Paula K. Schuller

Architectural Engineering
Mechanical Option

Advisor: Dr. Freihaut

LOCATION: Penn State Behrend
Knowledge Park Erie, PA

ADVANCED MANUFACTURING AND INNOVATION CENTER (AMIC)

June 10th, 2017

ADVANCED MANUFACTURING AND INNOVATION CENTER (AMIC)

Building Overview
Information | Existing System
Mechanical Depth
Location | Energy | Plausibility
Acoustical Breadth
Potential Solutions | Conclusion
Electrical Breadth
Energy | Cost | Plausibility
Conclusion

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Proposal

- **Mechanical Depth**
  - **Geothermal System**
- **Acoustical Breadth**
  - **Potential Solutions to Existing Noise Problems**
- **Electrical Breadth**
  - **Solar Panel Design**

Goals

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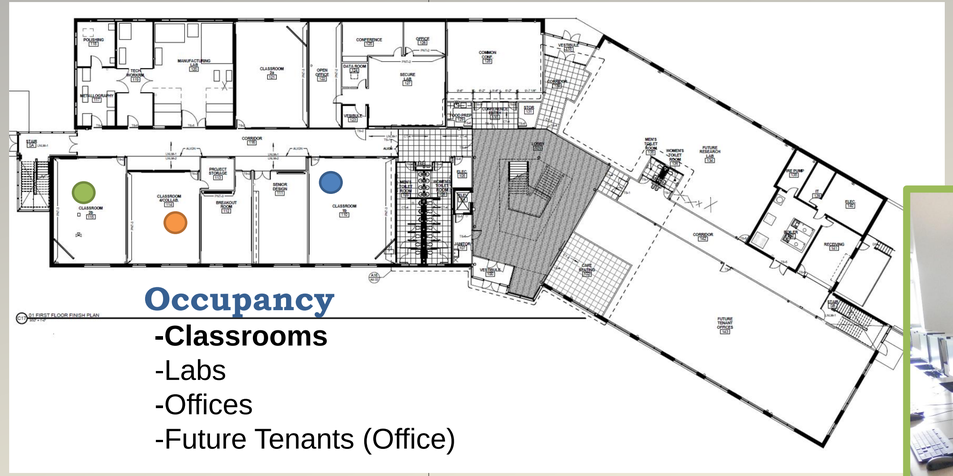

Occupancy

-Classrooms

-Labs

-Offices

-Future Tenants (Office)

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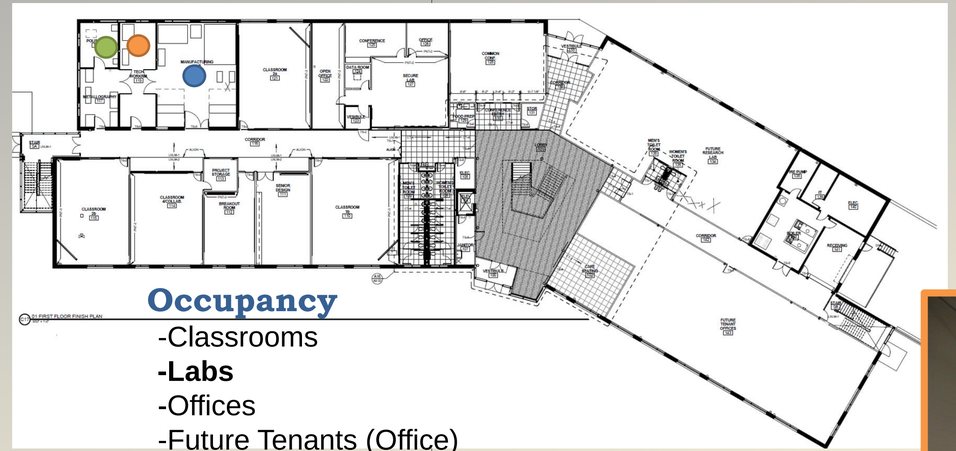

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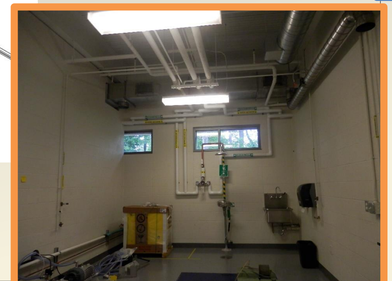

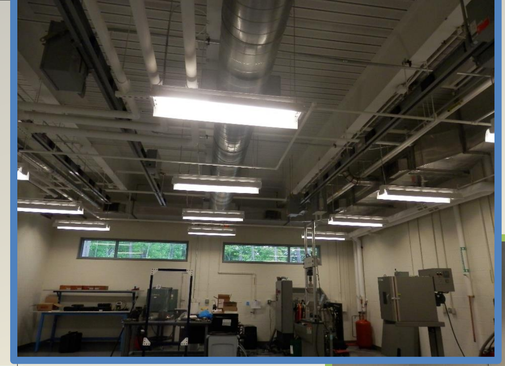

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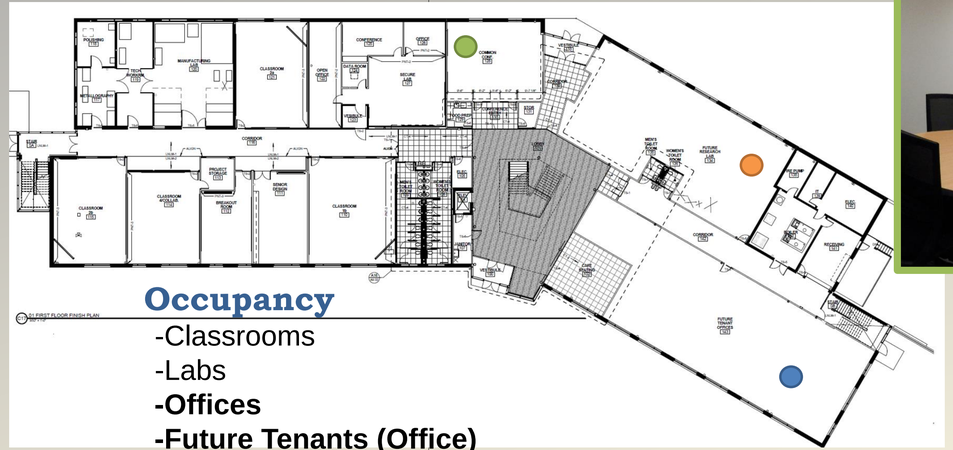

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Air Side:

4 RTU's to VAV boxes at each zone

Water Side:

