

CONCLUSION

- There is no one single preferred roofing type for all projects
- Sustainable roofs are no longer limited to one or two types

RECOMMENDATIONS

- Architects/Engineers should consider buildings function & owner wants before selecting a roof
- Cold Applied BUR was proper choice for the SSB



SSB with Offset Roof Eliminated

PROBLEM IDENTIFICATION

- SSB utilized very few sustainable techniques
- SSB generates no income to offset operating costs
- PSU has no buildings that incorporate onsite renewable energy

RESEARCH GOALS

- Design preliminary onsite renewable energy systems
- Make the SSB a research platform for PSU

PRESENTATION OUTLINE:

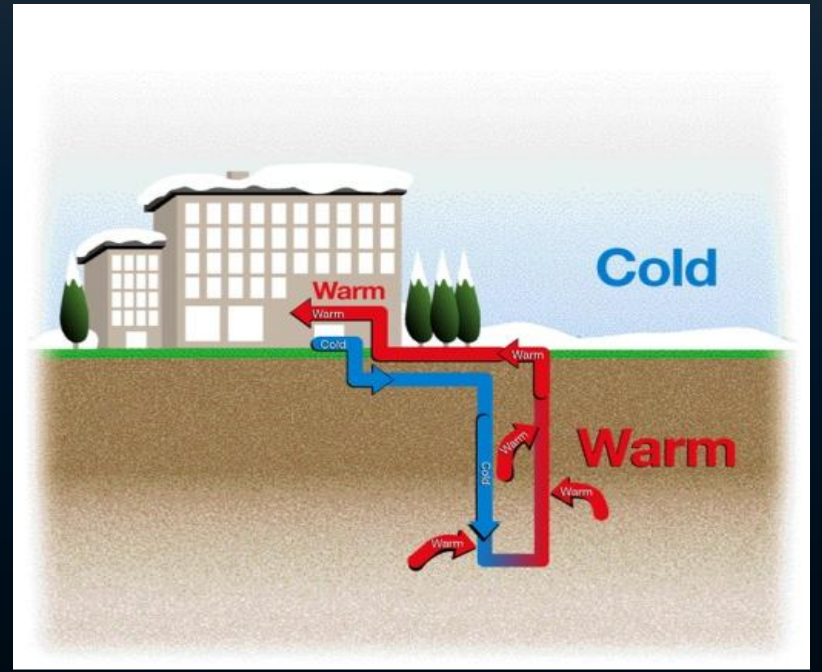


Image Taken From www.mcquay.com

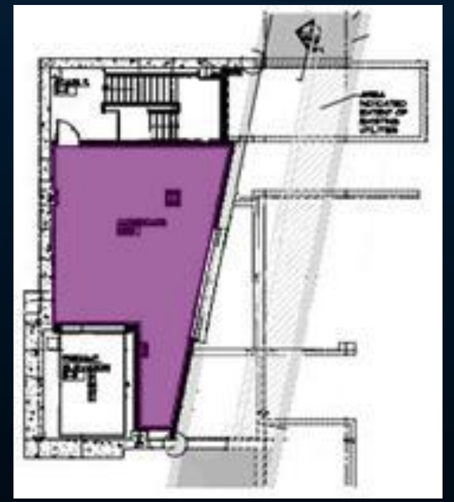
GEOTHERMAL SYSTEM

- Closed Loop Ground System
- 40 Wells
- Building broke down into 6 zones
- Total additional cost added to project: $478,000.00

