

Final Report:

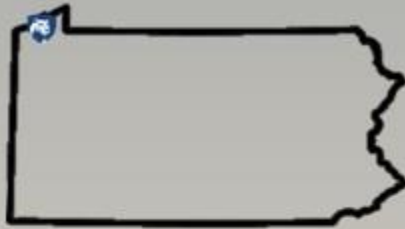
By: Paula Schuller



Location: Penn State Behrend (Erie, PA)

Option: Mechanical
Advisor: Freihaut
Semester: Spring 2017

ADVANCED MANUFACTURING AND INNOVATION CENTER (AMIC)



LOCATION: Penn State Behrend
Knowledge Park Erie, PA

OCCUPANCY: Business

CONSTRUCTION: September 2014 - July 2016

ARCHITECTURE

AMIC was designed for both Penn State University and Industry. The left wing of the building is specifically for Penn State Behrend ME department. This wing includes typical classrooms, offices, and senior thesis labs. The right wing was specifically designed for industry tenants. Some of these tenants were known from the beginning of the project while others signed up to occupy the spaces after construction had ended. These spaces include offices and high tech labs for specialty equipment.

ARCHITECT: Bostwick Design Partnership

STRUCTURAL ENGINEERS: Atlantic Engineering Services

MEP ENGINEERS: CJL Engineering

CIVIL ENGINEERS: Stanford Surveying and Engineering, P.C.

LANDSCAPE ARCHITECT: Dahlkemper Landscape Architects and Contractors

STRUCTURE

AMIC was designed with structural steel framing that tie into concrete slabs and footers. Since this building is only two stories it was designed mostly with 30' bays to provide the future tenants lots of flexibility.

LIGHTING

This building was designed to maximize solar gain through window shading devices and angled windows. Also a clearstory window runs along the entire length of the north side of the building allowing tons of natural sunlight though for the second floor during the day.

MECHANICAL

The building mechanical system is primarily a variable air volume (VAV) system. Supplying cool air to the spaces from the three roof top air handling units. The primary heating system is the radiant wall heating panels that run along the perimeter of the north side of the building. The heating is accomplished through two separate gas fired boilers.

Paula K. Schuller
Mechanical Option



Photo: Paula Schuller

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Amy Bridger - A special thanks to Amy for taking the time to give me a tour of AMIC.

Friends and Family

For helping me to get through college and always being there.

1 EXECUTIVE SUMMARY

This is the final analysis of the Advanced Manufacturing and Innovation Center located in Erie Pennsylvania. The conclusion to the yearlong investigation into the engineering systems within the building. Including a more detailed analysis into the mechanical systems, an acoustical analysis, and electrical analysis. The focus of this report is the redesign analysis of the mechanical system.

The mechanical system redesign is to potentially replace the existing system to improve energy efficiency, economic impacts and overall building design. The existing mechanical system is composed of four roof top air conditioning units that supply air to the separate wings of the building. The two boilers located in the mechanical room supply hot water to the radiant heating panels located throughout the building for heating purposes. This existing system will be compared to the redesign to determine which is the best for AMIC.

The mechanical system redesign was determined to be a geothermal system. This system is plausible in the location and could greatly reduce the total energy consumed as well as the environmental impact of the HVAC system. To be determined as the best option for AMIC, the geothermal system must be more efficient, environmentally friendly, and a lower cost than the existing system. It is a prediction that this system will not be determined best since the building is already constructed. It would have been a more plausible option if the building was still in the design phase.

In addition, an acoustical depth was done on the noise caused by the exiting mechanical equipment. The rooftop units are causing noise to resonate within the building. To eliminate this, many options were analyzed and researched to determine which option would be the most feasible as well as the least overall cost.

The last analysis was completed on whether solar panels would be an electrical design option. This would reduce the overall buildings electrical load and save AMIC in monthly utility costs. This system would be determined as feasible if the system saved AMIC annual energy, had a simple payback less than the life span of the solar panel system, and AMIC could withstand the additional dead load added to the roof.

Finally, the last section of this report is the final recommendations after all three analyses were complete. The recommendations consider all the initial conditions, energy impacts, environmental impacts, initial and lifespan costs, and finally plausibility.

2 INTRODUCTION

2.1 Building Background

The Advanced Manufacturing and Innovation Center (AMIC) is a newly constructed mixed-use building located in Erie, PA. The building sits on Penn State Behrend's knowledge park shown in Figure 1. The building was designed for two specific purposes. To provide Penn State mechanical engineering student's classroom and lab spaces. Also, to provide space for industries.



FIGURE 1: SITE LOCATION OF ADVANCED MANUFACTURING AND INNOVATION CENTER.

In the recent years Behrend has been pushing hard to incorporate industry into the classroom as well as providing students real projects provided by the engineering industry. AMIC is the first building designed specifically for both to work together. When Bostwick Design was first drafting the plans for the building they knew that half of it would be occupied by industry. However, they didn't know specifically what companies yet so it was designed for "Future Tenants." This is what it will be referred to throughout this report. The future tenant space is openly designed for maximum flexibility for when the tenants move in (east wing of AMIC).

AMIC is composed mostly of classrooms, offices, labs (west wing of AMIC) and the future tenant space (east wing of AMIC). In addition to these spaces there is also the lobby, bathrooms, mechanical, and electrical spaces shown in Figure 2. Being affiliated with Penn State Behrend the designers (Table 1) were cautious of energy savings. However, due to budget restrictions LEED was not an attainable option.

Finally, the design team was excited to be the first building of its kind bringing students and industry together. And as of right now one of the current tenants already has plans on expanding the building.

Table 1: 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

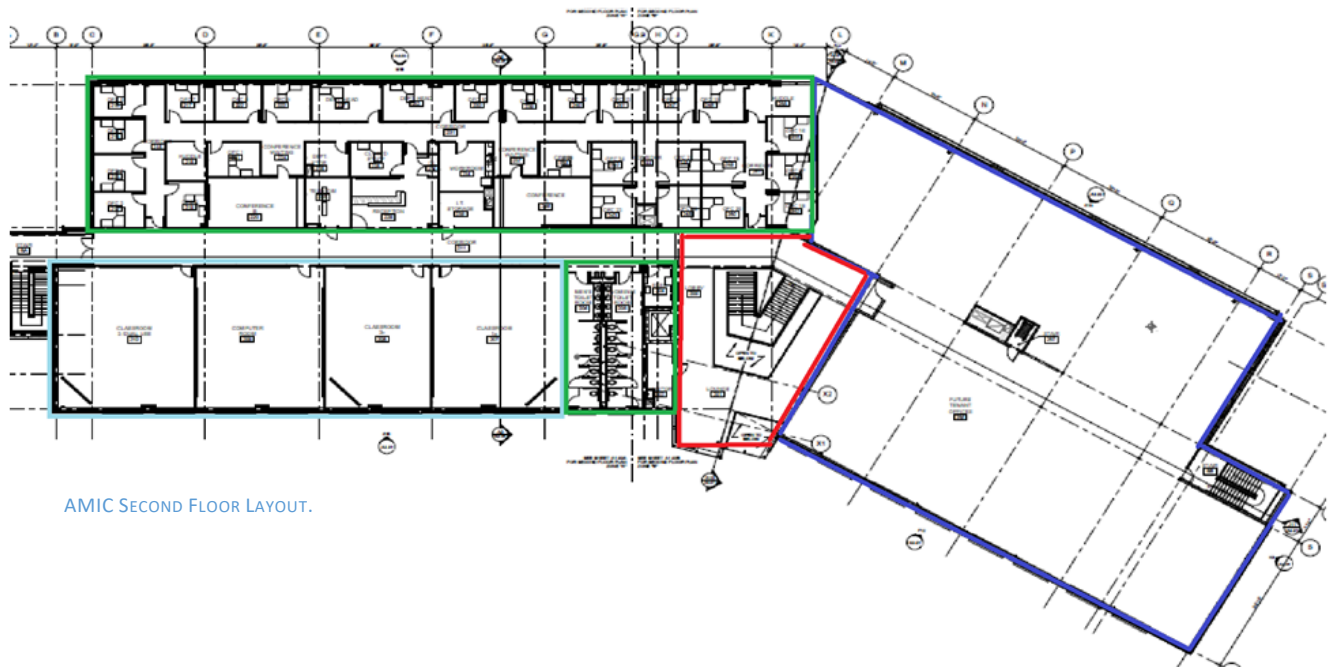
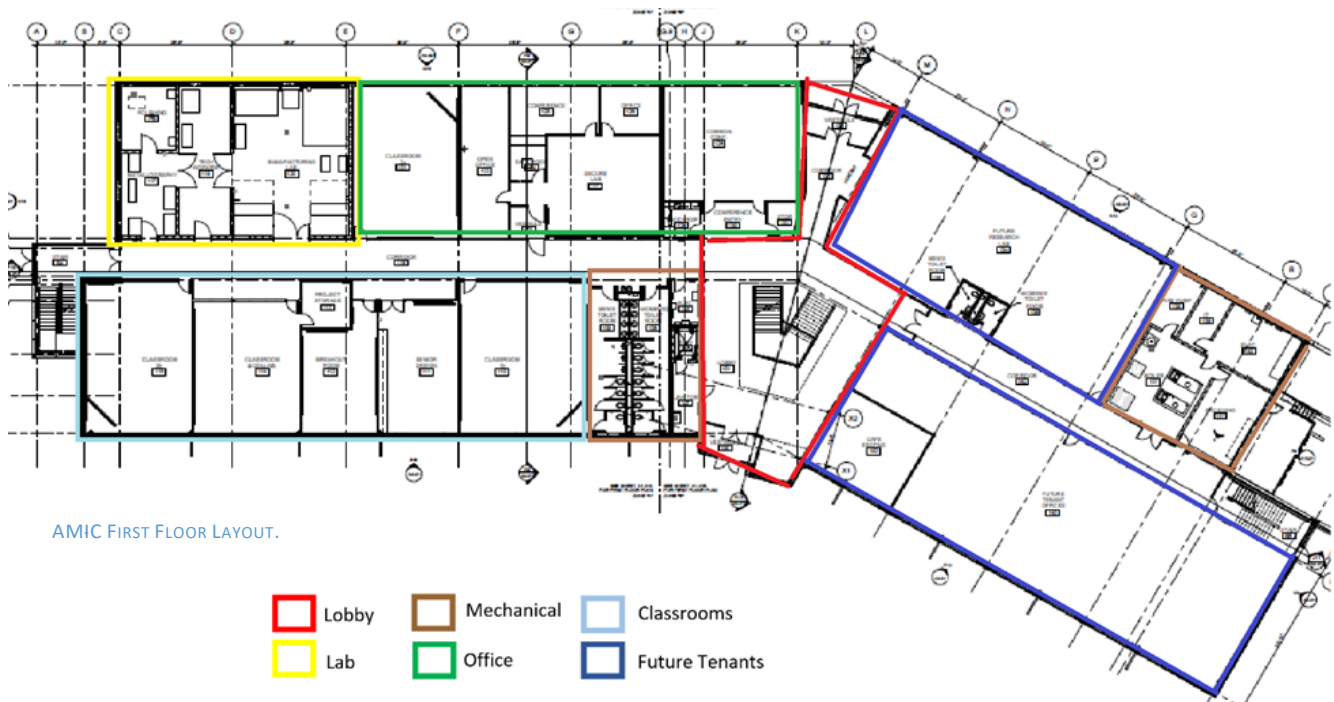


FIGURE 2: AMIC FIRST AND SECOND FLOOR LAYOUT.

2.2 Building Architecture

AMIC is a two story above grade, 59,300 square foot building. The building is structurally supported by steel columns on top of a reinforced concrete slab. The building was a 23-month construction from start to finish with a final estimated cost of about 16.5 million dollars.

Aesthetically the exterior is a brick façade with aluminum siding to match Behrend and Knowledge Park's campus. Shown in Figure 3.

Figure 4 shows how AMIC maximized the natural light by incorporating skylights throughout the building. As previously stated, the building was designed for ME students. One of the main design objectives was to leave most of the duct work and plumbing exposed. This can also be seen in the hallway in Figure 4 as well as in the first-floor classrooms seen in Figure 5.



FIGURE 3: BUILDING FAÇADE.



FIGURE 4: HALLWAY SHOWING NATURAL LIGHTING AND EXPOSED PLUMBING.

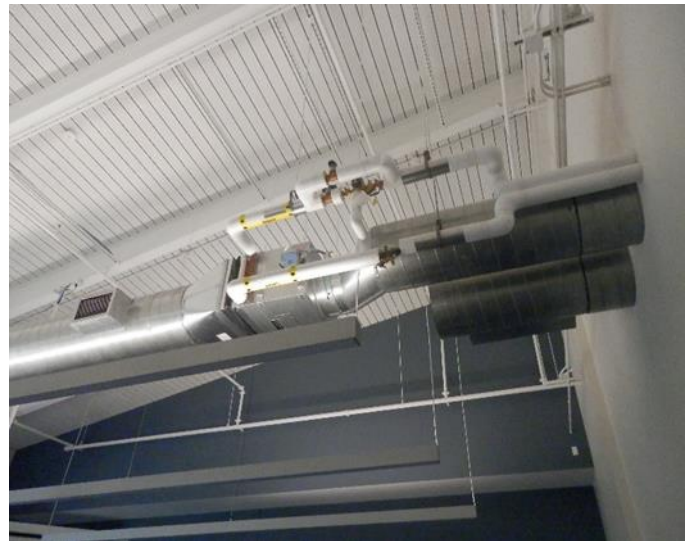


FIGURE 5: CLASSROOMS SHOWING EXPOSED MECHANICAL AND PLUMBING SYSTEMS.

3 EXISTING MECHANICAL SYSTEM

Note: Ashrae 62.1 and 90.1 2007 compliance checks were met in Tech Report 1.

3.1 Design Conditions

3.1.1 Outdoor Design Conditions

Penn State Behrend Campus is in Erie, PA. This area is categorized as climate zone 5-A: Cool and Humid (per ASHRAE 90.1 Standards) as seen in Figure 6 below. Temperatures in this region range from -10°F at peak heating and 100°F at peak cooling load. The annual rainfall is on average 42.21 inches per year due to the proximity to the great lakes.