2 gas fired boilers to radiant wall panels and fin tubes

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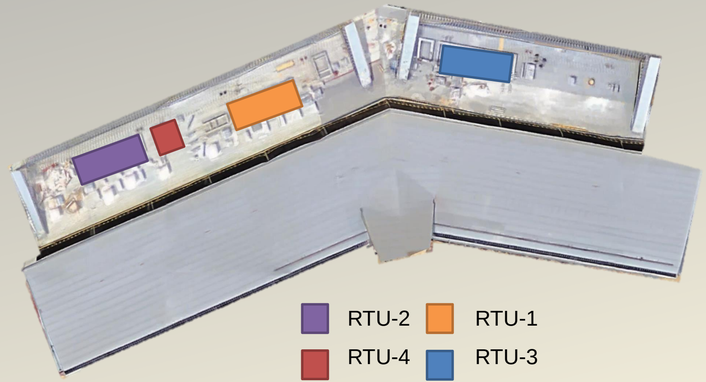
Existing Mechanical System



RTU-XX	LOCATION	MAX CFM	% OA
RTU-1	Left Wing First Floor	13,500	30
RTU-2	Left Wing Second Floor	16,800	26
RTU-3	Right Wing	28,330	20
RTU-4	Secure Lab	3,000	10

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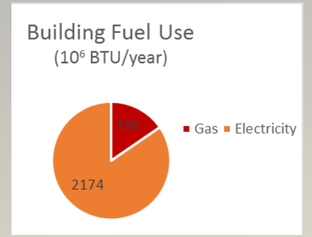

Annual Electric Cost:
$85,364

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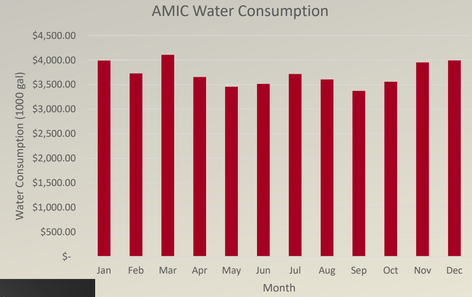
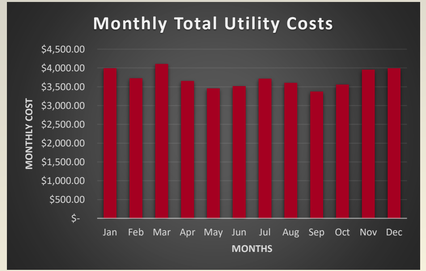
Existing Mechanical System





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Climate Zone
5-A

Ground Temperature

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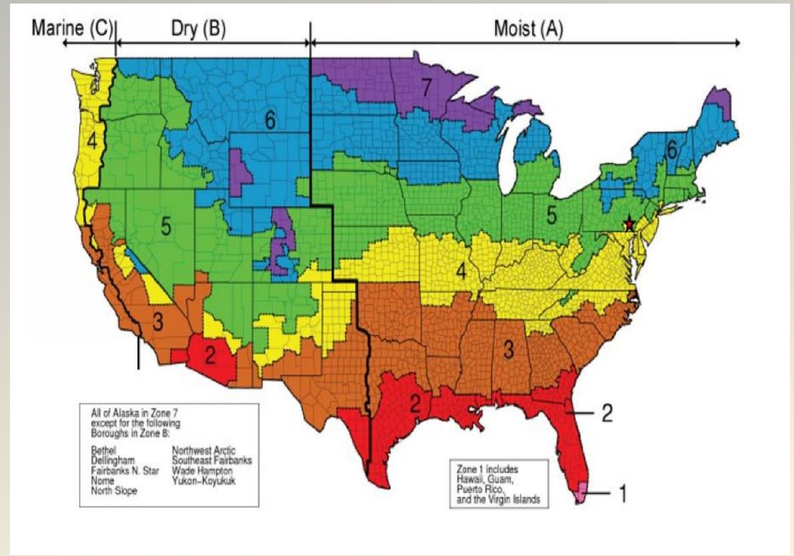
Geothermal System



Ground Source Heat Pump System

- **Location**
  Erie, PA
- **Climate**
  Cool and Humid
- **Ground Conditions**
  Year-round 52 °F

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Climate Zone
5-A

Cool and Humid

Ground Temperature

Year-round: 52 °F

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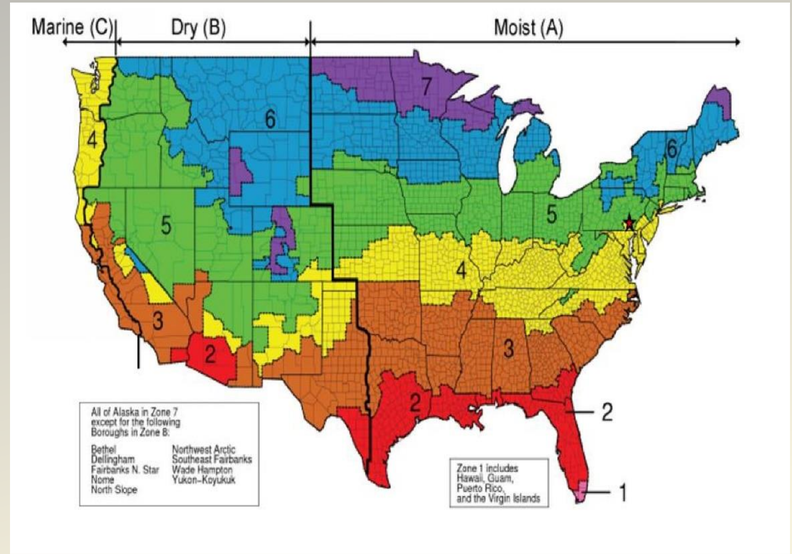
Geothermal System



Ground Source Heat Pump System

Advantages vs Disadvantages

➢ Open Loop

+ Lower initial cost
+ Consistent entering water temperature

- Water quality
- Environmental concerns at the discharge location
- Increased well pump usage
- Required discharge location

➢ Closed Loop

+ Control over water quality
+ Less overall maintenance
+ Zero energy consumption from the well pump

- High initial cost
- Large area for system
- Lower entering water temperature

ADVANCED MANUFACTURING AND INNOVATION CENTER (AMIC)

Climate Zone
5-A

Cool and Humid

Ground Temperature

Year-round: 52 °F

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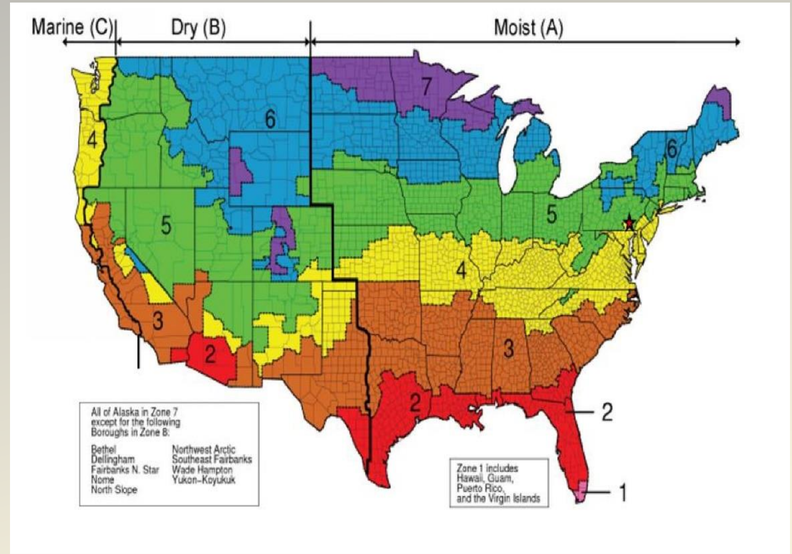
Geothermal System