1st Floor

2nd Floor

Lower Level



ANALYSIS III: PHOTOVOLTAIC ARRAY SYSTEM

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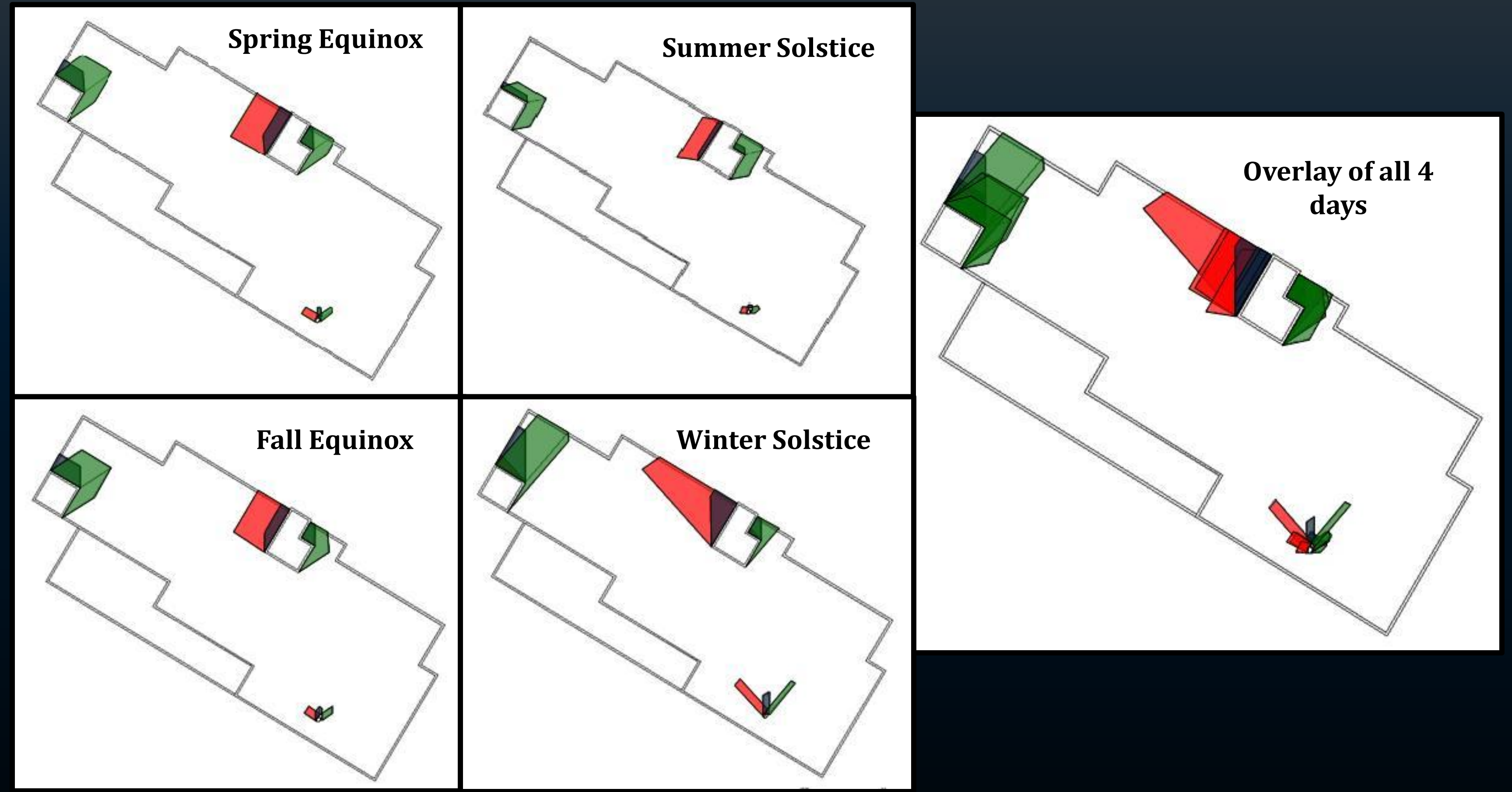
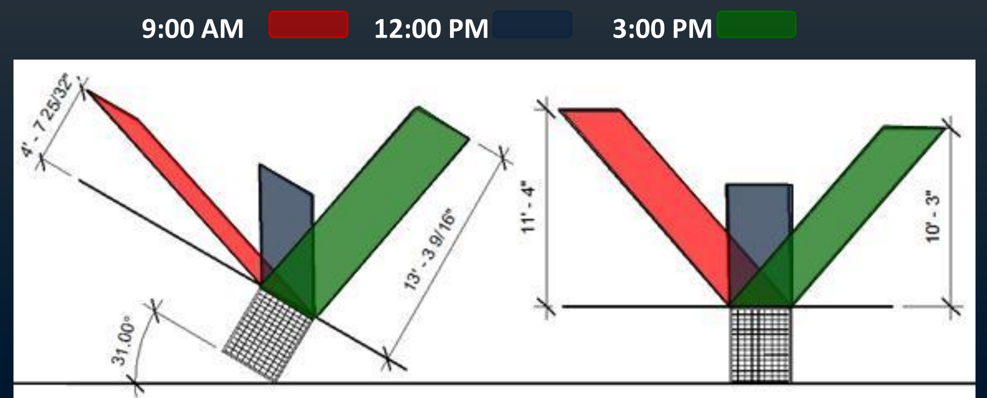
Day	Spring Equinox - March 20th/21st		
Time	9:00 A.M.	12:00 P.M.	3:00 P.M.
Altitude Angle (°)	30.66	49.98	35.14
Azimuth Angle (South = 0°)	-60.43	-5.33	54.25
Day	**Summer Solstice - June 21st/22nd**		
Time	9:00 A.M.	12:00 P.M.	3:00 P.M.
Altitude Angle (°)	47.2	73.07	50.34
Azimuth Angle (South = 0°)	-81.5	-6.6	78.15
Day	**Fall Equinox - September 22nd/23rd**		
Time	9:00 A.M.	12:00 P.M.	3:00 P.M.
Altitude Angle (°)	32.93	49.89	32.61
Azimuth Angle (South = 0°)	-57.11	0.30	57.39
Day	**Winter Solstice - December 21st/22nd**		
Time	9:00 A.M.	12:00 P.M.	3:00 P.M.
Altitude Angle (°)	13.1	26.27	14.42
Azimuth Angle (South = 0°)	-42.91	-1.33	40.87