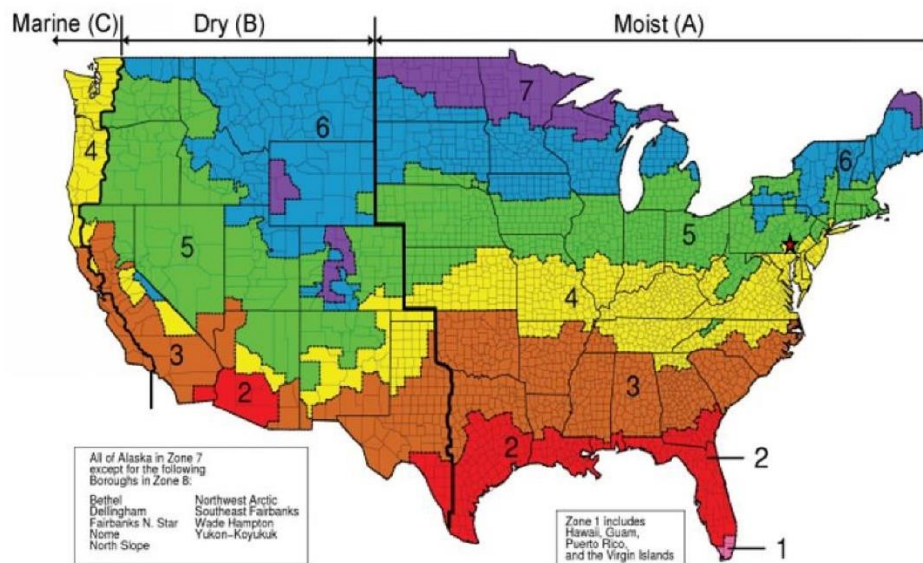


FIGURE 6: UNITED STATES CLIMATE ZONE MAP, ASHRAE STD 90.1- 2013.

The weather data utilized was heating at 99.6% and cooling at 0.4%. The heating conditions for the winter months uses a dry bulb of -5°F, and for the cooling months a dry bulb of 90°F. The peak coldest and hottest months of the year are January and July.

3.1.2 Indoor Design Conditions

The indoor design room condition thermostat settings are as follows:

- Cooling Dry Bulb - 75°F
- Heating Dry Bulb - 70°F
- Relative Humidity – 50%

On the left wing of the building the classrooms and labs have their own controls as they were designed as different zones. They are cooled by the rooftop units that provide the air down to the VAV boxes per zone and then the air is reheated per zone using horizontal unit heaters. In addition to the temperature controls the left wing of the building was fit with CO2 sensors as well as occupancy and vacancy sensors to reduce the overall heating and cooling loads of the building.

3.2 Building Loads

3.2.1 Load Assumptions

Occupant densities were determined for the office space, classrooms, and bathrooms using the furniture plans acquired from Bostwick Design Partnership. Calculating the total number of seats in each space to determine the occupancy for these spaces. To calculate the occupant densities for the manufacturing labs and future tenant spaces the densities were assumed using AHSRAE 62.1 Standards. This provided an accurate assumption of the number of people per square foot.

All information regarding the lighting loads were taken from the electrical drawings provided by CJL Engineering. Or when necessary assumed to be 1 w/sf. This is an accurate assumption for the buildings lighting loads.

Finally assume that the spaces within the building shall be occupied for 8-hour work days, 5 days a week. Since the building is almost entirely classrooms, offices, and tenant space (which is more offices) this is a valid assumption. The occupants of this building are going to occupy the building during normal business hours with few hours differing from this schedule. In addition, the building will be unoccupied on weekends except for maybe a few occupants and cleaning crews.

3.2.2 Heating and Cooling Requirements

Using Trane Trace 700 a model of AMIC was made for Technical Report Two. Per these results the outputs calculated are shown in Table 2. Also, showing the initial design conditions designed by Bostwick Design Partnership. Some of the discrepancies in the calculated values compared to the design values can be attributed to the differences in actual occupied time. AMIC will be occupied mostly during the school year. When using, Trane Trace the calculations are done year around. This could be one of the reasons for the slight differences. Additionally, to perform the Trane calculations group zoning was used instead of modeling each space individually.

Table 2: Cooling and Heating Loads. Design Verses Calculated.

RTU	Cooling Design		Heating Design		Cooling Calculated		Heating Calculated	
	MBH	CFM	MBH	CFM	MBH	CFM	MBH	CFM
RTU-1	597	13,500	761	13,500	271	7,027	171	2,438
RTU-2	611	16,800	741	16,800	612	15,083	416	5,350
RTU-3	1,076	28,330	1,290	28,330	1,130	61,680	649	19,137
RTU-4	74	3,000	180	3,000	145	2,595	73	867

3.2.3 Ventilation Requirements

AMIC met all the ventilation requirements through the roof top air handling units providing outside air to each space. This meets the AHSRAE 62.1 building ventilation. Also, to further exceed the requirements AMIC provides operable windows to most of the buildings spaces including the

classrooms, office spaces, and future tenant space. As for the manufacturing labs on the first floor the exhaust air requirements are also being met. The exhaust ducts for the manufacturing labs are separate from the rest of the building and exhaust 3830 CFM of air from the labs. These exhaust ducts run straight up through the building exhausting the air to the roof. Table 3 shows the design ventilation outside air flow verses the Trane Trace calculated ventilation outside air flow.

Table 3: Ventilation Rates. Design Verses Calculated.

RTU	Design OA Flow	Calculated OA Flow
	CFM	CFM
RTU-1	4,050	3,176
RTU-2	4,032	3,923
RTU-3	5,666	4,143
RTU-4	300	867

Note: For further ventilation and exhaust requirements and calculations of AMIC see Tech Report One.

3.3 System Equipment

The major mechanical equipment for AMIC including air and water side are summarized in the tables that follow:

Table 4: Conditioning Equipment Information.

RTU-XX	LOCATION	MAX CFM	% OA	COOLING MBH	COOLING SUPPLY	HEATING SUPPLY
RTU-1	Left Wing First Floor	13,500	30	761	50°F	95°F
RTU-2	Left Wing Second Floor	16,800	26	741	56°F	97°F
RTU-3	Right Wing	28,330	20	1,290	56°F	98°F
RTU-4	Secure Lab	3,000	10	74	53°F	65°F

Table 4 above shows an equipment breakdown. AMIC requires 4 RTU's. RTU-4 is only utilized for the secure lab space on the first floor of the building. RTU-4 is also the only gas fired roof top unit. The other RTU's are electric. RTU-1 and RTU-2 supply air to the left wing of the building (The classrooms and offices). RTU-3 exclusively supplies air to the right wing of the building (Future tenant space). These spaces have larger square footages and higher occupancy densities. Therefore, this unit is the largest to meet the needs of the space.

Table 5 below is a table of the four exhaust fans for each RTU. Due to code requirements in lab spaces the EF-1 must be the largest to meet ventilation and air requirements in this space.

Table 5: Exhaust Fan Schedule.

Exhaust Fan	Serves	Type	CFM	RPM	HP
EF-1	Manufacturing Labs	Nozzel	3,830	1,860	3.00
EF-2	General Exhaust	Centrifugal	1520	1,202	0.50
EF-3	General Exhaust	Centrifugal	1,420	752	0.25
EF-4	General Exhaust	Centrifugal	3030	935	0.75

Table 6: Boiler Schedule.

Boiler Number	Input MBH	Output @ 85% efficiency		Approximate Weight
		HP	MBH	
B-1	1800	46	1530	3721
B-2	1800	46	1530	3721

Table 6 above is a table of the two boilers. The boilers are used both for domestic water as well as for the fin tubes and radiant wall panels. Both boilers are completely identical.

Table 7 and 8 below are the fin tube and radiant heating panel tables. These are AMIC's main source of heating throughout the building. There is a total of 33 radiant heating panels throughout the building. However, they are all identical so the table only shows the information for RP-1.

Table 7: Fin Tube Schedule.

Fin Tube	Fins/ Foot	Length	BTU	GPM
FT-1	50	14'-0"	12,740	1.00
FT-2	50	4'-0"	3,640	0.50
FT-3	50	5'-0"	4,550	0.50
FT-4	50	8'-0"	7,280	0.50

Table 8: Radiant Heating Panel Schedule.

Radiant Heating Panel	BTU/SF	GPM
RP-1 (&2-33)	246	0.5

Below in Tables 9, 10, and 11 are some of the remaining building equipment. Table 10 the pumps to get the water throughout the building to heat or cool the spaces. Finally, Table 11 shows the unit heaters which are used in certain spaces to provide individual space controls.

Table 10: Remote Condensing Unit Schedule.

Remote Condensing Unit	Serves	Tons	MCA	MOP
RCU-1	RTAHU-1	50	91	100
RCU-2	RTAHU-2	50	91	100
RCU-3	RTAHU-3	90.1	192	225

Table 9: Pump Schedule.

Pump	Duty	Type	Location	HP	RPM	Efficiency (%)
P-1	Hot water system (duty)	Base Mounted End Suction	Boiler Room	15	1,750	74.5
P-2	Hot water system (stand-by)	Base Mounted End Suction	Boiler Room	15	1,750	74.5
P-3	Boiler Runaround	Incline ECM Motor	Boiler Room	1.1	3,300	-
P-4	Boiler Runaround	Incline ECM Motor	Boiler Room	1.1	3,300	-

Table 11: Unit Heater Schedule.

Unit Heater	CFM	MBH	GPM	Air Temp	Water Temp	RPM
CUH-1 (2&3)	330	30.1	2	144	144	1,050
HUH-1	420	15.7	1.2	60	180	1,350
HUH-2 (&3-12)	900	43.7	3	60	18	1,000

3.4 Energy Consumption

3.4.1 Fuel

AMIC is fueled by both electricity and gas. All boilers, emergency generators, and some HVAC equipment is fueled by gas. Everything else is fueled through electrical power.

The Figure 7 below shows the percent of total annual energy broken down into categories. The categories include: Heating energy, Cooling energy, Auxiliary energy, lighting and receptacles.

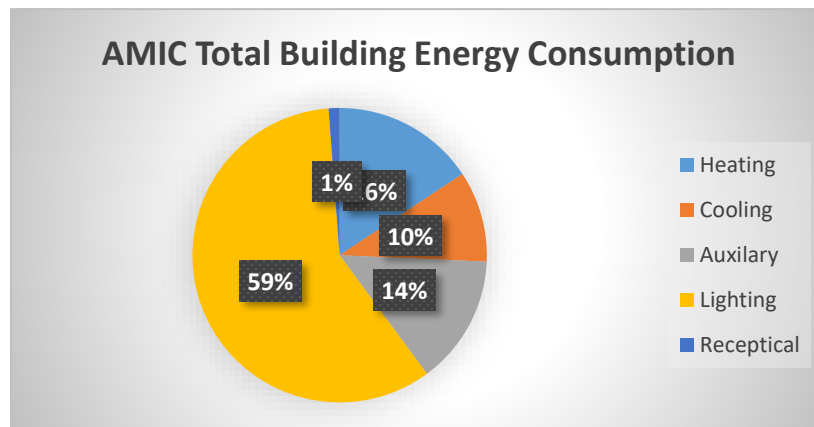


FIGURE 7: TOTAL BUILDING ENERGY CONSUMPTION.

Since AMIC is in Erie, PA the building requires heating for a greater portion of the year. Also, the building will be mostly occupied during the school year making the peak energy costs during the winter months. Only the right wing of the building will be occupied during the summer reducing the amount of electricity and limiting the building's right wing to only two RTAHU's. Also during the summer months, the receptacle and lighting load will be significantly reduced due to the reduced occupancy density.

3.4.2 Water

AMIC is conditions using 4 rooftop units. All of which utilize a water-based cooling system. Therefore, during the summer months when the RTU's are running at peak loads they are also consuming the most water. Figure 8 below shows that during the hottest months of the year the water consumption is slightly reduced but this is because only two RTU's will be utilized during the summer.

Therefore, using less water but also requiring the most cooling. Making these months very comparable to all the month's water consumption.

3.4.3 Annual

AMIC's building consumption as stated above is as expected for the type of building and mechanical systems utilized. The most water will be consumed during the summer months due to use of RTU's. The highest consumption of electricity will be during the summer months when the students, faculty, and occupants of the tenant spaces are at highest capacity. Thus, using the most lighting, receptacle, cooling, and heating energy. Figure 9 to the right shows the amount of electricity vs gas AMIC consumes annually. As shown clearly AMIC uses more than 4 times as much electricity annually as it does gas.

This is due to most of the buildings operating equipment is run by electricity. The only equipment that utilizes gas is the water boilers, and one RTU (RTU-4).

Note: These results were found using Trane Trace 700 using a model I created of AMIC and its building equipment.

Per a report that was done in 2013 before construction on AMIC had started the predicted cost of annual electric consumption was \$85,364 per year and for gas consumption, it was predicted to be \$14,192.

The yearly utility operating cost of AMIC is \$44,661. Figure 10 to the right shows a breakdown of AMIC's utility costs per month. On average the monthly total utility cost doesn't vary much per month.

The annual cost results shows that annually AMIC will have a utility cost per area of 0.88 \$/ft².

Note: This is a product of the initial Trane Trace Model.

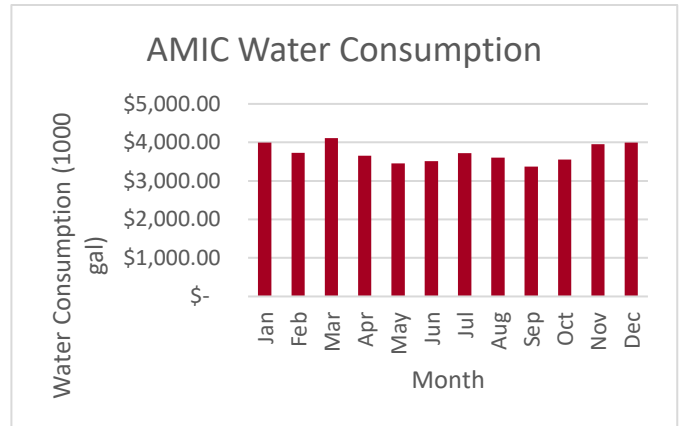


FIGURE 8: MONTHLY WATER CONSUMPTION.

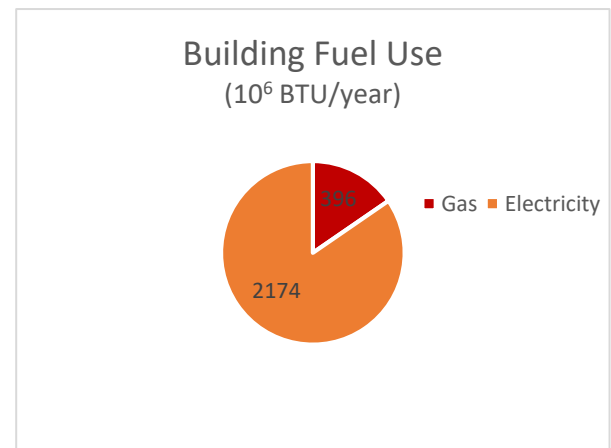


FIGURE 9: ANNUAL FUEL CONSUMPTION.