Ground Source Heat Pump System

Advantages vs Disadvantages

➢ Horizontal System

+ Lower initial cost

- Less Effective
- Consumes more energy
- Could freeze depending on system

➢ Vertical System

+ More efficient
+ Consumes less energy

- High initial cost

Closed Loop-Vertical Bore field Ground Source Heat Pump System

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Bore Field:

64 Boreholes
Potential of 19 more

20’ Spacing

Trane Trace Bore Field Results	
Design Flow	153 GPM
Boreholes Required	64
Borehole Depth	400 ft.
Borehole Radius	2.25 in

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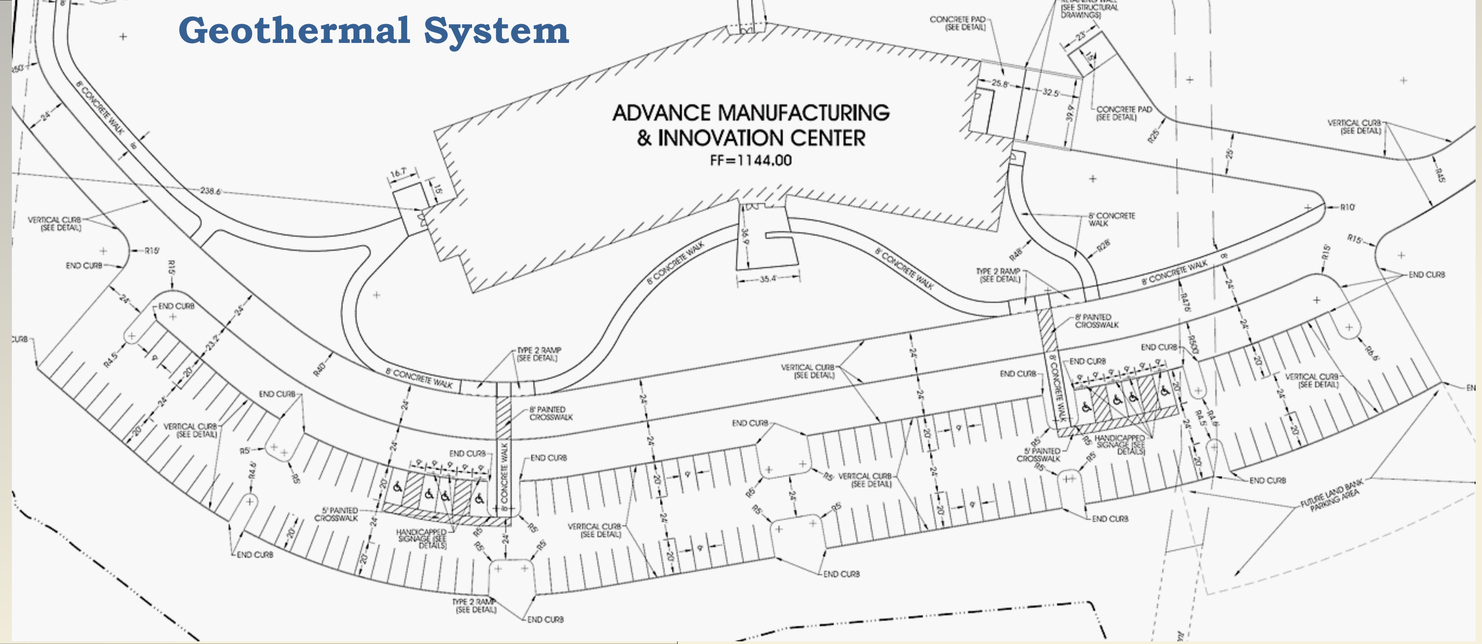
Geothermal System



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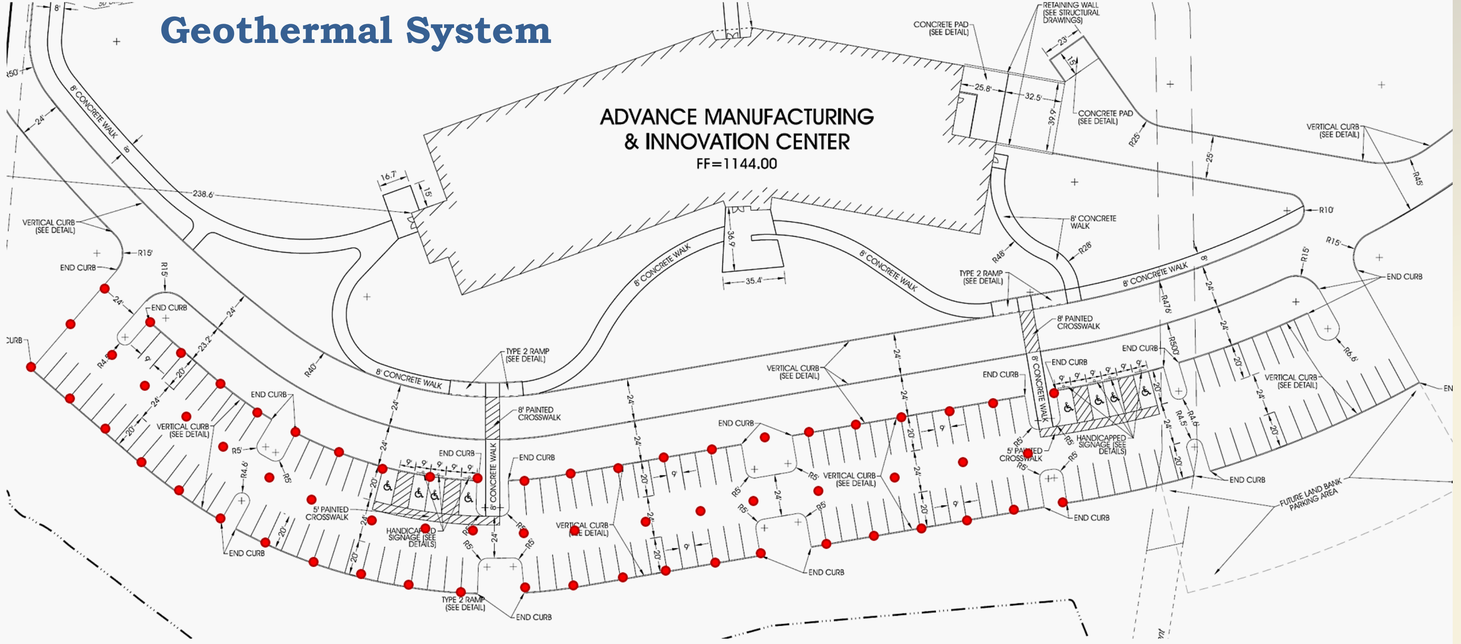