SITE & BUILDING SHADE ANALYSIS

- Sun Position in sky
- Optimum solar window: 9:00 AM – 3:00PM
- No shade on building
- Rooftop projection shadows





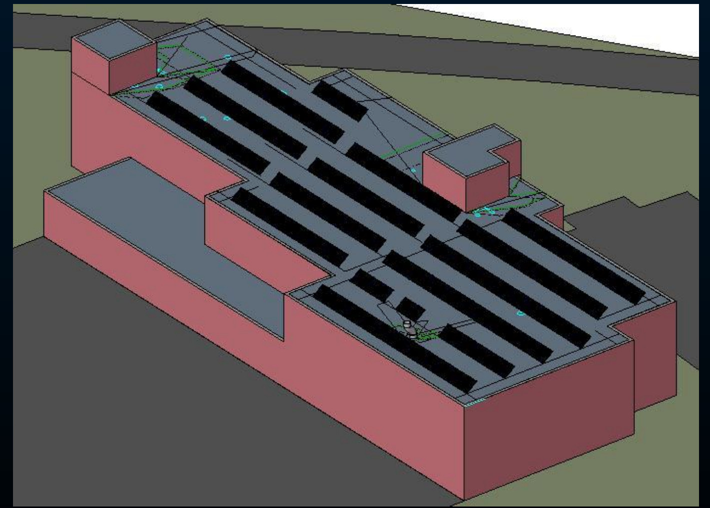
Minimum Row Spacing Determined by Shadow Lengths