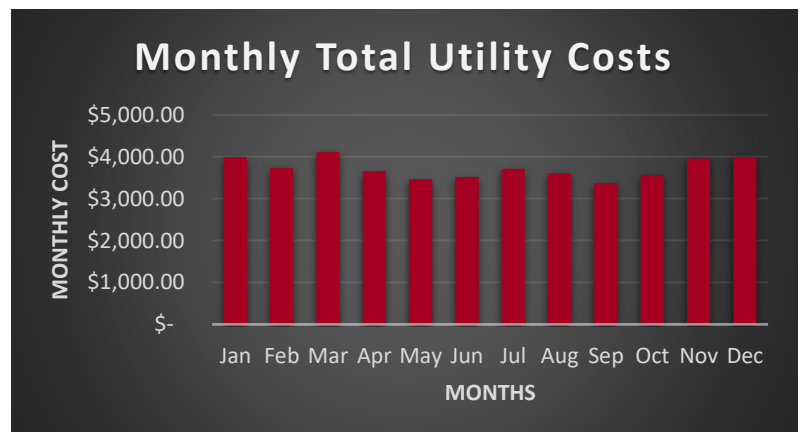


FIGURE 10: TOTAL UTILITY COSTS.

3.4.4 Emissions

AMIC consumes a large amount of energy which also produces emissions. Annually AMIC produces 774,456 pounds of CO₂ per year. This is by far its greatest offender to the environment. However, AMIC also produces 6,025 gm/year of SO₂ and 1,158 gm/year of NO_x.

3.5 Initial Cost

AMIC had a total cost of \$16.5 Million and is a total of 59,300 SF. This works out to be a total of about \$270 per square foot. The total cost of the mechanical system was \$1.625 Million for a total mechanical cost per square foot of about \$27.4.

3.6 Overall Evaluation

3.6.1 Design Evaluation

The mechanical system of the Advanced Manufacturing and Innovation Center exceeds the minimum requirements set by ASHRAE. AMIC tried to strive for as much energy efficiency as possible within their budget. However, not accomplishing any LEED accreditation they did also strive to stay within Penn State's standards on Environmental performance within a building.

Using both an air side and water side heating and cooling system the building saves annual energy. On the air side, there are 4 RTU's that provide air to the VAV boxes in each zone. On the water side, there are two gas fired boilers that provide hot water to the radiant wall panels as well as the fin tubes along the perimeter of the zones. Using both the air and the water systems maximizes the buildings overall energy use.

The overall Evaluation of the mechanical system is positive and is a well-designed system for the type of building. One negative though, is that the building is already experiencing some noise issues from the roof top air handling units. The roof is an ideal location for to provide maximum space for occupancy it is also an unideal location for large vibrating equipment. So, the only recommendation that I would make would be to move the equipment on grade to reduce any noise and vibration problems caused by the mechanical equipment.

3.6.2 Critique

AMIC is well designed considering all the budget constraints however it could be even better. One improvement could be the energy efficiency of the building. As roof top units are common and generally efficient for the type of building there are also alternatives that exist that may be more efficient. Another goal would be to reduce water usage as much as possible as well as reducing AMIC's annual carbon footprint. Most importantly if a new system were chosen over the current system for the previous reasons the most important factor is life cycle cost. How much is the new system going to cost annually vs initially.

4 PROPOSED REDESIGN

4.1 System Type

4.1.1 Geographic Location

When considering potential other mechanical system options, one stood out above all the other options: A Geothermal System. Utilizing a geothermal heat pump system has the possibility to reduce annual energy consumption and not require natural gas or electricity to heat or cool the building as a boiler or rooftop unit would. A geothermal or ground source heat pump system requires the uses of a refrigerant and utilizes the ground as a heat source and heat sink to heat and cool the building. Since the ground temperature is constant throughout the year this makes a ground source heat pump system energy efficient.

One reason for choosing a ground source heat pump system is that the system already exists on the other side of Penn State's campus. Two residence halls named Almy and Ohio hall are both supplied heating and cooling through an underground geothermal system. The system is located underneath both building's parking lots. The buildings are both supplied with enough heating and cooling year-round. This proves both that this location is plausible to have a geothermal system and an effective one. Almy and Ohio hall were designed and built at separate times as were their current geothermal systems. As the second one was built it was expanded and combined with the existing one on site.

A couple years ago, Behrend had a complication with the system as one of the pipes froze and burst. It was rumored that the problem was due to the Erie location having too extreme winter conditions which is why the pipe froze. However, this was not the case. After further investigation, the pipe was one that was connected to the building not the geothermal system and was an uninsulated exterior pipe. Therefore, the pipe had frozen. Other than this once slight complication the geothermal system at Behrend is energy efficient and effective.

4.1.2 Geothermal Heat Pump Type

A ground source heat pump system has many options to consider and make an educated decision. These are based on the location, climate, and ground conditions. As stated above the location is possible for a geothermal system to exist. As for the climate and ground conditions Erie is in climate zone 5-A. Erie has a constant ground temperature of 52 degrees Fahrenheit year-round. So now a decision must be made on an open-loop, closed-loop, horizontal, or vertical system.

The main advantages to an open loop system are the initial cost to install is cheaper and the entering water temperature is consistent. The disadvantages to an open loop system would be the water quality and the environmental concerns at the discharge location, the increased well pump energy usage, and the requirement of a discharge location. The advantages to a closed loop system include having control of the water, less maintenance, and zero energy consumption from the well pump. The disadvantages to the closed loop system include a high initial cost to install, requires a large amount of space for the system, and has a lower entering water temperature.

The open and closed loop systems have advantages and disadvantages so the best decision really is based on the project and location. For this project, and with such high goals of energy efficiency and environmental concerns the best option would be a closed loop system. Another reason for this is

that there is no reasonable discharge location near the site as well as AMIC has plenty of space to place a closed loop system.

AMIC located in Erie, PA made the choice between a horizontal and vertical system and this is an even easier decision based on the location. Though a vertical system is more expensive, a horizontal system is less effective and consumes more energy. Additionally, it would not work in a cold climate unless additional antifreeze liquids were used. Therefore, the best and most efficient options would be to use a vertical closed loop system.

4.1.3 Adequate Space Allowance

The location of Penn State Behrend's Campus is surrounded by woods and open space. After the construction of AMIC, many trees were taken down to allow space for a sizable parking lot. After some calculations, which determine that the parking lot has enough square footage to run the geothermal system underneath the parking lot. This will be discussed in full later. Additionally, as will be later discussed the mechanical room as well will have enough space for the new required equipment necessary for the geothermal system.

4.2 Geothermal Layout

As discussed above a closed loop vertical borehole system will be used for AMIC. The area surrounding AMIC was filled with trees before the construction of the parking lot. The parking lot will be plenty large enough to host the bore field to support the heating and cooling of AMIC. (as seen below).

According to the TRANE TRACE 700 results, using a vertical bore field and set the ground source heat pump (GSHP) to high efficiency, Table 12 below shows the results.

Table 12: Trane Trace Model Results.

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

The borehole depth of 400 feet was chosen to reduce the depth of required excavation and the initial install cost. Though this will increase the total number of boreholes needed to heat and cool AMIC year-round, the parking lot has the space to do so.

Additionally, the boreholes must maintain a minimum of 20 feet spacing between each one. Using the parking lot as guidelines each parking space is 9 feet so three parking spaces exceeds the minimum requirement. Figure 11 below shows how the configuration of the 64 required boreholes would be arranged under the parking lot with the required spacings. Additionally, it shows the extra space that the parking lot had to host an additional 20 boreholes. These could be used for future additions to AMIC if the owner chooses to do so.

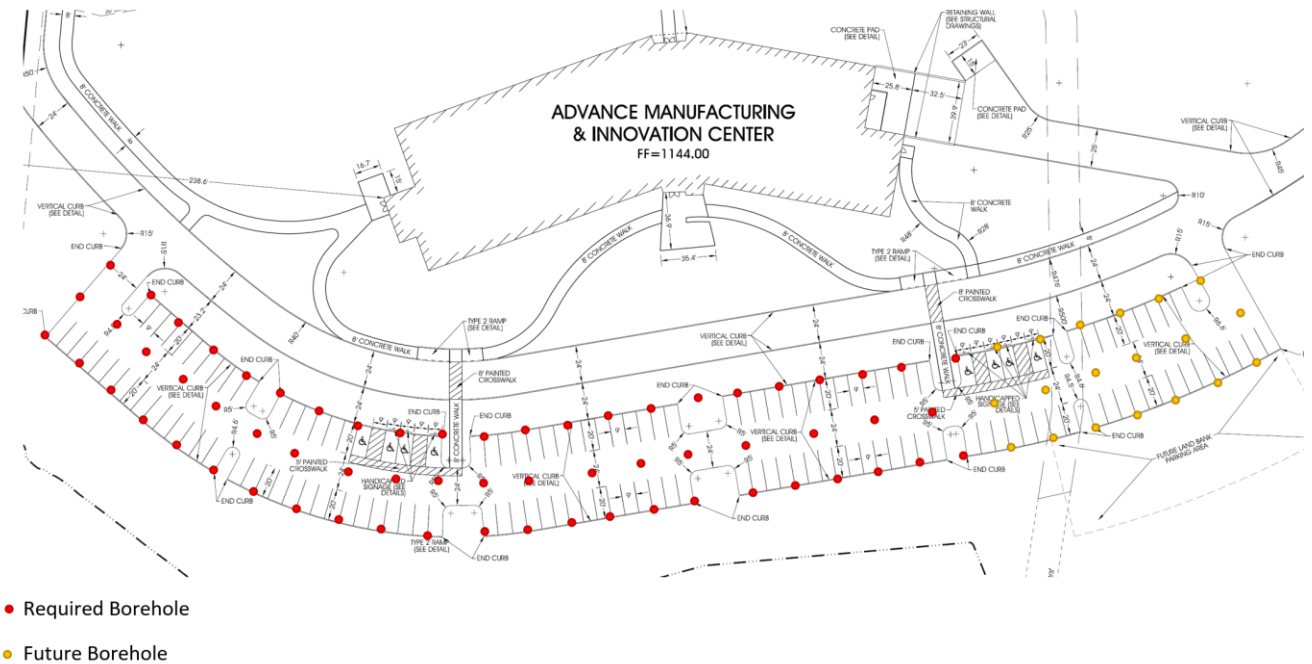


FIGURE 11: BOREHOLE LOCATIONS AND POTENTIAL FUTURE LOCATIONS.

4.3 Equipment

To run the geothermal system a new heat pump must be selected. The new pump will exclusively run the geothermal system while the other pumps are kept as is. The pump that was chosen in this case was the same pump as is already utilized in AMIC. Bell & Gossett Series e-1510. The reason for this pump is because it meets the motor capacity needed to serve AMIC. Also, keeping the same make and model keeps the project analogous. Below in Table 13 are some of the specs of this specific pump.

Table 13: Geothermal Pump Schedule.

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 %

Below in Figure 12 shows the existing boiler room layout. With the proposed redesign, there will be no more use for the two boilers. B-1 and B-2 which are shown in the red circle. These will be eliminated and in the mechanical room there will be plenty space for the new pump needed for the geothermal system.

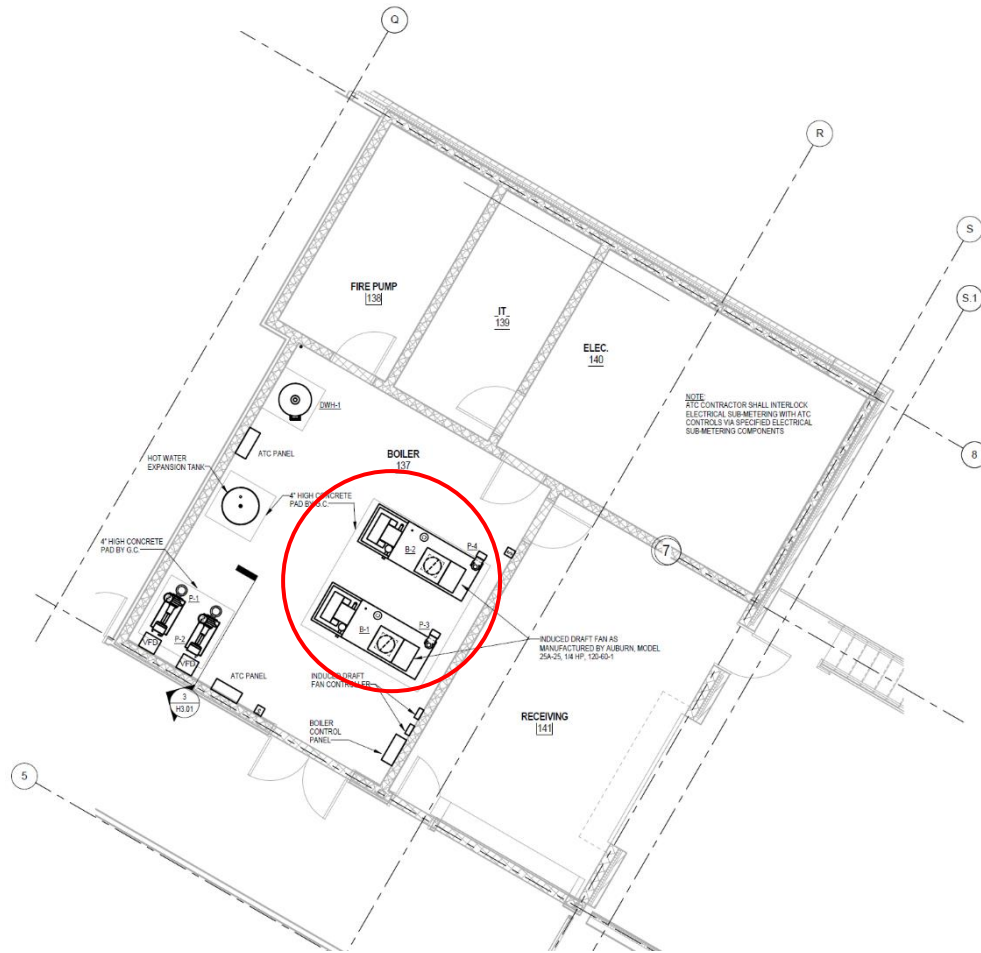


FIGURE 12: EXISTING BOILER ROOM LAYOUT.