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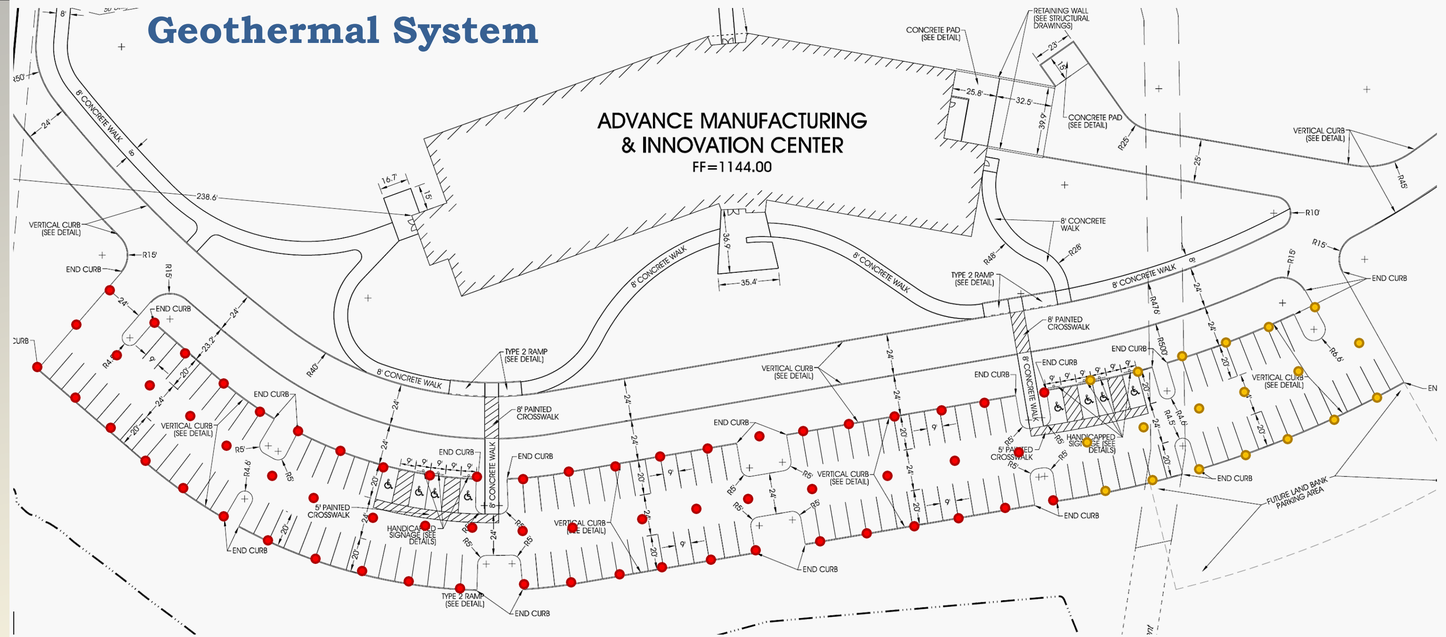

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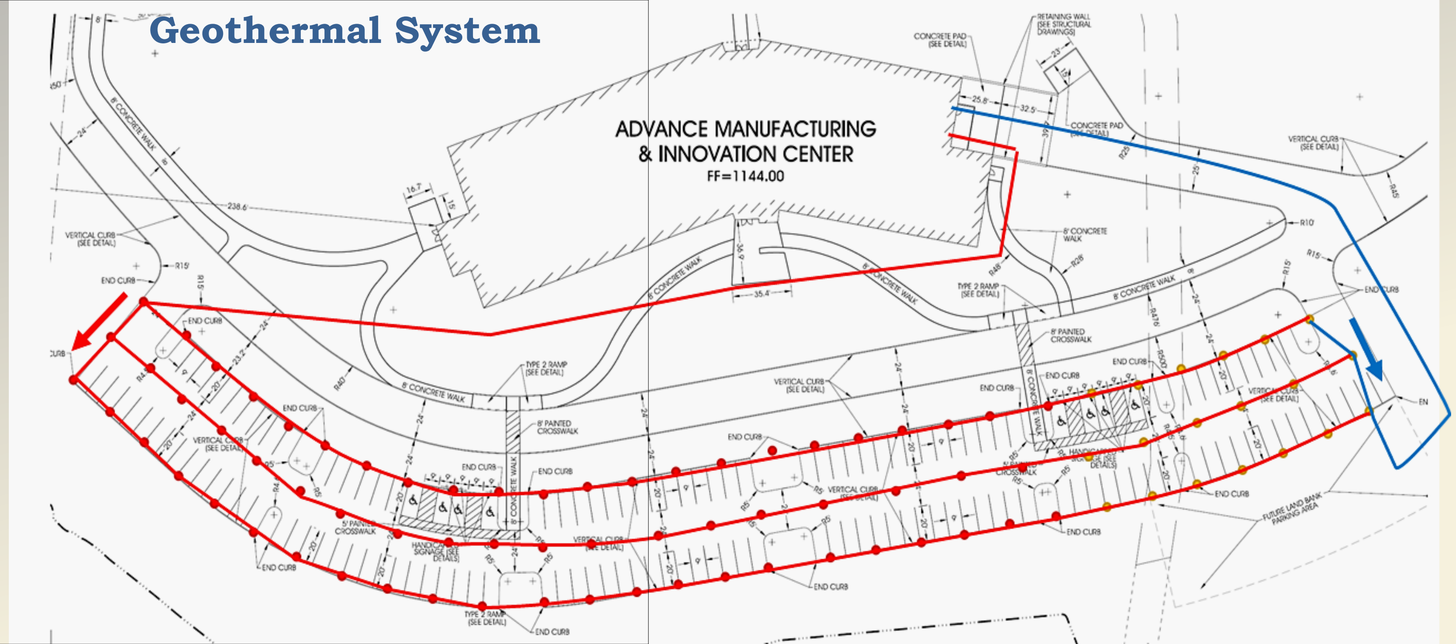

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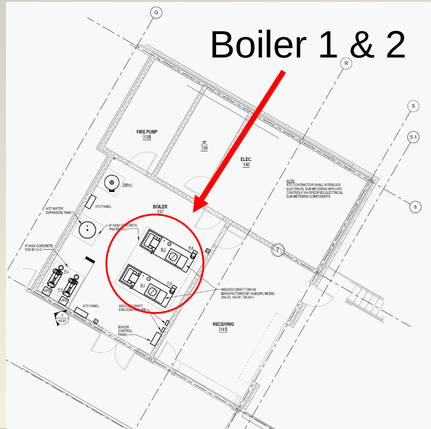
Geothermal System
Adequate Space Allowance