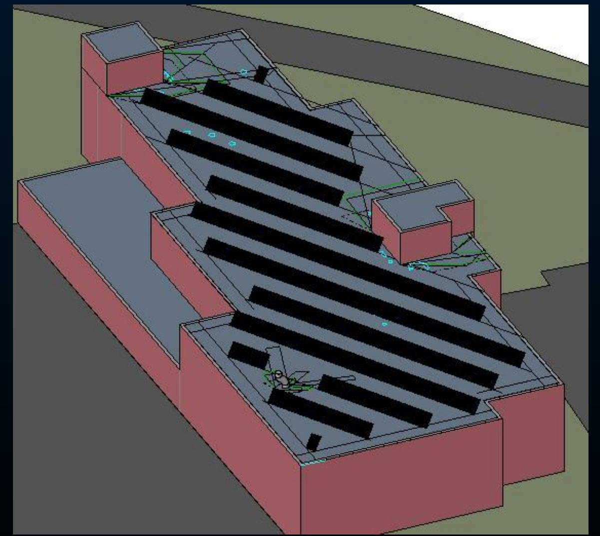
FINAL SYSTEM DESIGN

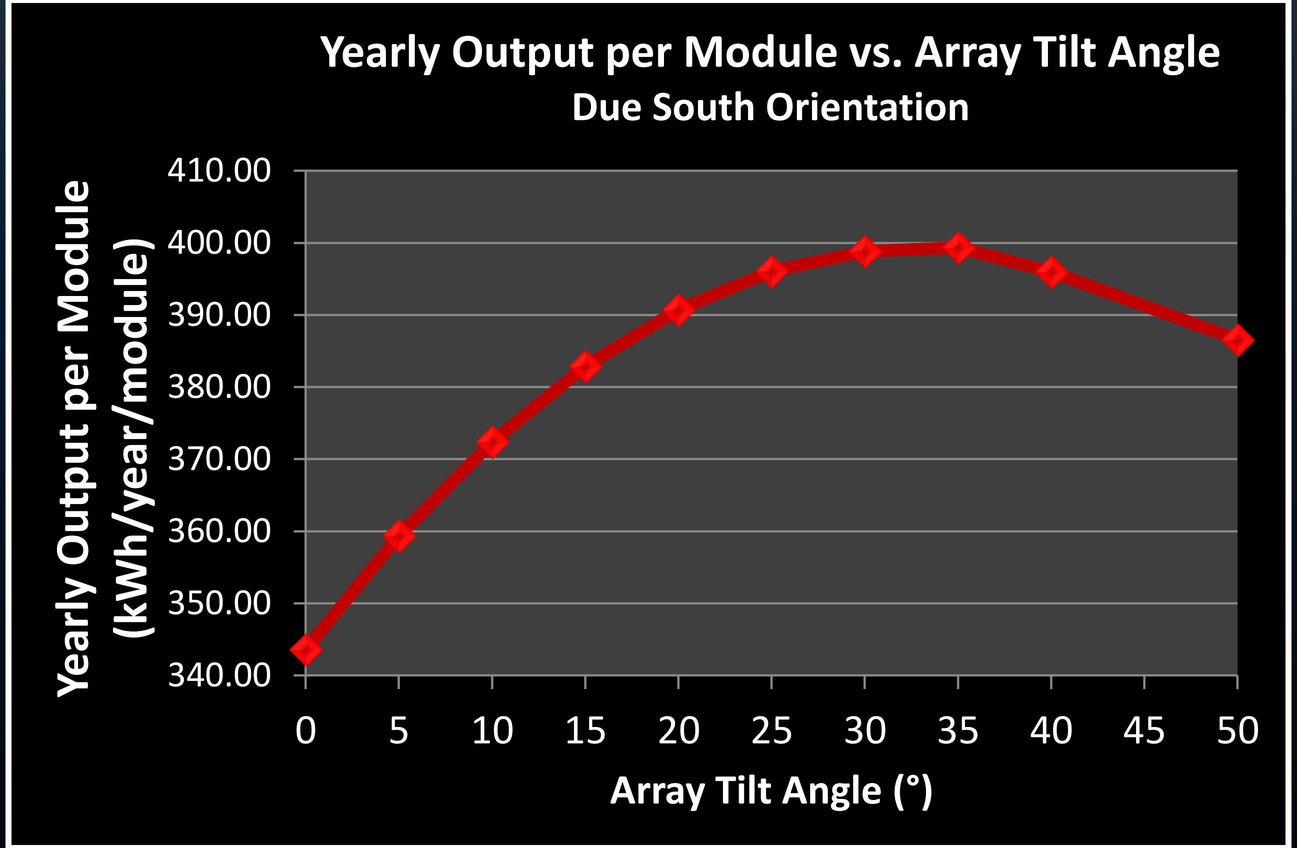
- Due south orientation
- 1-axis tracking (adjustable tilt)
  - Row spacing = minimum per 35°