Figure 13 below is the borehole configuration showing the water supply and return to building.

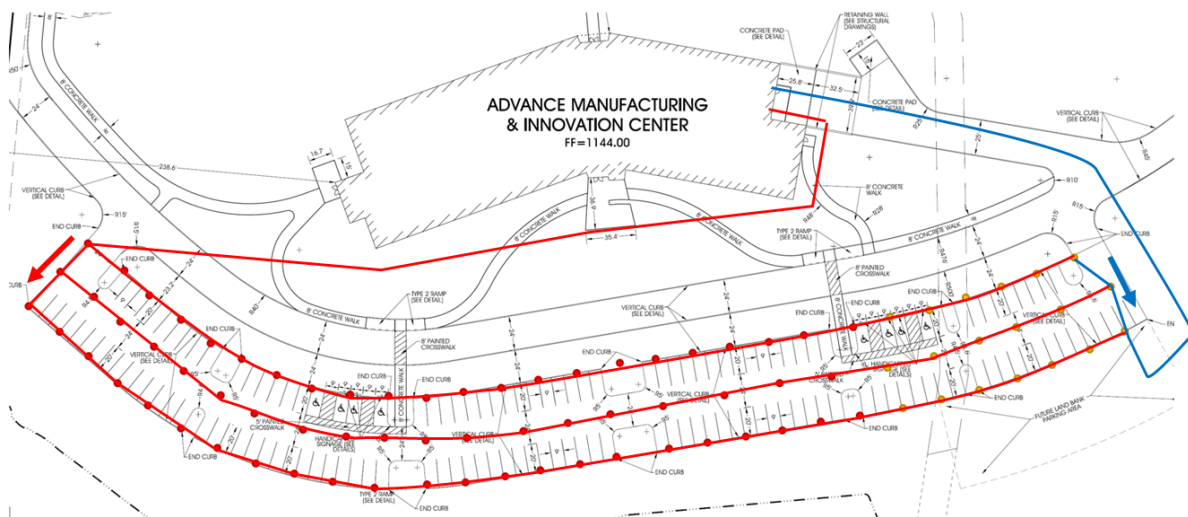


FIGURE 13: BOREHOLE CONFIGURATION TO BUILDING.

4.4 Energy Consumption

To determine if this system is better for the owner we need to compare the owner's final goals for AMC. Ideally AMIC would be as energy efficient as possible, reduce overall building emissions, and minimize total cost. Here these factors will be analyzed for the geothermal system and then compared to the existing boilers system.

4.4.1 Monthly and Annual Energy

All systems have different energy consumptions. AMIC has an existing system using boilers and rooftop units for yearly heating and cooling. In the proposed redesign AMIC would utilize a geothermal system which would eliminate the use of both the boilers and the rooftop units. Both systems were modeled in Trane Trace 700 and the energy results were compared for the most energy efficient system.

Figure 14 below is a graph showing the electric energy consumption consumed with each system by month. The existing system shows that the energy consumption during the summer months is much greater than during the winter months due to cooling.

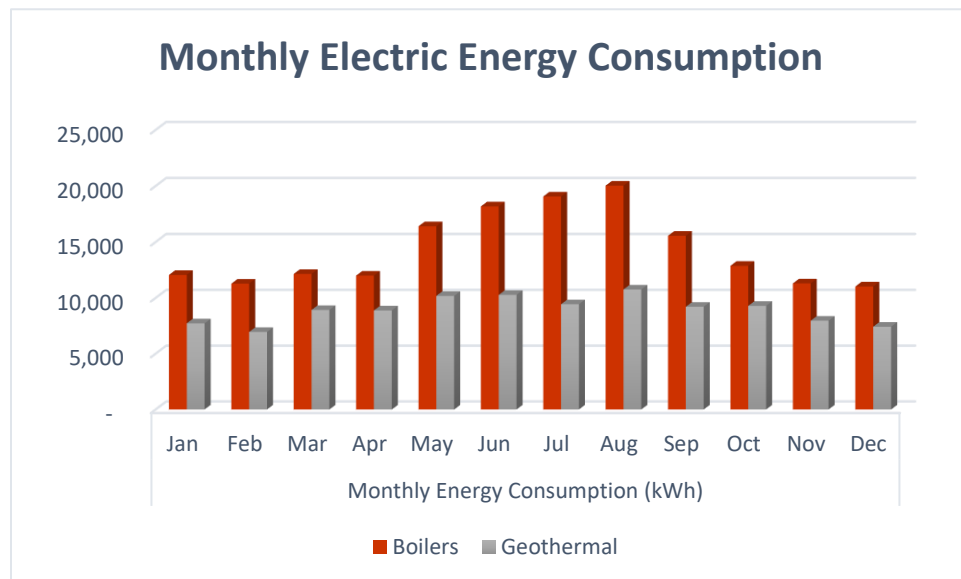


FIGURE 14: MONTHLY ELECTRIC ENERGY CONSUMPTION.

Additionally Figure 14 shows that the geothermal system consumes a more constant amount of energy each month as well as less energy each month than the current boiler system.

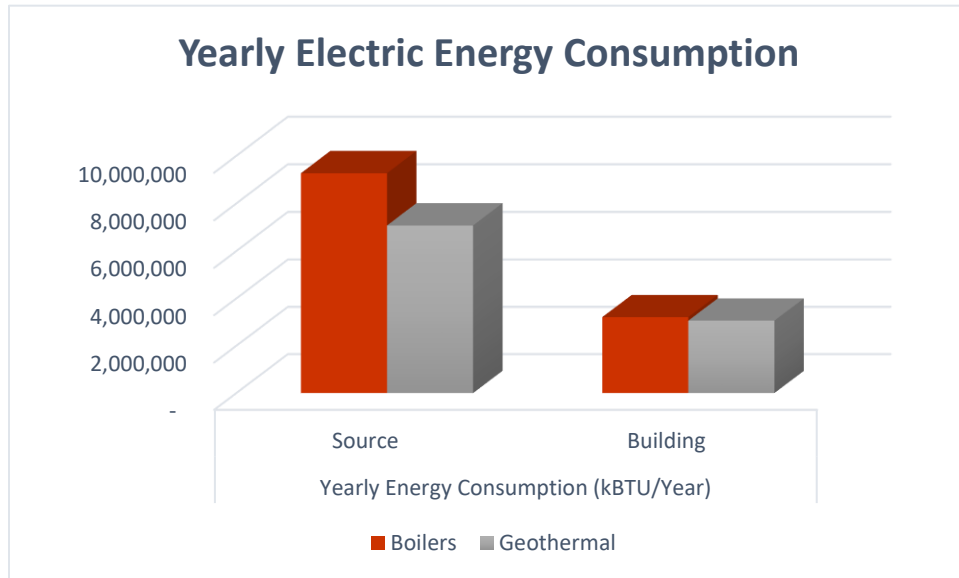


FIGURE 15: YEARLY MONTHLY ENERGY CONSUMPTION.

Figure 15 above shows the comparison of the boilers system and the geothermal system's yearly energy consumption. In both the source energy and building energy the boiler system consumed more total energy than the geothermal system.

Overall the geothermal system consumes less total energy. Thus, being the better choice in terms of energy consumption.

4.4.2 Emissions

The environmental impacts are also an important factor in deciding which system would be best for AMIC. Penn State realizes that it's their job to reduce their total impact whenever possible. Table 14 shows the Trane Trace results for the total annual emissions. The geothermal system releases less emissions in all three categories: CO₂, SO₂, and NO_x.

Table 14: Total Annual Emissions.

Emissions			
	CO ₂ (lbm/year)	SO ₂ (gm/year)	NO _x (gm/year)
Boilers	1,140,698	8,875	1,706
Geothermal	704,524	5,481	1,053

Overall, just looking at the emissions of both systems, the better option would be the geothermal system.

4.5 Cost

4.5.1 Initial Cost

AMIC's initial cost for construction of the existing mechanical system was a total of \$1.625 million dollars. According to an additional construction cost analysis that was performed.

Estimating an initial cost of the proposed geothermal system is slightly more difficult. To do an initial cost analysis on the geothermal system, a case study was used with similar specs to the system proposed for AMIC. The case study used is a database of ground source heat pumps created by the Research Institute of Tennessee Valley.

Table 15: Cost Comparison AMIC vs Case Study.

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

Table 9 above shows the general comparison of the case study to AMIC. The similar location and building size, makes this case study very comparable to AMIC. Therefore, the case study can be used for a cost comparison. The case study has a total loop and mechanical cost of \$1.6371 million dollars. This means that the \$/ft-bore is \$11.97.

From this case study, a valid assumption of the total loop and mechanical cost for AMIC would be approximately \$1.6 million dollars. As a comparison to the original system, they are approximately the same initial cost to install.

4.5.2 Utility Cost

Monthly utility costs per month were calculated using Trane Trace. For the boilers system, this included both electric and gas. The geothermal system only included the monthly electric costs. Figure 16 below shows both systems monthly utility costs. The geothermal system shows a more constant monthly utility cost per month. The geothermal system is also at least \$1000 cheaper than the boilers system each month.

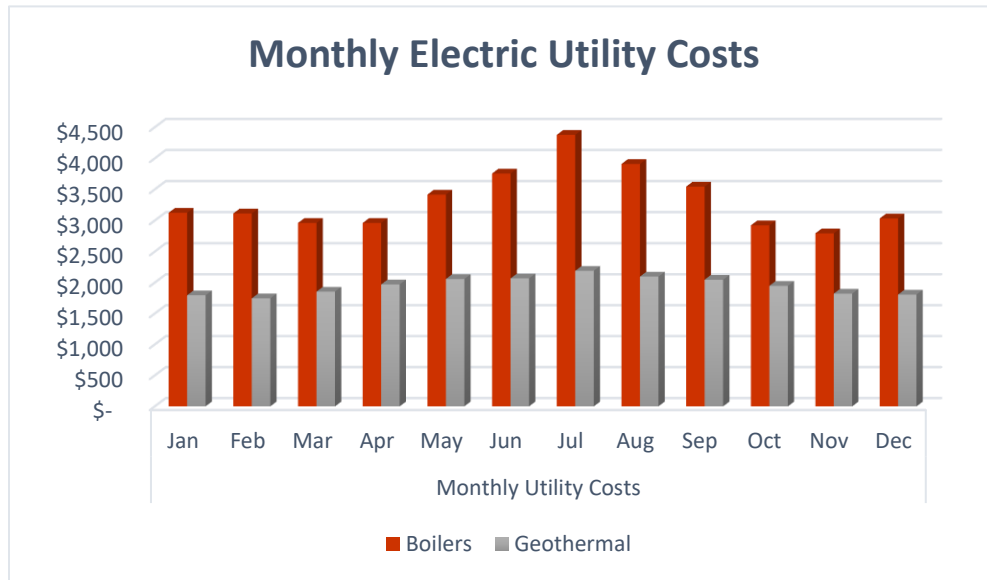


FIGURE 16: MONTHLY UTILITY COST.

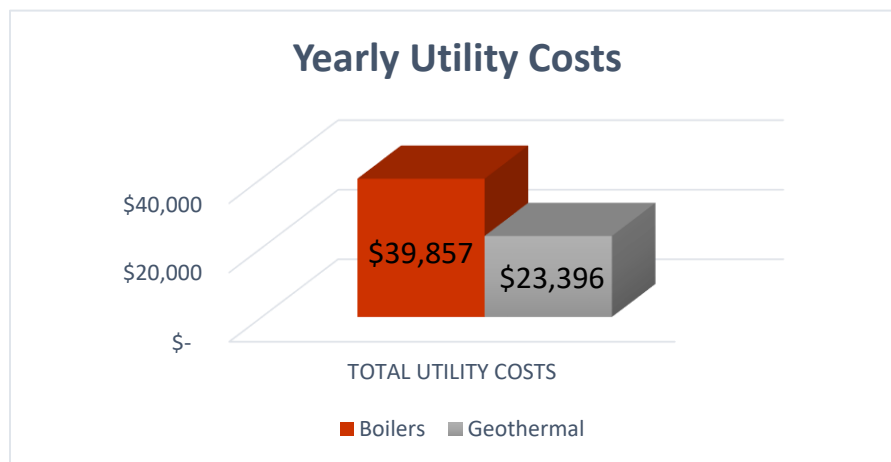


FIGURE 17: TOTAL ANNUAL UTILITY COSTS.

Overall, the initial costs of both systems are approximately \$1.6 million dollars. Therefore, the initial costs of the system would not make for the best deciding factor between the two systems. For the yearly utility costs in Figure 17 above, the geothermal system has less annual utility costs.

4.6 Plausibility

4.6.1 Plausible

AMIC currently runs on four rooftop units and two boilers to heat and cool the building. The proposed redesign is a geothermal system. The system is determined plausible if the following criteria are met: location, adequate space requirements, and equipment space. As well as the proposed system exceeds the following criteria: energy consumption, emissions, initial cost, and utility costs.

The location of Erie, PA was confirmed that it is plausible for a geothermal system. Additionally, AMIC has the required mechanical space for the interior equipment. Finally, AMIC's parking lot hosts plenty of space for the bore field. These criteria are all met. The geothermal system consumes less annual energy than the original system. It also produces significantly less emissions than the original system. The initial cost of both systems are 1.6 million dollars which does not impact the decision of which system is more cost effective. Finally, the utility costs of a geothermal system are over 1000 dollars cheaper than the existing system each month.

Based on these seven criteria, a geothermal system is very plausible. It would be more energy efficient as well as more cost efficient than the current HVAC system. One thing to keep in mind would be the fact that the building is already constructed. A geothermal system is plausible for a new construction. However, it would not be plausible for AMIC because it would not make sense to redesign the entire HVAC system and tear up the existing parking lot. These things would cost too much money to offset any savings that the geothermal system might have.

4.6.2 Long Term Effects

A ground source heat pump system has long term effects which need to be considered when designing a geothermal system. A borehole system uses the ground as a heat sink therefore, one of the side effects is that the ground temperature will increase by about 1-5 °F over time. For this reason, the system needs to be designed for these long-term conditions and not the initial ground conditions.