- ✓ AMIC's Parking Lot
- ✓ Mechanical Room



Geothermal System
Equipment

Geothermal Pump						
Make/ Model	Impeller Size	Motor HP	BHP	Motor RPM	GPM	Efficiency
Bell and Gossett 1510 Series	9.5"	15	8.75	1750	320	74.5 %

Note: Consistent with existing pump

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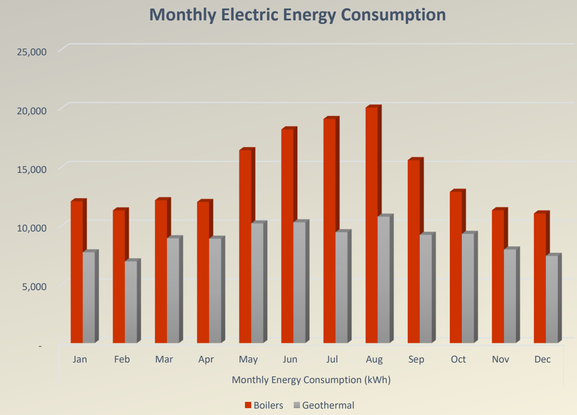
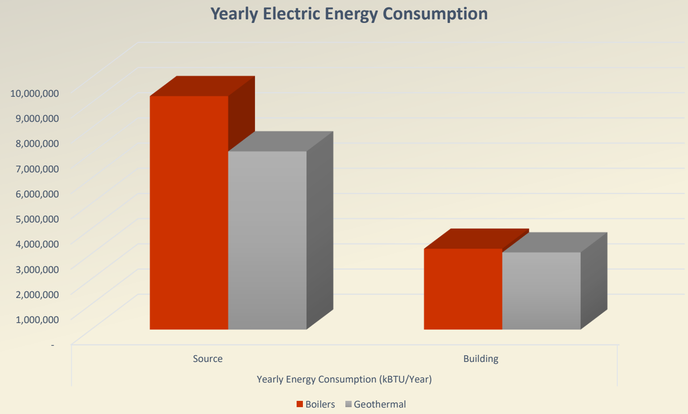
Emissions			
	CO2 (lbm/year)	SO2 (gm/year)	NOX (gm/year)
Boilers	1,140,698	8,875	1,706
Geothermal	704,524	5,481	1,053

Geothermal System Energy Consumption





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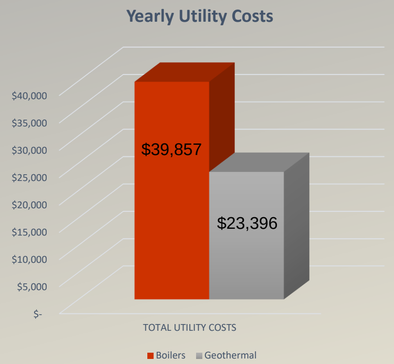

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Geothermal System Cost Comparison

Cost Comparison									
	Location	**Type**	**Building Area (SF)**	**Occupancy (people)**	**Type**	**# Boreholes**	**Ft/bore**	**Total Feet**	**GPM**
Case Study (2007)	Sandy Valley, OH	Elementary School	78,800	682	Vertical	128	305	39,040	576
AMIC (2016)	Erie, PA	School/University	59,300	592	Vertical	64	400	25,600	492

Case Study:

$1.6371 million dollars or 11.97 $/ft-bore

AMIC Mechanical System Initial Cost:

$1.6 million dollar

Existing System Cost ≈ Geothermal System Cost

Note:

Geothermal systems increase the ground temperature by 1 to 5 °F over time

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Geothermal System Plausibility

➢ Must Meet Requirements

- 🗸 Adequate space requirements
- 🗸 Adequate equipment space

➢ Should Meet Criteria

- 🗸 Reduced annual energy consumption
- 🗸 Reduced annual emissions
- 🗸 Reduced annual utility Costs
- 🗸 Reduced initial cost

Geothermal System Conclusion

Therefore a Geothermal System is Plausible

****However it is not plausible on an exiting building.**
The redesign costs would not be worth the efforts.

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AMIC Noise Concerns

Noise Caused by the 4 Rooftop Air Handling Units

- **Air-borne Noise**
- **Structure-borne Noise**
- **Vibration Noise**

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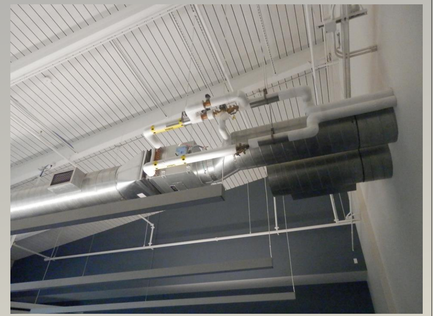

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Air-borne Noise (insertion loss)

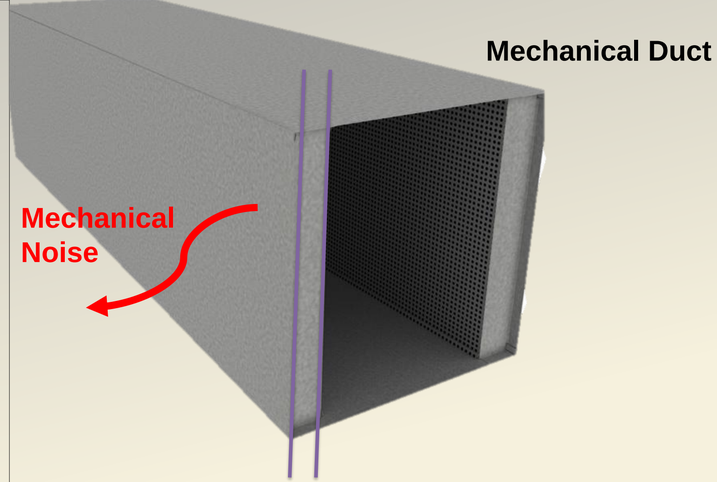
Increase the Fiberglass Lining in Ductwork

- Thickness
- Density

Will Reduce:

Total HVAC Duct Noise's
Occupant Noise Complaints

Extremely Expensive
*Not feasible to redesign all the ducts in an existing building



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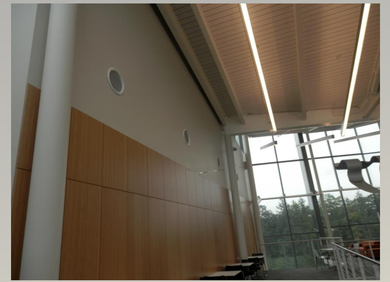