ARRAY ORIENTATION & TILT COMPARISON

Angle	Array Orientation	Min. Row Spacing to Avoid Shading	Max # of Panels	kWh/ Panel/ Year
35°	Rotated 31°	11'-10"	252	385.39
	Due South	9'-9"	253	399.34
30°	Rotated 31°	10'-5"	248	386.42
	Due South	8'-8"	269	398.81


Rotated 31° Orientation with 35° Tilt


Due South Orientation with 35° Tilt



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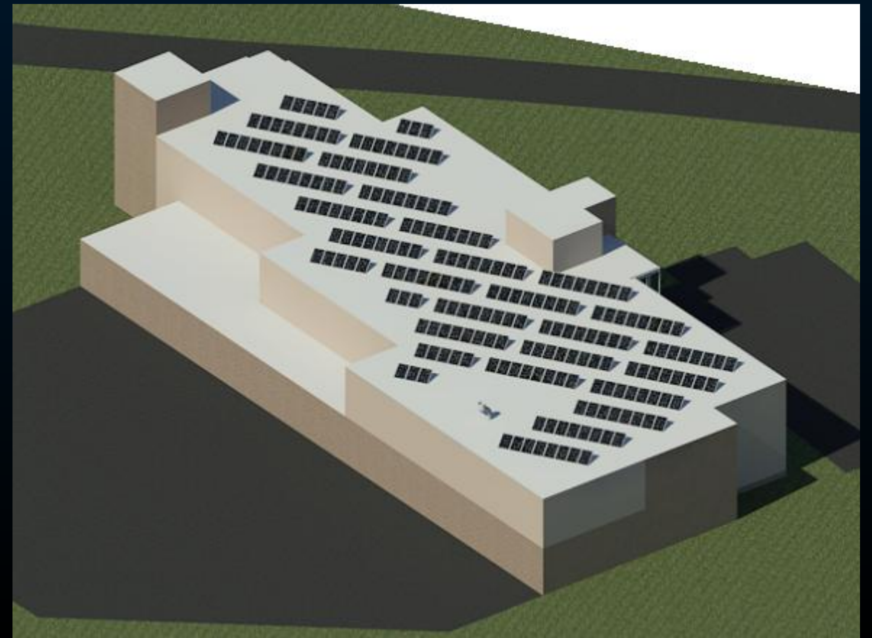
SUNPOWER E19-320 MODULES

- Per NEC max PV array voltage = 600V
- Max voltage calculated at lowest ambient temperature:

Maximum Module Voltage = 72.22V

600V/72.22V = 8.3 => 8 Modules in series max

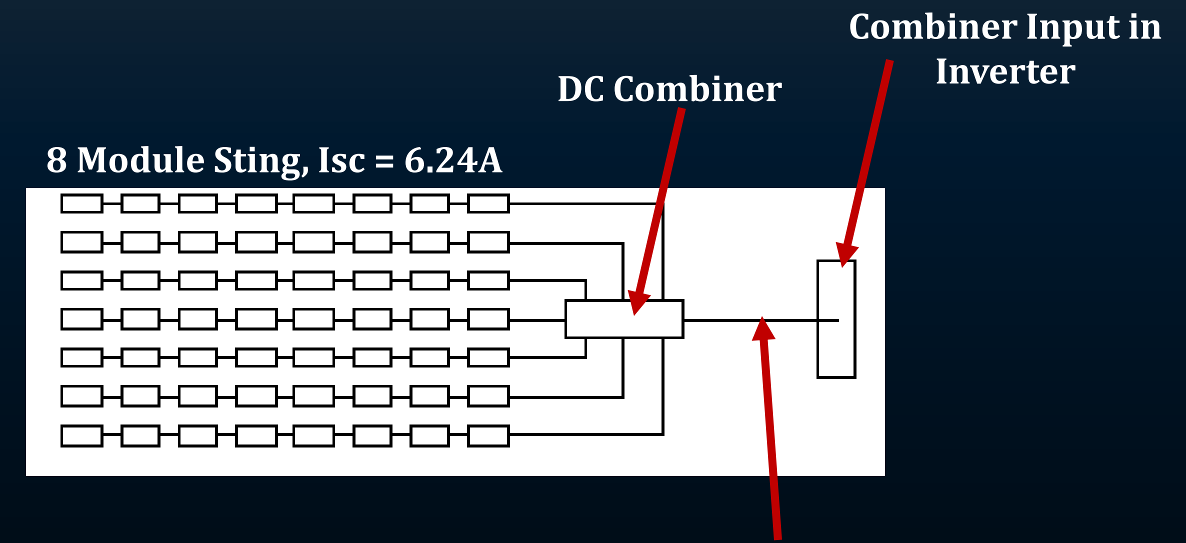


FINAL LAYOUT & SYSTEM SIZE

28 Strings * 8 modules/string * 320W = 71.68kW

SATCON POWERGATE PLUS 75kW INVERTER

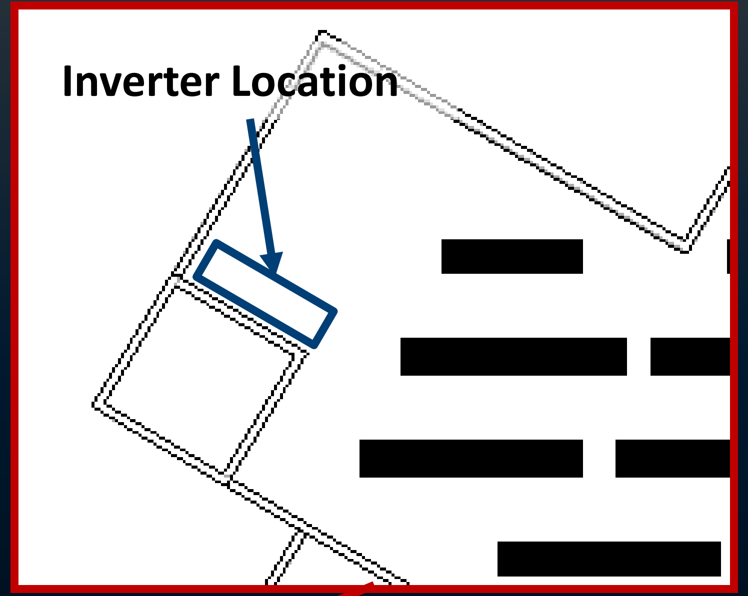
- 6 combiner inputs rated at 80A
- 7 string per inverter input

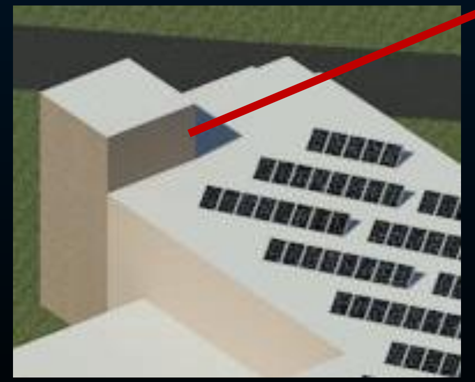


6.24 A/string * 7 strings * 1.56 = 68.14A

68.14A < 80A => OK

ANALYSIS III: PHOTOVOLTAIC ARRAY SYSTEM





FEED FROM INVERTER TO COMBINER PANEL/BOX SIZING

•Max current from inverter data sheet: 91A/phase

•91A x 1.56 (NEC Multiplier) = 142A

•NEC Table 310.15(B)(2)(a): Multiplier for 4-6 current carrying conductors in a raceway = 0.8