5 ACOUSTIC BREADTH ANALYSIS

5.1 Noise Concerns

AMIC was constructed from September 2014 to July 2016 when it was finished. During construction, there were early concerns about noise within the building. Especially noise created by the mechanical system. The concerns were initially brought up by on site engineers and maintenance staff. After construction was completed the noise problems continued and were confirmed as both airborne and structure borne noise. The noise is being generated by the four roof top units directly above the left wing of the building where the class rooms are located.

To reduce the noise problem within AMIC, potential solutions will be investigated. These potential solutions will include an analysis of each solution as well as a cost impact. Then a final solution will be chosen as the best potential solution to the noise issue.

5.2 Existing System

As stated in previous sections, AMIC's mechanical system includes four roof top units. Each of these units are mounted on Type 2 acoustic isolators with a Type A neoprene direct mount. AMIC specs state that the rubber neoprene mounts have a minimum deflection of 1 inch. Figure 18 shows the existing mechanical equipment on the roof of AMIC with a Type 2 acoustic neoprene base.

AMIC specs state that all exterior ducts and low velocity supply and return ducts must be lined with 1-1/2" fiberglass insulation with a 1-1/2lb density and have a noise reduction coefficient no less than 0.7. All other ducts must be lined with 1/2" fiberglass insulation.



FIGURE 18: EXISTING HVAC EQUIPMENT WITH TYPE 2 BASE.

5.3 Potential Solutions

This section will discuss the potential solutions for AMIC's noise problems. It will analyze each solution and the cost of implementing each solution. The potential solutions that will be analyzed include: structural borne solution, insertion loss in ducts, vibration isolation, and the current equipment location.

5.3.1 Structure Borne

A structural borne solution could be the reconstruction of the roof which the mechanical equipment sits on. Structure borne noise is usually the larger portion of noise problems. By redoing the roof of AMIC the total building vibration would be significantly reduced and potentially even eliminated. One way to reduce structural borne noise would be to add a floating floor. This would increase the impact isolation class from about a 50 to a possible 72.

AMIC would not be a good fit for a floating floor. The equipment is already on the roof and would not be very feasible to redo the building's roof. Additionally, it would be extremely costly to make these changes.

5.3.2 Insertion Loss

The noise can also travel through the ducts. Though the ducts have some fiberglass lining in them, increasing the lining would increase the insertion loss. Another option would be to increase the density of the duct lining as well. Both options would decrease the overall airborne noise level through the ductwork. The amount that it would decrease would depend on the amount of lining added and the density of the lining.

This option would also not be feasible as the ductwork is already in place. Going back through the ductwork to add additional lining would be extremely expensive and not be effective for the work that it would require to install.

5.3.3 Vibration Isolation

Equipment that sits on the roof creates a lot of vibration through the structure of the building. Vibration isolation is already used for the mechanical equipment on the roof. It utilizes a Type 2 vibration isolator with a Type A neoprene direct mount. Which is a basic rubber neoprene base that the equipment sits on. By upgrading the vibration isolation equipment, the structural borne noise could be significantly reduced.

To increase the vibration isolation there are isolator options and mounting options. The isolator options include: rubber mounts (Type 2), spring mounts (Type 3), restrained spring mounts (Type 4A), and housed spring mounts (Type 4B). The mounting options include: direct mount (Type A), mounting rails (Type B1), and isolation base (Type C). With each of these increased options there is more vibration isolation and less structure borne noise throughout the building. However, there is also more cost associated with each.

The vibration and noise from the mechanical equipment needs a better vibration isolation option. The mechanical equipment would be best suited for the isolation base (Type C) with spring

mounts (Type 3). This new combination would significantly reduce the amount of vibration transmitted through the structure of AMIC. Below Figure 19 is this new base with spring isolators.



FIGURE 19: INERTIAL BASE WITH SPRING MOUNTS.

The cost of this would be somewhat expensive. To replace the existing vibration isolation equipment, the mechanical equipment would need to be lifted off the roof. Then the new inertial base with springs could be added to the mechanical equipment. The new inertial base and spring isolators have a small cost compared to the cost of lifting the mechanical equipment.

5.3.4 Equipment Location

The easiest way to eliminate airborne and structural borne sound within the building would be to move the problem equipment. Moving the mechanical equipment off the roof would eliminate the sound from resonating throughout the building. The relocation of this equipment could be on the side or behind the building. There is adequate space in these locations. The only new requirement would be a concrete pad for the mechanical equipment to sit on.

Relocation of the equipment is feasible. However, the roof was already designed for the heavy loads of the equipment. If the equipment was moved off of the roof then the roof would have essentially been overdesigned. Also, if the equipment is relocated then the ducts would also have to be rerouted to the new equipment location. In some areas, this might be an easier task than others but overall it would be extremely costly.

5.4 Conclusion

To reduce the total sound and vibration transmitted through AMIC there were four options. Most of the possible options were costly and would not be worth the effort. They all would have been more plausible before the construction was complete. Now, the best option is the new vibration isolation equipment. It would be the least costly and easiest to install while being the most effective. The base should be an inertial Type C base with Type 3 spring mounts.

6 ELECTRICAL BREADTH ANALYSIS

6.1 Solar Design

When AMIC was constructed there was little to no budget for anything LEED related. However, adding solar panels to the roof would greatly reduce AMIC's total electrical load consumption. By utilizing the sun's free energy, the total building energy consumption would be reduced as well as the total annual electrical costs.

The roof of AMIC is partially sloped and partially flat. About half of the total roof area is titled at a 10-degree slope. A 10-degree slope is the ideal tilt for solar panels to maximize the total solar absorbed. This would be the perfect location for solar panels on the roof. Since the roof is already sloped, the solar panels could lay flat on this section of roof. Thus, saving money on installation and wind resistance bracing systems for the solar panels. Figure 20 Below is the roof layout and the solar panel potential design layout.

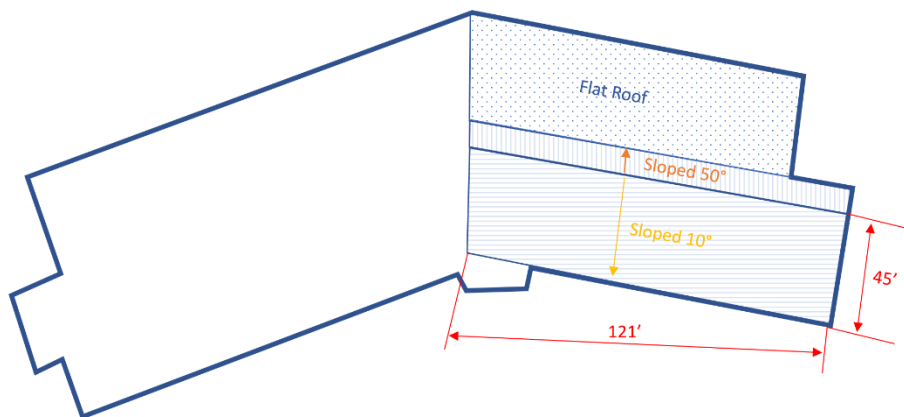


FIGURE 20: EAST WING ROOF LAYOUT.

This design layout would use the tilted portion of the east wing roof. This portion of the roof has an area of 5,445 SF. With the panels having a potential of holding 315 modules.

6.2 Initial Concerns

Solar panels are not plausible in all cases. They depend on the type of building, location as it pertains to the weather, and cost. AMIC is a perfect building type to use solar panels. The classrooms and office spaces will be consuming energy constantly and the solar panels can reduce the total load. However, the location of AMIC is one initial concern. Erie Pennsylvania is not the sunniest location. Additionally, the local location of AMIC is surrounded by trees. As the building is only two stories tall and the solar panels would go on the roof, the trees present a real threat of shadows. Any shadow on the solar panels could reduce their efficiency by up to 80 percent.

Finally, the cost of solar panels is a concern. Solar panels have a high initial cost and though they save money annually they only have a 25 to 30-year life cycle. Therefore, if the simple payback period is greater than 30 years then the solar panels would not be worth the cost.

6.3 Calculations

Figure 21 below shows the solar panel calculations including: number of modules per string, number of strings, total number of modules, and number of inverters. These are the total number that would fit on the east wing on the tilted half of the roof. The SunPower E-series 327 model was used as the chosen solar panel model. See Appendix B for the spec sheet. Table 16 below is some of the values used from the spec sheet to do the calculations.

Table 16: Solar Panel Specifications.

SUNPOWER SOLAR PANEL SPECS	
Nominal Power	327 W
Rated Voltage	54.7 V
Rated Current	5.98 A
Open-Circuit Voltage (Voc)	64.9 V
Max System Voltage	1000 V
Voltage Temp Coefficient	-176.6 mV/°C
Weight	41 lbs

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

$V_{oc} = 64.9 \text{ V}$ $T = 176.6 \text{ mV/}^\circ\text{C}$ $STC = 25^\circ\text{C}$ Assume Annual Low Temp of -26°C
 $\Delta T = -51^\circ\text{C}$

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

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

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

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

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

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

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

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

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

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

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

FIGURE 21: SOLAR PANEL CALCULATIONS.

These calculations include some assumptions. Including: 1000V DC System, SMA 20,000 Watt Inverter, STC 25°C, Annual Low Temperature of -26°C, and Max PV 25,000 Watts. From these calculations, 13 modules per string, 6 strings of modules, (4) 20 KW inverters. For a total of 312 modules.

6.4 Energy Consumption

Utilizing the SunPower model solar panels each would produce 327 Watts of energy per hour of sun. According to the previous calculations if 312 solar panels were used, then the panels total power would be 102,024 Watts. If each solar panel absorbed 10 hours of the sun's energy then, the solar panels could produce 204 million watts per year. Figure 22 below shows the rest of the energy calculations. The building consumes 940 million watts per year. Therefore, the solar panels could potentially produce about 22 percent of the total building's electric energy consumption.

1 BTU = 0.293 Watt-Hours

Solar Panels

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

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

Building

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

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

FIGURE 22: SOLAR PANEL ENERGY CALCULATIONS.

6.5 Cost

Solar panels save the building energy as stated above but they are also expensive. Solar panels have a life span of 25 to 30. Therefore, for them to be cost effective the simple payback of them must be less than 30 years. Below, Figure 23 is the cost calculations. The solar panels save AMIC about \$24,000 per year. Assuming an installation cost of about \$7 per panel, the total installation cost would be about \$714,000. Making the simple payback of this solar system 29 years. Making this system plausible.

$$\begin{aligned}
 & (312 \text{ modules}) * (327 \frac{\text{Watts}}{\text{Module-hour}}) * (10 \frac{\text{hours}}{\text{Day}}) * (200 \frac{\text{days}}{\text{year}}) \\
 & = 204,048,000 \frac{\text{Watt-Hour}}{\text{year}}
 \end{aligned}$$

Installation Cost 1 Watt = \$7

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

$$\$7 * (102,024 \text{ Watts}) = \$714,168$$

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

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

FIGURE 23: SOLAR PANEL COST CALCULATIONS.

6.5 Conclusion

The solar panel system would be plausible for AMIC. It would sit on the roof at an angle of 10°. The east wing of the roof could hold a total of 312 modules. The system would save AMIC annually. The simple payback of the system would be 29 years which is within the possibility of the solar panels life span. One thing to consider about the solar panel system would be that the roof would have to be redesigned to with stand additional dead loads. Each panel weighs 41 pounds, for an additional dead load of almost 13,000 lbs. (Calculation shown below.)

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

7 FINAL RECCOMENDATIONS

7.1 Mechanical Depth

The geothermal system for AMIC would be plausible. It would reduce energy consumption and thus reducing utility costs. However, since the building is already exiting a geothermal system would cost too much to install and the energy savings wouldn't out way the initial costs. Therefore, for AMIC a geothermal system would not be recommended.

7.2 Acoustic Breadth

The current HVAC system located on the roof of AMIC is causing a lot of noise complaints. To reduce the noise problems the best option would be to add vibration isolation equipment. Specifically, a vibration base for the HVAC roof top units. This is the best possible option for AMIC. This would be recommended if the noise gets to be too high. If so then this option is recommended.

7.3 Electrical Breadth

A solar panel system added to the roof of AMIC would reduce the total energy consumption. AMIC has a roof slope of 10° which is the ideal slope for solar panels. The system would reduce the total energy consumption by 22%. With the high initial cost and the added dead load to the roof are things to consider. If both can be overcome then this system would be recommended.

8 REFERENCES

**All pictures of AMIC taken by Paula Schuller unless otherwise stated

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


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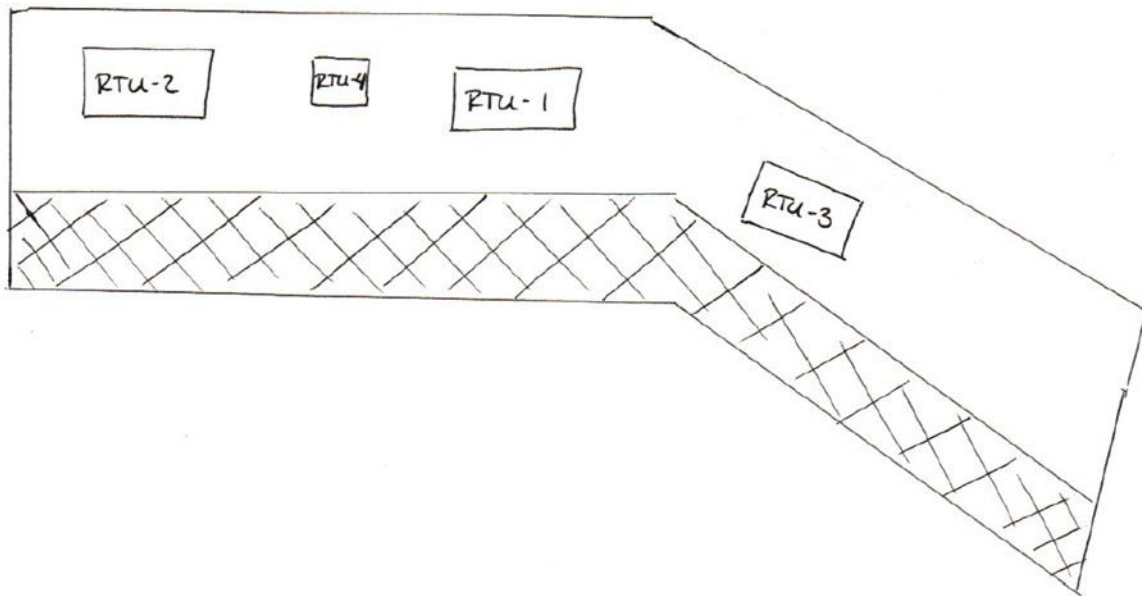
9 APPENDIX