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Structure-borne Noise

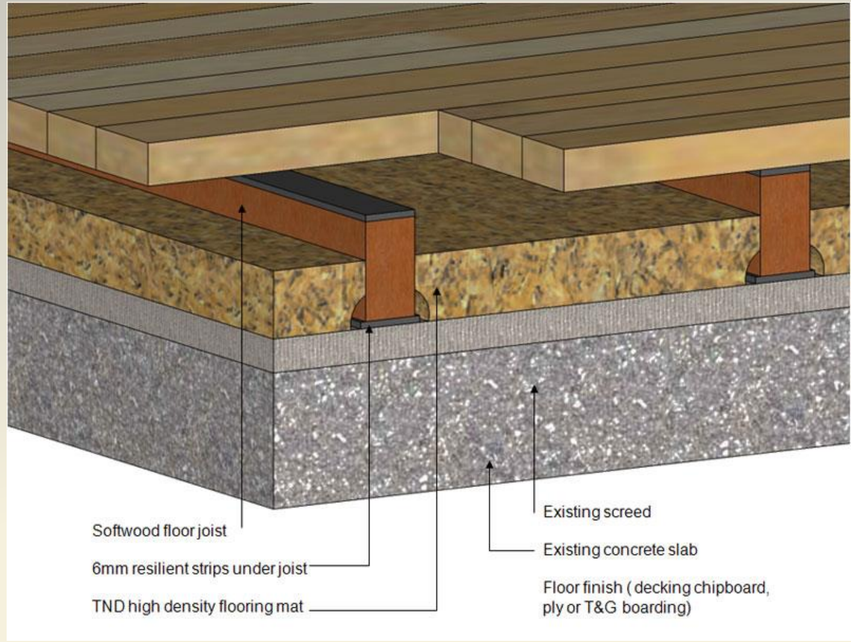
*usually largest contributor to buildings noise

Make AMIC's Roof a Floating Floor

Will Reduce:

Total HVAC Noise
Total Building Vibrations
Occupant Noise Complaints

Extremely Expensive
*Not feasible to redesign the roof of an existing building



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Vibration Isolation

Will Reduce:

Total HVAC Noise
Total Building Vibrations
Occupant Noise Complaints

Will Cost More Money

-Cheaper then other option

Inertial Base

For RTU's

Isolation Base Type C
Spring Mounts Type 3

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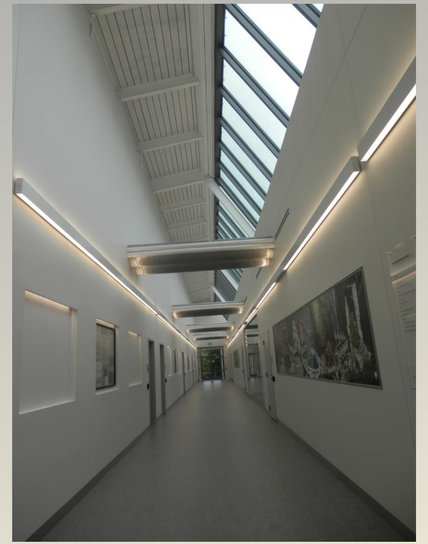

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Conclusion

- **Air-borne Noise (insertion loss)**
  Too Expensive & Not Plausible
- **Structure-borne Noise (floating floor)**
  Too Expensive & Not Plausible
- **Vibration Noise (inertial base)**
  Least Expensive, Plausible
- **Alternative Option: Equipment Relocation**
  Expensive (best option preconstruction)

Best Option

Cheapest and Most Plausible Option

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Initial Concerns:

- Location (sun availability)
- Placement of panels
- Cost (payback)

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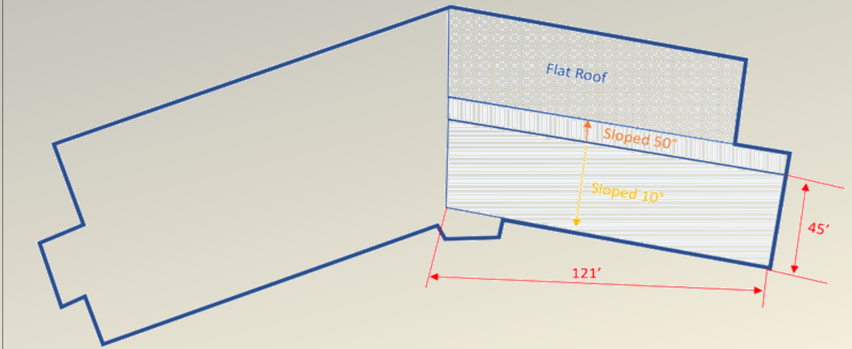
Solar Panels
Location



5,445 SF
Potential of 315 Panels

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Solar Panels

Energy

1000V DC System
327 Solar Panel Sun Power Model
SMA 20,000 W inverter

V_{oc} = 64.9 V T= 176.6 mv/°C STC = 25°C Assume Annual Low Temp of -26°C

ΔT = -51°C

$\frac{1000V}{64.9\,V/mod} = 15.4\,modules \rightarrow 15$

$$AV = \left(-0.1766\frac{V}{°C}\right) * (-51°C) = 9\ V$$

$$Max\ V_{oc} = 64.9\ V + 9\ V = 73.9\ V$$

$$\frac{1000V}{73.9\,V/mod} = 13.5\,modules/string \rightarrow 13$$

$$1\,string * (13\,modules) * \left(0.327\frac{\text{kw}}{\text{module}}\right) = 4.25\ \text{kw/string}$$

$$\frac{25\ kw/mv}{4.25\ /string} = 5.56\,string/inverter \rightarrow 6\,strings$$

$$6 * 4.24\,kw = \left(\frac{25.5\ \text{kw}}{20\ \text{kw}}\right) = 1.26$$

$$6\,strings * (13\,modules) = 78\ \text{modules}$$

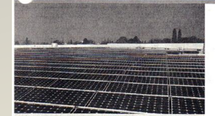
$$\frac{315\ \max modules}{78\ module/\,inverter} = 4.04\,inverters \rightarrow 4$$

$$4\,inverters * (78\,modules) = 312\ \text{modules}$$

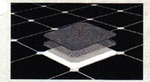
4 20kw inverter
25.1 kw DC
6 strings of 13 modules
312 Total Modules

SUNPOWER®
MORE ENERGY. FOR LIFE.™

E-SERIES COMMERCIAL SOLAR PANELS



- 20.4% efficiency
Captures more sunlight and generates more power than conventional panels.
- High performance
Delivers excellent performance in real world conditions, such as high temperatures, clouds and low light.[2,7]
- Commercial grade
Optimized to maximize returns and energy production, the E-Series panel is a bankable solution for commercial solar applications.



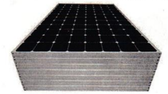
Maxeon® Solar Cells: Fundamentally better.
Engineered for performance, designed for reliability.