•NEC Table 310.16 (90°C Wire): 2/0 AWG = 195A

195A x 0.8 = 156A > 142A => OK

AC FUSED DISCONNECT SWITCH SIZING

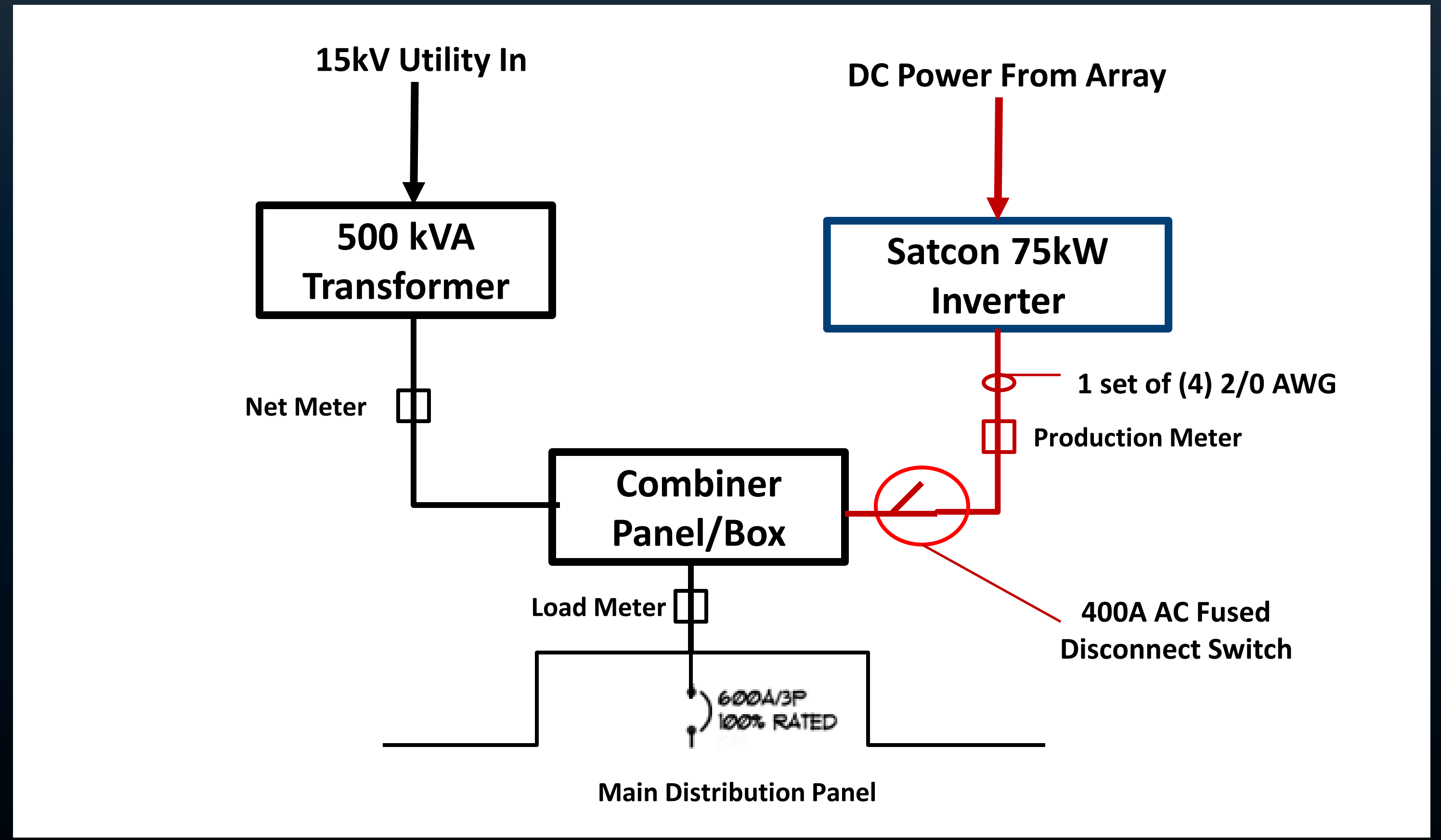
•Max current from inverter data sheet: 91A/phase