Appendix A: Mechanical Schematics

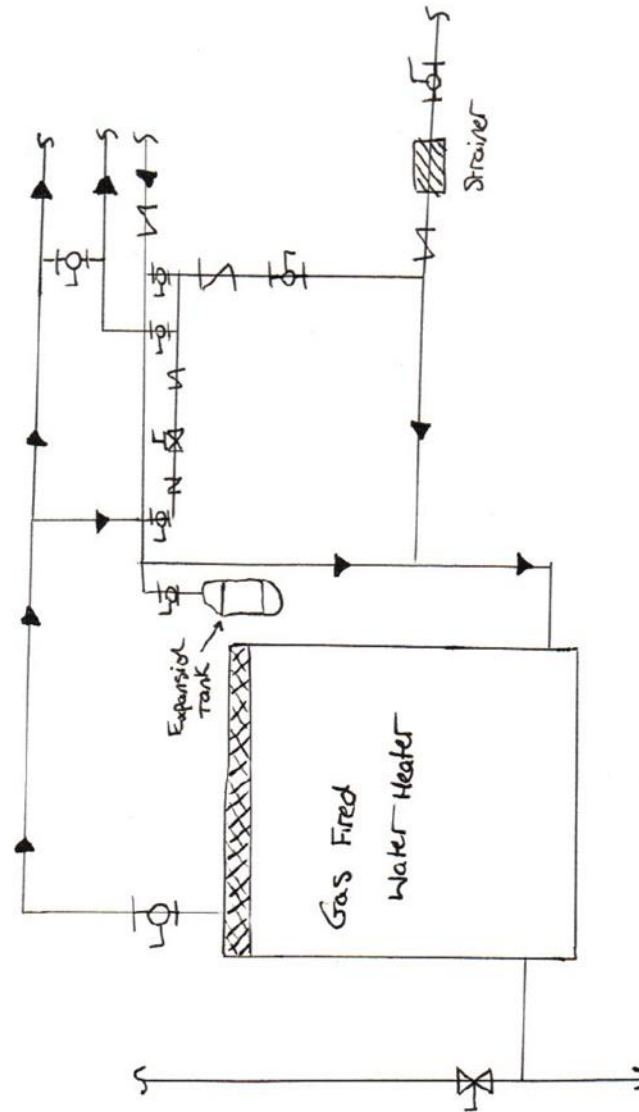
Mechanical Schematic Legend

- — Shut off valve
- — Temperature control valve
- — Ball valve
- — Check valve
- — Strainer

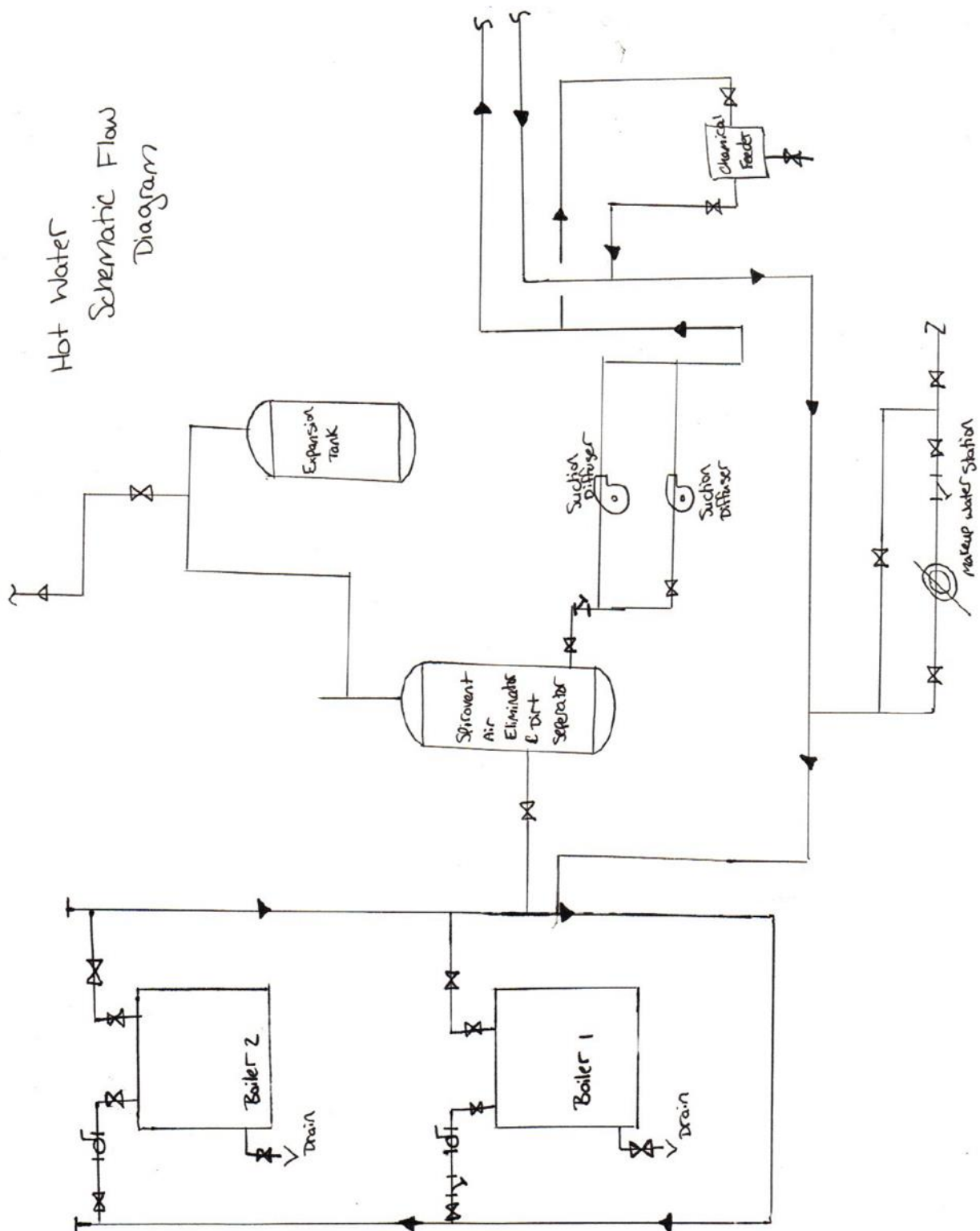
Mechanical Roof Plan



GAS Fired Water Heater With circulating Pump Schematic



Hot Water Schematic Flow Diagram

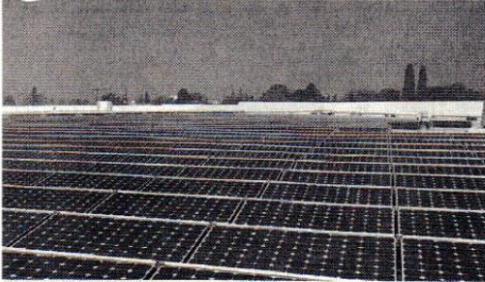


Appendix B: Solar Panel Spec Sheet

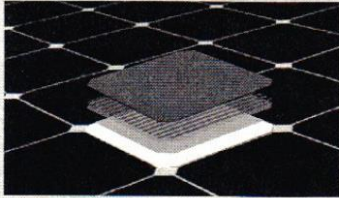
SUNPOWER

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.^{1,2,3}
- **Commercial grade**
Optimized to maximize returns and energy production, the E-Series panel is a bankable solution for commercial solar applications.



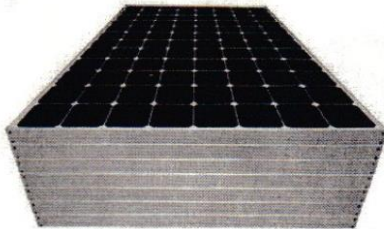
Maxeon® Solar Cells: Fundamentally better.
Engineered for performance, designed for reliability.

Engineered for peace of mind
Designed to deliver consistent, trouble-free 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

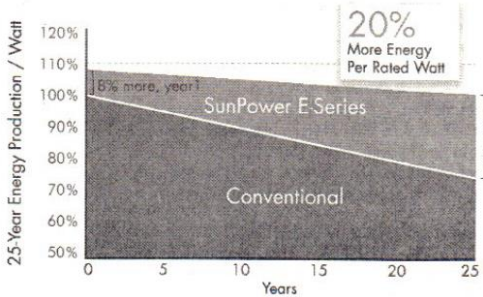
E20 - 327 PANELS

HIGH EFFICIENCY⁶

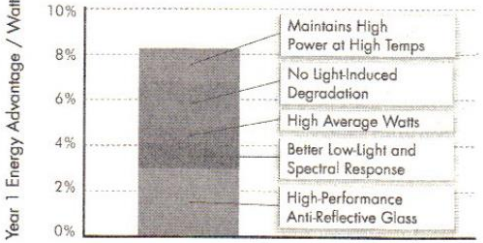
Generate more energy per square foot
E-Series commercial panels convert more sunlight to electricity producing 36% more power per panel,¹ and 60% more energy per square foot over 25 years.^{3,4}

HIGH ENERGY PRODUCTION⁷


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



Years	SunPower E Series	Conventional
0	100%	100%
5	108%	95%
10	116%	90%
15	124%	85%
20	132%	80%
25	140%	75%



Advantage Factor	Percentage
Maintains High Power at High Temps	~1.5%
No Light-Induced Degradation	~1.5%
High Average Watts	~1.5%
Better Low-Light and Spectral Response	~1.5%
High-Performance Anti-Reflective Glass	~1.5%
Total Advantage	7-9%



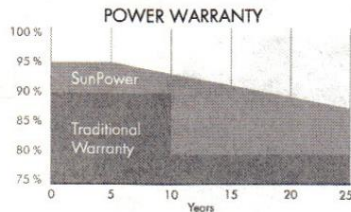
www.sunpowercorp.com

SUNPOWER

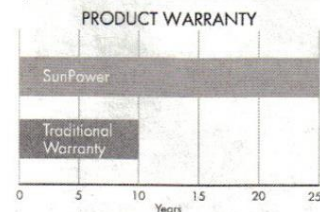
MORE ENERGY. FOR LIFE.™

E-SERIES COMMERCIAL SOLAR PANELS

SUNPOWER OFFERS THE BEST COMBINED POWER AND PRODUCT WARRANTY



More guaranteed power: 95% for first 5 years,
-0.4%/yr. to year 25.⁸



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

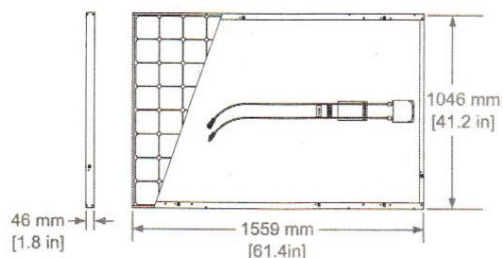
ELECTRICAL DATA		
	E20-327-COM	E19-310-COM
Nominal Power ¹² (P _{nom})	327 W	310 W
Power Tolerance	+5/-3%	+5/-3%
Avg. Panel Efficiency ¹³	20.4%	19.3%
Rated Voltage (V _{mpp})	54.7 V	54.7 V
Rated Current (I _{mpp})	5.98 A	5.67 A
Open-Circuit Voltage (V _{oc})	64.9 V	64.4 V
Short-Circuit Current (I _{sc})	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/m ² front & back Snow: 112 psf, 5400 Pa, 550 kg/m ² 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 5 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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Document # 505701 Rev B /LTP_US

Appendix C: Partial Trane Trace Results for Technical Report 2

Tech Report 2 Cover Page

AMIC

Location	Erie, Pennsylvania
Building owner	
Program user	
Company	
Comments	
By	ACADEMIC
Dataset name	X:\Thesis\Thesis trane model Final2.trc
Calculation time	02:46 PM on 10/13/2016
TRACE® 700 version	6.3.2
Location	Erie, Pennsylvania
Latitude	42.0 deg
Longitude	80.0 deg
Time Zone	5
Elevation	732 ft
Barometric pressure	29.1 in. Hg
Air density	0.0739 lb/cu ft
Air specific heat	0.2444 Btu/lb-°F
Density-specific heat product	1.0840 Btu/h-cfm-°F
Latent heat factor	4.771.9 Btu-min/h-cu ft
Enthalpy factor	4.4348 lb-min/hr-cu ft
Summer design dry bulb	85.0 °F
Summer design wet bulb	72.0 °F
Winter design dry bulb	9.0 °F
Summer clearness number	1.00
Winter clearness number	1.00
Summer ground reflectance	0.20
Winter ground reflectance	0.20
Carbon Dioxide Level	400 ppm
Design simulation period	January - December
Cooling load methodology	TETD-TA1
Heating load methodology	UATD



Tech Report 2 System Summary

SYSTEM SUMMARY
DESIGN HEATING CAPACITIES
By ACADEMIC

Alternative 1

System Coil Capacities

System Description	System Type	Main System Btu/h	Aux System Btu/h	Preheat Btu/h	Reheat Btu/h	Humid. Btu/h	Optional Vent Btu/h	Stg 1 Desic Regen Btu/h	Stg 2 Desic Regen Btu/h	Stg 1 Frost Prevention Btu/h	Stg 2 Frost Prevention Btu/h	Heating Totals Btu/h
RTU-1	Single Zone Variable Air Volume	-171,302	0	0	0	0	0	0	0	0	0	-171,302
RTU-2	Single Zone Variable Air Volume	-416,901	0	0	0	0	0	0	0	0	0	-416,901
RTU-3	Single Zone Variable Air Volume	-649,093	0	0	0	0	0	0	0	0	0	-649,093
RTU-4	Single Zone Variable Air Volume	-72,976	0	0	0	0	0	0	0	0	0	-72,976
Totals		-1,310,272	0	0	0	0	0	0	0	0	0	-1,310,272

Building Plant Capacities

		Peak Loads												
Plant	System	Main Coil MBh	Preheat Coil MBh	Reheat Coil MBh	Humid. Coil MBh	Aux Coil MBh	Opt Vent Coil MBh	Misc Load MBh	Stg 1 Desic. Regen. MBh	Stg 2 Desic. Regen. MBh	Stg 1 Frost Prev. MBh	Stg 2 Frost Prev. MBh	Base Utility MBh	Absorption Load MBh
Heating plant - 006		1,310	0	0	0	0	0	0	0	0	0	0	0	0
	RTU-1	171	0	0	0	0	0	0	0	0	0	0	0	0
	RTU-2	417	0	0	0	0	0	0	0	0	0	0	0	0
	RTU-3	649	0	0	0	0	0	0	0	0	0	0	0	0
	RTU-4	73	0	0	0	0	0	0	0	0	0	0	0	0

Building peak load is 1,310.3 MBh.