Engineered for peace of mind
Designed to deliver consistent, troublefree energy over a very long lifetime.[4,5]

Designed for reliability
The SunPower Maxeon Solar Cell is the only cell built on a solid copper foundation. Virtually impervious to the corrosion and cracking that degrade Conventional Panels.[4,5]

#1 Ranked in Fraunhofer durability test.[10]
100% power maintained in Atlas 25+ comprehensive PVDI Durability test.[11]

HIGH PERFORMANCE & EXCELLENT RELIABILITY

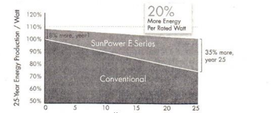


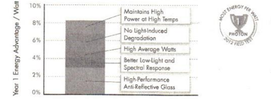
E20 SERIES

E20 · 327 PANELS

HIGH EFFICIENCY[6]
Generate more energy per square foot
E-Series commercial panels convert more sunlight to electricity producing 36% more power per panel,[1] and 60% more energy per square foot over 25 years.[3,4]

HIGH ENERGY PRODUCTION[9]
Produce more energy per rated watt
More energy to power your operations. High year one performance delivers 7.9% more energy per rated watt.[3] This advantage increases over time, producing 20% more energy over the first 25 years to meet your needs.[4]





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ADVANCED MANUFACTURING AND INNOVATION CENTER (AMIC)

Building Overview
Information | Existing System
Mechanical Depth
Location | Energy | Plausibility
Acoustical Breadth
Potential Solutions | Conclusion
Electrical Breadth
Energy | Cost | Plausibility
Conclusion

Paula K. Schuller

Solar Panels
Energy

1 BTU = 0.293 Watt-Hours

Solar Panels

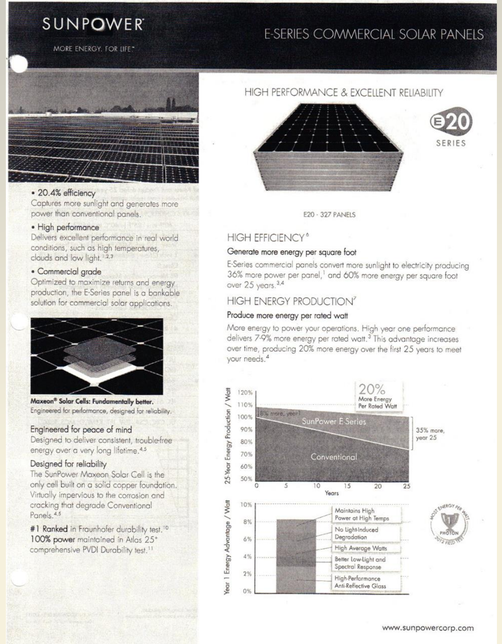
(312 modules) * (327 $\frac{Watts}{Module-hour}$) * (10 $\frac{hours}{Day}$) * (200 $\frac{days}{year}$)

= 204,048,000 $\frac{Watt-Hour}{year}$

Building

($\frac{3,209,342,000\ BTU}{year}$) * ($\frac{0.293\ Watt-hour}{BTU}$) = 940,337,206 Watt-Hour/year

$\frac{204,048,000\ Watt-hour}{940,337,206\ Watt-hour}$ = 22% of yearly energy


SUNPOWER
MORE ENERGY. FOR LIFE.
E-SERIES COMMERCIAL SOLAR PANELS
HIGH PERFORMANCE & EXCELLENT RELIABILITY
E20 SERIES
• 20.4% efficiency
Captures more sunlight and generates more power than conventional panels.
• High performance
Delivers excellent performance in real world conditions, such as high temperatures, clouds and low light.[2,3]
• Commercial grade
Optimized to maximize returns and energy production, the E-Series panel is a bankable solution for commercial solar applications.
E20 · 327 PANELS
HIGH EFFICIENCY[6]
Generate more energy per square foot
E-Series commercial panels convert more sunlight to electricity producing 36% more power per panel,[1] and 60% more energy per square foot over 25 years.[3,4]
HIGH ENERGY PRODUCTION[7]
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Engineered for performance, designed for reliability.
Engineered for peace of mind
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#1 Ranked in Fraunhofer durability test.[10]
100% power maintained in Atlas 25+ comprehensive PVDI Durability test.[11]
20% More Energy Per Rated Watt
SunPower E-Series
Conventional
35% more, year 25
25 Year Energy Production / Watt
Years
Year 1 Energy Advantage / Watt
Maintains High Power at High Temps
No Light-Induced Degradation
High Average Watts
Better Low-Light and Spectral Response
High-Performance Anti-Reflective Glass
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Energy | **Cost** | Plausibility
Conclusion

Solar Panel Life Span
25 to 30 years

Paula K. Schuller

Solar Panels
Cost

(312 modules) * (327 $\frac{Watts}{Module-hour}$) * (10 $\frac{hours}{Day}$) * (200 $\frac{days}{year}$)

= 204,048,000 $\frac{Watt-Hour}{year}$

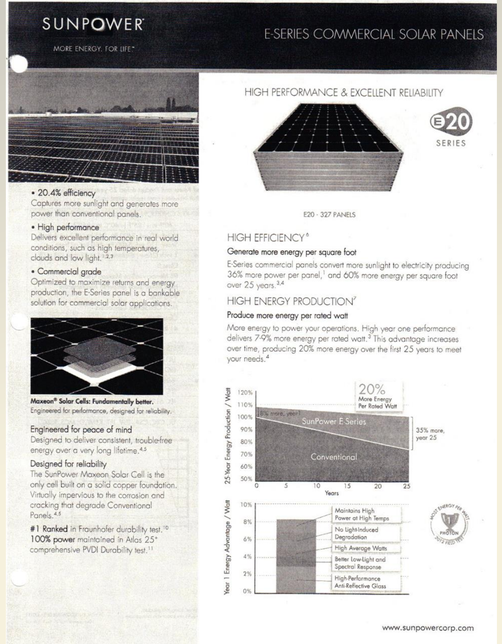
Installation Cost 1 Watt = $7

(312 modules) * (327 $\frac{Watts}{Module-hour}$) = 102,024 Watts

$7 * (102,024 Watts) = $714,168

(204,048,000 $\frac{Watts}{hour}$) * 12 ($\frac{cents}{KWatt-hour}$) * ($\frac{1\ KWatt}{1000\ Watts}$) * ($\frac{\$1}{100\ cents}$) = $24,485 savings per year

$\frac{\$714,168\ (instalation)}{\$24,485\ (savings)}$ = 29 years payback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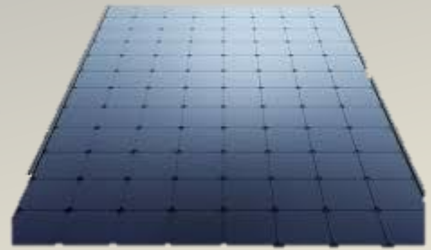

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Solar Panels

312 Modules

Saves 22% of Annual Energy

Saves $24,485 Annually

Payback = 29 Years

Note: The roof would have to be analyzed in order to account for the added dead load of the solar panels