•91A x 3 phases 1.25 (NEC Multiplier) = 342A

•Ideal fused disconnect switch size: 350A => not available => 400A

•Interrupt Rating must be greater than; 500kVA / (.480kV * 3^(1/2)) = 600A

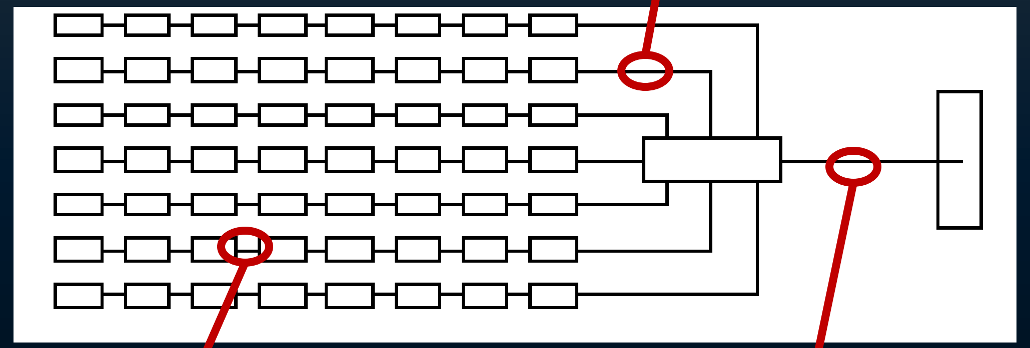
LOAD SIDE CONNECTION



ANALYSIS III: PHOTOVOLTAIC ARRAY SYSTEM

PRESENTATION OUTLINE:

String to DC Combiner box Wire Size: #8 AWG



Module to Module Wire Size: #10 AWG

DC Combiner box to Inverter Wire Size: #2 AWG

System Design: 4 Identical groups as shown above

STRING TO DC COMBINER BOX WIRE SIZING

•Isc: 6.24A

• Maximum String Current = 6.24A * 1.56 (NEC multiplier for wire sizing) = 9.73A

•From NEC Table 310.15(B)(2)(c): 22°C

Adjusted Temperature = (36°C + 22°C) = 58°C

From NEC Table 310.16: 0.71 for 90°C wire

From NEC Table 310.16, #12 AWG 90°C Wire =

25A * .71 = 17.75A> 9.73 => *Ok.*

Common practice is to us a minimum of #10AWG for PV Systems

STRING TO DC COMBINER BOX POWER LOSS CHECK

Power Loss Equation = $\frac{(Number\ of\ Current\ Carrying\ WIres) * (Wire\ Factor) * \left(\frac{Length}{1000}\right) * I^2}{Total\ Watts}$

From NEC table 8: Wire factor for #10AWG = 1.26Ω/kFT

Average Wire Length: 50ft

Imp= 5.86A

Power Loss = $\frac{\left(\frac{2\ current\ carrying\ conductors}{string}\right) * \frac{1.26\Omega}{kFT} * \frac{50ft}{1000} * 5.86^2}{8\ modules * 320\ W/module} * 28\ strings = 3.7\%$

=> Increase wire size to # 8 to limit power loss

ANALYSIS III: PHOTOVOLTAIC ARRAY SYSTEM

PV SYSTEM ESTIMATE

Item	Description	Cost
Resized Steel Joists		$1,106.20
Sunpower E19-320 Solar Modules		$476,400.00
Sacton Powergate Plus 75kW Inverter		$36,000.00
Wire		$5,538.00
Misc.		$26,740.00
	Total Cost:	$545,784.20

ESTIMATED COST OF SYSTEM

Cost of PV System Alone: $545,784.00

- OPTION 1: Relocated RTU's to lower roof
  - **Total Cost:** $495,004.00
- OPTION 2: Installation with Geothermal System
  - **Total Cost:** $967,702.00

ESTIMATED YEARLY OUTPUT OF SYSTEM

From PVWatts: 102,240 kWh

Total Value of Electricity Produced ≈ $10,000.00

Estimated yearly building electric usage: 547,500 kWh

Percent PV system will offset building usage: 19%

PRESENTATION OUTLINE:

CONCLUSION

- SSB roof idea for photovoltaic array
- 98% of additional cost to add a Geothermal system is the installation of the wells & horizontal piping

RECOMMENDATIONS

- Install both Geothermal & PV array on SSB
- PSU can use SSB to research operating techniques of buildings with these systems to figure out best way to incorporate them into their building projects of the future

PRESENTATION OUTLINE:

ANALYSIS I:

- **Minimum Geopier element spacing often governs design**
- **Cost to increase concrete foundation element sizes is minimal compared to total cost of project**

ANALYSIS II:

- Sustainable roofing goes beyond LEED
- A cheaper roof is not always the best choice for every project

ANALYSIS III:

- Wire size is often governed by power loss, not NEC minimum requirements
- PV array layout on rotated buildings needs to be analyzed closely

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PRESENTATION OUTLINE:

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QUESTIONS

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