Tech Report 2 Monthly Utility Costs

MONTHLY UTILITY COSTS
By ACADEMIC

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative 1													
Electric													
On-Pk Cons. (\$)	2,762	2,491	2,815	2,579	2,611	2,647	2,827	2,732	2,525	2,579	2,717	2,771	32,055
On-Pk Demand (\$)	871	913	928	911	794	802	809	803	797	835	909	862	10,235
Total (\$):	3,632	3,405	3,743	3,490	3,406	3,449	3,636	3,535	3,322	3,413	3,626	3,633	42,289
Gas													
On-Pk Cons. (\$)	357	323	357	139	0	0	0	0	0	125	322	357	1,981
Water													
On-Pk Cons. (\$)	2	1	7	27	53	67	81	70	51	21	7	2	390
Monthly Total (\$):	3,992	3,729	4,108	3,656	3,458	3,517	3,717	3,605	3,373	3,559	3,954	3,993	44,661

Building Area = 50,625 ft²
Utility Cost Per Area = 0.88 \$/ft²

Tech Report 2 Economic Summary

Economic Summary

Project Information

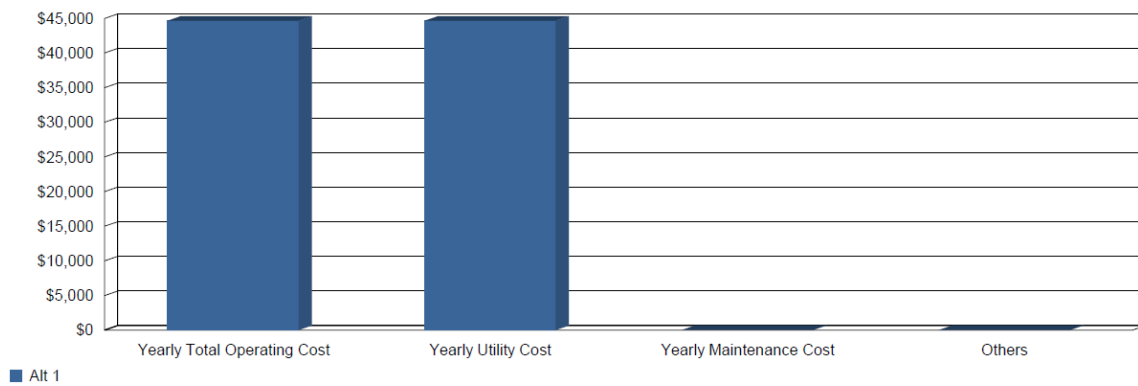
Location: Erie, Pennsylvania
 Project Name: AMIC
 User:
 Company:
 Comments:

Study Life: 40 years
 Cost of Capital: 10 %
 Alternative 1: AMIC

Economic Comparison of Alternatives

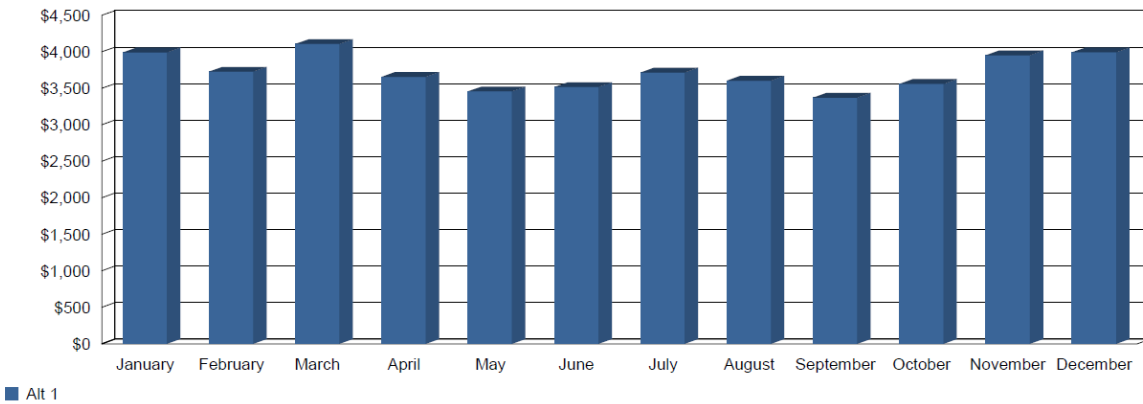
Yearly Savings (\$)	First Cost Difference (\$)	Cumulative Cash Flow Difference (\$)	Simple Payback (yrs.)	Net Present Value (\$)	Life Cycle Payback (yrs.)	Internal Rate of Return (%)	Life Cycle Cost Difference

Annual Operating Costs



Yearly Total Operating Cost (\$)	Yearly Utility Cost (\$)	Yearly Maintenance Cost (\$)	Plant kWh/ton-hr

Monthly Utility Costs



Tech Report 2 Energy Consumption Summary

ENERGY CONSUMPTION SUMMARY

By ACADEMIC

	Elect Cons. (kWh)	Gas Cons. (kBtu)	Water Cons. (1000 gals)	% of Total Building Energy	Total Building Energy (kBtu/yr)	Total Source Energy* (kBtu/yr)
Alternative 1						
Primary heating						
Primary heating		396,176		15.4 %	396,176	417,028
Other Htg Accessories	2,453			0.3 %	8,373	25,123
Heating Subtotal	2,453	396,176		15.7 %	404,550	442,151
Primary cooling						
Cooling Compressor	52,246			6.9 %	178,315	534,998
Tower/Cond Fans	14,490		390	1.9 %	49,453	148,374
Condenser Pump				0.0 %	0	0
Other Clg Accessories	8,760			1.2 %	29,898	89,703
Cooling Subtotal....	75,495		390	10.0 %	257,666	773,074
Auxiliary						
Supply Fans	43,883			5.8 %	149,773	449,362
Pumps	63,086			8.4 %	215,314	646,006
Stand-alone Base Utilities				0.0 %	0	0
Aux Subtotal....	106,969			14.2 %	365,086	1,095,369
Lighting						
Lighting	443,475			58.9 %	1,513,580	4,541,195
Receptacle						
Receptacles	8,760			1.2 %	29,899	89,707
Cogeneration						
Cogeneration				0.0 %	0	0
Totals						
Totals**	637,154	396,176	390	100.0 %	2,570,781	6,941,495

Tech Report 2 Energy Cost Budget

Energy Cost Budget / PRM Summary

By ACADEMIC

Project Name: AMIC	Date: October 13, 2016
City: Erie, Pennsylvania	Weather Data: Erie, Pennsylvania

Note: The percentage displayed for the "Proposed/ Base %" column of the base case is actually the percentage of the total energy consumption.

		* Alt-1 AMIC		
		Energy 10 ⁶ Btu/yr	Propose d / Base %	Peak kBtu/h
Lighting - Conditioned	Electricity	1,513.6	59	173
Space Heating	Electricity	8.4	0	2
	Gas	396.2	15	96
Space Cooling	Electricity	208.2	8	55
Pumps	Electricity	215.3	8	51
Heat Rejection	Electricity	49.5	2	8
Fans - Conditioned	Electricity	149.8	6	38
Receptacles - Conditioned	Electricity	29.9	1	3
Total Building Consumption		2,570.8		

		* Alt-1 AMIC
Total	Number of hours heating load not m	0
	Number of hours cooling load not m	0

		* Alt-1 AMIC	
		Energy 10 ⁶ Btu/yr	Cost/yr \$/yr
Electricity		2,174.6	42,289
Gas		396.2	1,981
Total		2,571	44,270

Tech Report 2 Monthly Energy Consumption

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----													
Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 1 AMIC													
Electric													
On-Pk Cons. (kWh)	55,237	49,823	56,292	51,578	52,228	52,942	56,533	54,640	50,499	51,571	54,335	55,419	641,095
On-Pk Demand (kW)	87	91	93	91	79	80	81	80	80	83	91	86	93
Gas													
On-Pk Cons. (therms)	715	645	715	279	0	0	0	0	0	250	644	715	3,962
On-Pk Demand (therms/hr)	1	1	1	1	0	0	0	0	0	1	1	1	1
Water													
Cons. (1000gal)	2	1	7	27	53	67	81	70	51	21	7	2	390
Energy Consumption					Environmental Impact Analysis								
Building	51,047 Btu/(ft2-year)				CO2	774,456 lbm/year							
Source	137,913 Btu/(ft2-year)				SO2	6,025 gm/year							
					NOX	1,158 gm/year							
Floor Area	50,625 ft2												

ONLY

Appendix D: Partial Trane Trace Results for Proposed System (Boilers)

Boilers Cover Page

AMIC

Location	Erie, Pennsylvania
Building owner	
Program user	
Company	
Comments	
By	ACADEMIC
Dataset name	X:\Thesis Spring\Practice\THESIS TRANE MODEL FINAL33.TRC
Calculation time	03:24 PM on 02/10/2017
TRACE® 700 version	6.3.2
Location	Erie, Pennsylvania
Latitude	42.0 deg
Longitude	80.0 deg
Time Zone	5
Elevation	732 ft
Barometric pressure	29.1 in. Hg
Air density	0.0739 lb/cu ft
Air specific heat	0.2444 Btu/lb·°F
Density-specific heat product	1.0840 Btu/h·cfm·°F
Latent heat factor	4.771.9 Btu·min/h·cu ft
Enthalpy factor	4.4348 lb·min/hr·cu ft
Summer design dry bulb	85.0 °F
Summer design wet bulb	72.0 °F
Winter design dry bulb	9.0 °F
Summer clearness number	1.00
Winter clearness number	1.00
Summer ground reflectance	0.20
Winter ground reflectance	0.20
Carbon Dioxide Level	400 ppm
Design simulation period	January - December
Cooling load methodology	TETD-TA1
Heating load methodology	UATD



Boilers System Summary

SYSTEM SUMMARY
DESIGN HEATING CAPACITIES
By ACADEMIC

Alternative 1

System Coil Capacities

System Description	System Type	Main System Btu/h	Aux System Btu/h	Preheat Btu/h	Reheat Btu/h	Humid. Btu/h	Optional Vent Btu/h	Stg 1 Desic Regen Btu/h	Stg 2 Desic Regen Btu/h	Stg 1 Frost Prevention Btu/h	Stg 2 Frost Prevention Btu/h	Heating Totals Btu/h
RTU-1	Single Zone Variable Air Volume	-171,302	0	0	0	0	0	0	0	0	0	-171,302
RTU-2	Single Zone Variable Air Volume	-416,901	0	0	0	0	0	0	0	0	0	-416,901
RTU-3	Single Zone Variable Air Volume	-649,093	0	0	0	0	0	0	0	0	0	-649,093
RTU-4	Single Zone Variable Air Volume	-72,976	0	0	0	0	0	0	0	0	0	-72,976
Totals		-1,310,272	0	0	0	0	0	0	0	0	0	-1,310,272

Building Plant Capacities

Plant	System	Main Coil MBh	Preheat Coil MBh	Reheat Coil MBh	Humid. Coil MBh	Aux Coil MBh	Opt Vent Coil MBh	Misc Load MBh	Stg 1 Desic. Regen. MBh	Stg 2 Desic. Regen. MBh	Stg 1 Frost Prev. MBh	Stg 2 Frost Prev. MBh	Base Utility MBh	Absorption Load MBh
Heating plant - 006		1,310	0	0	0	0	0	0	0	0	0	0	0	0
	RTU-1	171	0	0	0	0	0	0	0	0	0	0	0	0
	RTU-2	417	0	0	0	0	0	0	0	0	0	0	0	0
	RTU-3	649	0	0	0	0	0	0	0	0	0	0	0	0
	RTU-4	73	0	0	0	0	0	0	0	0	0	0	0	0

Building peak load is 1,310.3 MBh.

Boilers Monthly Utility Costs

MONTHLY UTILITY COSTS
By ACADEMIC

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative 1													
Electric													
On-Pk Cons. (\$)	246	222	284	283	325	328	301	343	294	296	254	237	3,413
Off-Pk Cons. (\$)	593	534	552	608	631	629	768	640	648	587	564	619	7,373
On-Pk Demand (\$)	582	617	629	635	646	652	656	653	648	632	622	575	7,548
Off-Pk Demand (\$)	374	374	387	444	455	459	463	461	457	431	381	375	5,061
Total (\$):	1,795	1,746	1,853	1,970	2,057	2,068	2,190	2,097	2,046	1,947	1,821	1,806	23,396
Gas													
On-Pk Cons. (\$)	54	68	8	0	0	0	0	0	0	0	0	34	164
Water													
On-Pk Cons. (\$)	0	0	0	0	0	0	0	0	0	0	0	0	0
Monthly Total (\$):	1,850	1,814	1,861	1,970	2,057	2,068	2,190	2,097	2,046	1,947	1,821	1,839	23,560

Building Area = 50,625 ft²
Utility Cost Per Area = 0.47 \$/ft²

Boilers Economic Summary

Economic Summary

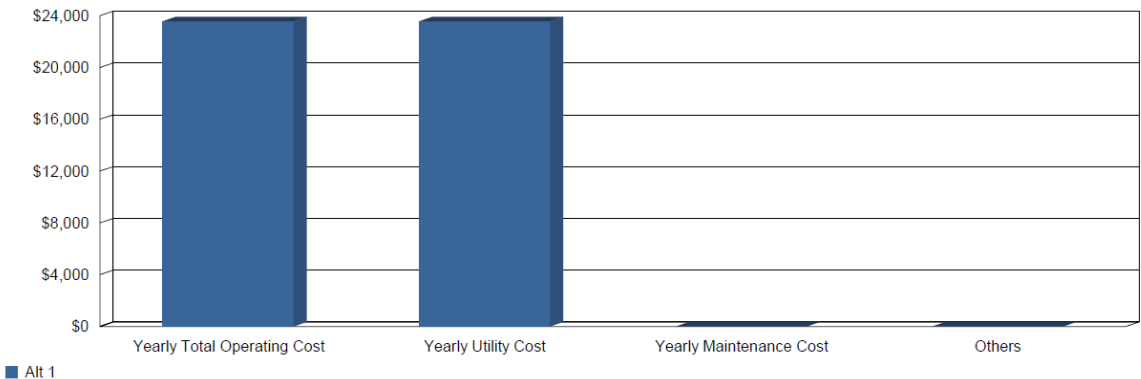
Project Information

Location	Erie, Pennsylvania	Study Life:	40 years
Project Name	AMIC	Cost of Capital:	10 %
User		Alternative 1:	AMIC
Company			
Comments			