(41 lbs./module) *(312 modules) =12,792 lbs.
of dead weight added
to the roof

ADVANCED MANUFACTURING AND INNOVATION CENTER (AMIC)

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Conclusions

- **Geothermal System**
  - Would reduce total energy
    - **Not Plausible**
- **Noise Concerns**
  - Best option would be a vibration isolation base
- **Solar Panels**
  - Would reduce total energy
    - **Plausible if roof can support added dead load**

ADVANCED MANUFACTURING AND INNOVATION CENTER (AMIC)

Design Team

Architects	**Bostwick Design Partnership**
Structural Engineers	Atlantic Engineering Services
MEP Engineers	CJL Engineering
Civil Engineers	Stanford Surveying and Engineering, P.C.
Landscape Architects	Dahlkemper Landscape Architects and Contractors

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ADVANCED MANUFACTURING AND INNOVATION CENTER (AMIC)

Paula K. Schuller

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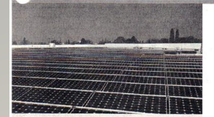
E-SERIES COMMERCIAL SOLAR PANELS



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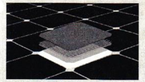

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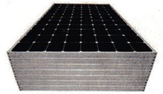

E20 SERIES

E20 - 327 PANELS

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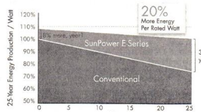

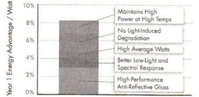

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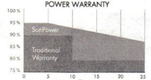
E-SERIES COMMERCIAL SOLAR PANELS

SUNPOWER OFFERS THE BEST COMBINED POWER AND PRODUCT WARRANTY

POWER WARRANTY



More guaranteed power: 95% for first 5 years, -0.4%/yr. to year 25.[8]

PRODUCT WARRANTY

Combined Power and Product defect 25 year coverage that includes panel replacement costs.[9]

ELECTRICAL DATA	E20-327-COM	E19-310-COM
Nominal Power[12] (Pnom)	327 W	310 W
Power Tolerance	+5/-3%	+5/-3%
Avg. Panel Efficiency[13]	20.4%	19.3%
Rated Voltage (Vmpp)	54.7 V	54.7 V
Rated Current (Impp)	5.98 A	5.67 A
Open-Circuit Voltage (Voc)	64.9 V	64.4 V
Short-Circuit Current (Isc)	6.46 A	6.05 A
Max. System Voltage	1000 V UL & 1000 V IEC	
Maximum Series Fuse	20 A	
Power Temp Coef.	-0.38% / °C	
Voltage Temp Coef.	-176.6 mV / °C	
Current Temp Coef.	3.5 mA / °C	

OPERATING CONDITION AND MECHANICAL DATA	
Temperature	-40°F to +185°F (-40°C to +85°C)
Max load	Wind: 50 psf, 2400 Pa, 245 kg/m² front & back Snow: 112 psf, 5400 Pa, 550 kg/m² front
Impact resistance	1 inch (25mm) diameter hail at 52 mph (23 m/s).
Appearance	Class B
Solar Cells	96 Monocrystalline Maxeon Gen II
Tempered Glass	High transmission tempered Anti-Reflective
Junction Box	IP-65 Rated
Connectors	MC4 Compatible Connectors
Frame	Class 2 silver anodized
Weight	41 lbs (18.6 kg)

TESTS AND CERTIFICATIONS	
Standard tests	UL1703, IEC 61215, IEC 61730
Quality tests	ISO 9001:2008, ISO 14001:2004
EHS Compliance	RoHS, OHSAS 18001:2007, lead free
Ammonia test	IEC 62716
Salt Spray test	IEC 61701 (passed maximum severity)
PID test	Potential-Induced Degradation free: 1000V[10]
Available listings	UL, CEC, CSA, TUV, JET, KEMCO, MCS, FSEC

REFERENCES:
1 All comparisons are SPR-E20-327 vs. a representative conventional panel: 240W, approx. 1.6 m², 15% efficiency.
2 PVEvolution Labs "SunPower Shading Study," Feb 2013.
3 Typically 7-9% more energy per watt, BEW/DNV Engineering "SunPower Yield Report," Jan 2013.
4 SunPower 0.25%/yr degradation vs. 1.0%/yr conv. panel. Campeau, Z. et al. "SunPower Module Degradation Rate," SunPower white paper, Feb 2013; Jordan, Dirk "SunPower Test Report," NREL, Oct 2012.
5 "SunPower Module 40-Year Useful Life" SunPower white paper, Feb 2013. Useful life is 99 out of 100 panels operating at more than 70% of rated power.
6 Out of all 2600 panels listed in Photon International, Feb 2012. 7 8% more energy than the average of the top 10 panel companies tested in 2012 (151 panels, 102 companies), Photon International, March 2013.
8 Compared with the top 15 manufacturers. SunPower Warranty Review, Feb 2013.
9 Some exclusions apply. See warranty for details.
10 9 of top 8 panel manufacturers were tested by Fraunhofer ISE, "PV Module Durability Initiative Public Report," Feb 2013.
11 Compared with the non-stress-tested control panel. Atlas 25+ Durability test report, Feb 2013.
12 Standard Test Conditions (1000 W/m² irradiance, AM 1.5, 25° C).
13 Based on average of measured power-values during production.

See http://www.sunpowercorp.com/facts for more reference information.
For more details, see extended datasheet: www.sunpowercorp.com/datasheets. Read safety and installation instructions before using this product.
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1000V DC System
327 Solar Panel Sun Power Model
SMA 20,000 W inverter

V_{oc} = 64.9 V T= 176.6 mv/°C STC = 25°C Assume Annual Low Temp of -26°C

ΔT = -51°C

$$\frac{1000V}{64.9\ V/mod} = 15.4\ modules \rightarrow 15$$

$$\Delta V = \left(-0.1766\frac{V}{°C}\right) * (-51°C) = 9\ V$$

$$Max\ V_{oc} = 64.9\ V + 9\ V = 73.9\ V$$

$$\frac{1000V}{73.9\ V/mod} = 13.5\ modules/string \rightarrow 13$$

$$1\ string * (13\ modules) * \left(0.327\frac{\text{kw}}{\text{module}}\right) = 4.25\ \text{kw/string}$$

$$\frac{25\ kw/mv}{4.25\ /string} = 5.56\ string/inverter \rightarrow 6\ strings$$

$$6 * 4.24\ kw = \left(\frac{25.5\ \text{kw}}{20\ \text{kw}}\right) = 1.26$$

$$6\ strings * (13\ modules) = 78\ \text{modules}$$

$$\frac{315\ \max modules}{78\ module/\ inverter} = 4.04\ inverters \rightarrow 4$$

$$4\ inverters * (78\ modules) = 312\ \text{modules}$$

4 20kw inverter
25.1 kw DC
6 strings of 13 modules
312 Total Modules

1 BTU = 0.293 Watt-Hours

Solar Panels

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