Economic Comparison of Alternatives

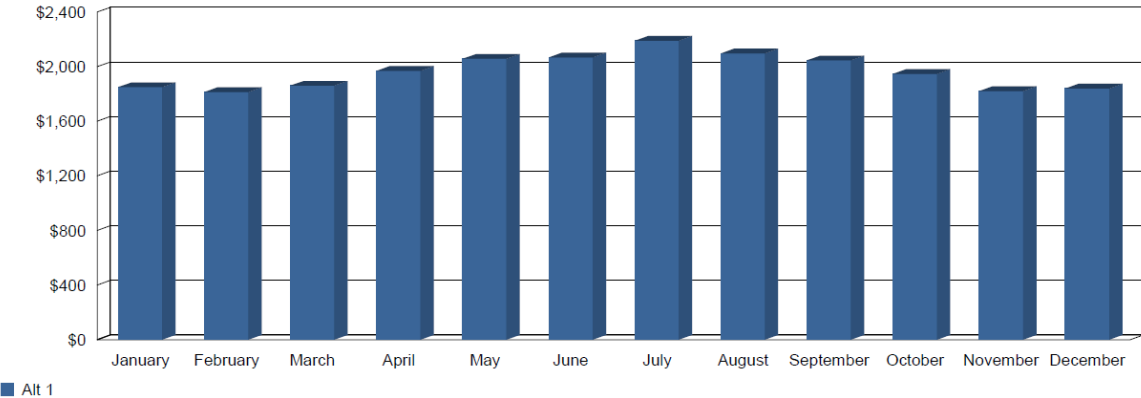
Yearly Savings (\$)	First Cost Difference (\$)	Cumulative Cash Flow Difference (\$)	Simple Payback (yrs.)	Net Present Value (\$)	Life Cycle Payback (yrs.)	Internal Rate of Return (%)	Life Cycle Cost Difference
---------------------	----------------------------	--------------------------------------	-----------------------	------------------------	---------------------------	-----------------------------	----------------------------

Annual Operating Costs



Yearly Total Operating Cost (\$)	Yearly Utility Cost (\$)	Yearly Maintenance Cost (\$)	Plant kWh/ton-hr
----------------------------------	--------------------------	------------------------------	------------------

Monthly Utility Costs



Boilers Energy Consumption Summary

ENERGY CONSUMPTION SUMMARY

By ACADEMIC

	Elect Cons. (kWh)	Gas Cons. (kBtu)	Water Cons. (1000 gals)	% of Total Building Energy	Total Building Energy (kBtu/yr)	Total Source Energy* (kBtu/yr)
Alternative 1						
Primary heating						
Primary heating		1,085,438		35.4 %	1,085,438	1,142,567
Other Htg Accessories	6,702			0.8 %	22,873	68,625
Heating Subtotal	6,702	1,085,438		36.2 %	1,108,311	1,211,191
Primary cooling						
Cooling Compressor	52,246			5.8 %	178,315	534,998
Tower/Cond Fans	14,490		390	1.6 %	49,453	148,374
Condenser Pump				0.0 %	0	0
Other Clg Accessories	8,760			1.0 %	29,898	89,703
Cooling Subtotal....	75,495		390	8.4 %	257,666	773,074
Auxiliary						
Supply Fans	43,883			4.9 %	149,773	449,362
Pumps				0.0 %	0	0
Stand-alone Base Utilities	949			0.1 %	3,239	9,718
Aux Subtotal....	44,832			5.0 %	153,011	459,080
Lighting						
Lighting	443,475			49.4 %	1,513,580	4,541,195
Receptacle						
Receptacles	8,760			1.0 %	29,899	89,707
Cogeneration						
Cogeneration				0.0 %	0	0
Totals						
Totals**	579,264	1,085,438	390	100.0 %	3,062,467	7,074,247

Boilers Monthly Energy Consumption

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----													
Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 1													
AMIC													
Electric													
On-Pk Cons. (kWh)	7,721	8,951	8,916	8,880	10,182	10,272	9,434	10,756	9,210	9,290	7,959	7,419	106,991
Off-Pk Cons. (kWh)	24,717	22,263	23,016	25,322	26,307	26,229	31,994	26,667	26,996	24,466	23,480	25,772	307,228
Mid-Pk Cons. (kWh)	12,699	11,486	14,092	12,829	15,819	16,519	15,186	17,298	14,371	13,774	12,787	12,127	168,987
On-Pk Demand (kW)	72	76	77	78	79	80	81	80	80	78	76	71	81
Off-Pk Demand (kW)	64	64	66	76	78	78	79	79	78	73	65	64	79
Mid-Pk Demand (kW)	66	68	75	78	79	80	80	80	79	76	71	67	80
Gas													
On-Pk Cons. (therms)	116	146	17	0	0	0	0	0	0	0	0	72	351
Off-Pk Cons. (therms)	1,885	1,996	1,176	242	0	0	0	0	0	218	542	1,628	7,687
Mid-Pk Cons. (therms)	814	814	336	36	0	0	0	0	0	32	116	667	2,816
On-Pk Demand (therms/hr)	2	2	0	0	0	0	0	0	0	0	0	1	2
Off-Pk Demand (therms/hr)	6	7	5	2	0	0	0	0	0	2	3	5	7
Mid-Pk Demand (therms/hr)	6	7	4	1	0	0	0	0	0	1	3	5	7
Water													
Cons. (1000gal)	2	1	7	27	53	67	81	70	51	21	7	2	390
Energy Consumption													
Building	60,759 Btu/(ft2-year)												
Source	140,535 Btu/(ft2-year)												
Floor Area													
	50,625 ft2												
Environmental Impact Analysis													
CO2						704,524 lbm/year							
SO2						5,481 gm/year							
NOX						1,053 gm/year							

Appendix E: Partial Trane Trace Results for Existing System (Geothermal)

Geothermal Cover Page

AMIC

Location
Building owner
Program user
Company
Comments

Erie, Pennsylvania

By
Dataset name

ACADEMIC
X:\THESIS SPRING\NEW TRACE
RESULTS\GEOTHERMAL.TRC

Calculation time
TRACE® 700 version

04:31 PM on 02/10/2017
6.3.2

Location
Latitude
Longitude
Time Zone
Elevation
Barometric pressure

Erie, Pennsylvania
42.0 deg
80.0 deg
5
732 ft
29.1 in. Hg

Air density
Air specific heat
Density-specific heat product
Latent heat factor
Enthalpy factor

0.0739 lb/cu ft
0.2444 Btu/lb·°F
1.0840 Btu/h·cfm·°F
4,771.9 Btu·min/h·cu ft
4.4348 lb·min/hr·cu ft

Summer design dry bulb
Summer design wet bulb
Winter design dry bulb
Summer clearness number
Winter clearness number
Summer ground reflectance
Winter ground reflectance
Carbon Dioxide Level
Design simulation period
Cooling load methodology
Heating load methodology

85.0 °F
72.0 °F
9.0 °F
1.00
1.00
0.20
0.20
400 ppm
January - December
TETD-TA1
UATD



Geothermal System Summary

SYSTEM SUMMARY
DESIGN HEATING CAPACITIES
By ACADEMIC

Alternative 1

System Coil Capacities

System Description	System Type	Main System Btu/h	Aux System Btu/h	Preheat Btu/h	Reheat Btu/h	Humid. Btu/h	Optional Vent Btu/h	Stg 1 Desic Regen Btu/h	Stg 2 Desic Regen Btu/h	Stg 1 Frost Prevention Btu/h	Stg 2 Frost Prevention Btu/h	Heating Totals Btu/h
Ground Source Heat Pump	Water Source Heat Pump	-1,501,940	0	0	0	0	0	0	0	0	0	-1,501,940
Totals		-1,501,940	0	0	0	0	0	0	0	0	0	-1,501,940

Building Plant Capacities

		Peak Loads												
Plant	System	Main Coil MBh	Preheat Coil MBh	Reheat Coil MBh	Humid. Coil MBh	Aux Coil MBh	Opt Vent Coil MBh	Misc Load MBh	Stg 1 Desic. Regen. MBh	Stg 2 Desic. Regen. MBh	Stg 1 Frost Prev. MBh	Stg 2 Frost Prev. MBh	Base Utility MBh	Absorption Load MBh
Backup Boiler		1,502	0	0	0	0	0	0	0	0	0	0	0	0
	Ground Source Heat Pump	1,502	0	0	0	0	0	0	0	0	0	0	0	0
Building peak load is 1,501.9 MBh.														

Geothermal Monthly Utility Costs

MONTHLY UTILITY COSTS
By ACADEMIC

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative 1													
Electric													
On-Pk Cons. (\$)	385	360	388	383	523	580	608	639	496	411	361	352	5,485
Off-Pk Cons. (\$)	1,153	1,095	966	884	920	937	1,241	960	953	873	885	1,144	12,021
On-Pk Demand (\$)	822	846	884	1,030	1,227	1,409	1,572	1,438	1,301	1,042	925	807	13,303
Off-Pk Demand (\$)	764	813	723	599	746	830	957	873	794	597	623	730	9,049
Total (\$):	3,124	3,114	2,960	2,906	3,416	3,756	4,378	3,909	3,545	2,922	2,793	3,033	39,857
Monthly Total (\$):	3,124	3,114	2,960	2,906	3,416	3,756	4,378	3,909	3,545	2,922	2,793	3,033	39,857

Building Area = 50,625 ft²
Utility Cost Per Area = 0.79 \$/ft²

Geothermal Economic Summary

Economic Summary

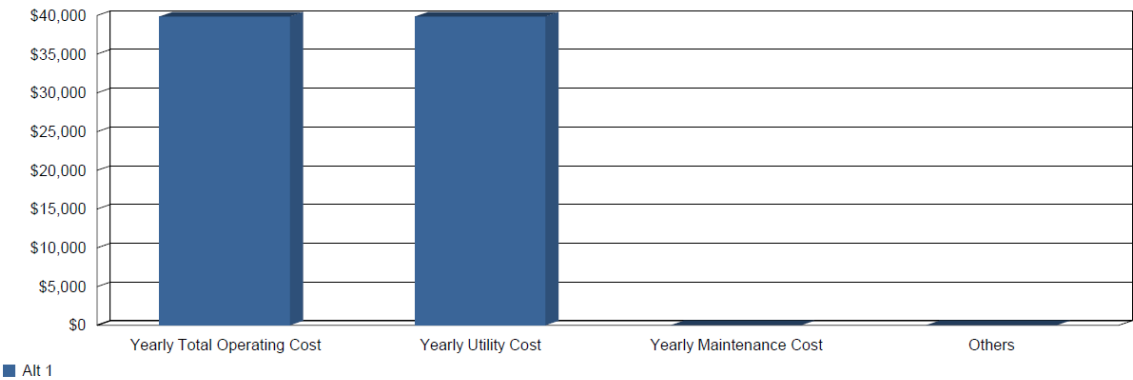
Project Information

Location	Erie, Pennsylvania	Study Life:	40 years
Project Name	AMIC	Cost of Capital:	10 %
User		Alternative 1:	AMIC
Company			
Comments			

Economic Comparison of Alternatives

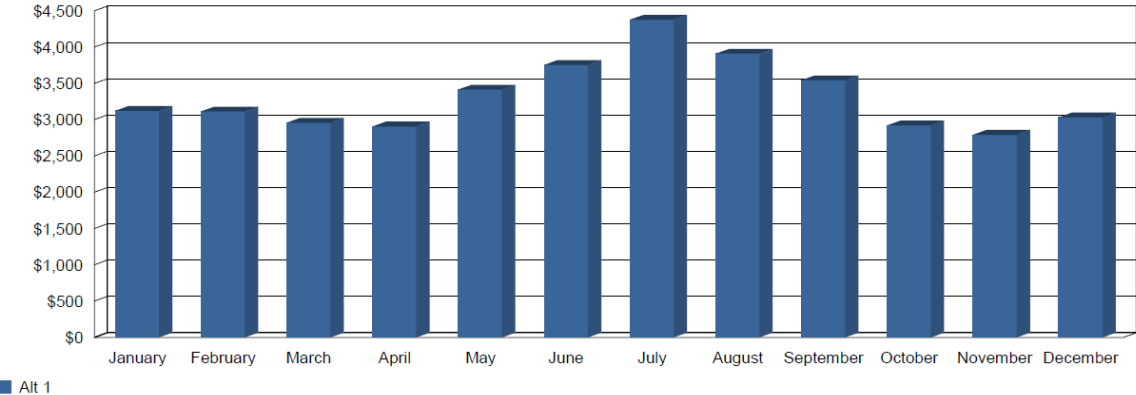
Yearly Savings (\$)	First Cost Difference (\$)	Cumulative Cash Flow Difference (\$)	Simple Payback (yrs.)	Net Present Value (\$)	Life Cycle Payback (yrs.)	Internal Rate of Return (%)	Life Cycle Cost Difference
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Annual Operating Costs



Yearly Total Operating Cost (\$)	Yearly Utility Cost (\$)	Yearly Maintenance Cost (\$)	Plant kWh/ton-hr
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Monthly Utility Costs



Geothermal Energy Consumption Summary

ENERGY CONSUMPTION SUMMARY

By ACADEMIC

	Elect Cons. (kWh)	% of Total Building Energy	Total Building Energy (kBtu/yr)	Total Source Energy* (kBtu/yr)
Alternative 1				
Primary heating				
Primary heating	75,850	8.1 %	258,875	776,703
Other Htg Accessories		0.0 %	0	0
Heating Subtotal	75,850	8.1 %	258,875	776,703
Primary cooling				
Cooling Compressor	109,554	11.7 %	373,909	1,121,840
Tower/Cond Fans		0.0 %	0	0
Condenser Pump		0.0 %	0	0
Other Clg Accessories	219	0.0 %	746	2,238
Cooling Subtotal....	109,773	11.7 %	374,655	1,124,078
Auxiliary				
Supply Fans	208,945	22.2 %	713,131	2,139,606
Pumps	92,576	9.9 %	315,962	947,982
Stand-alone Base Utilities	949	0.1 %	3,239	9,718
Aux Subtotal....	302,471	32.2 %	1,032,332	3,097,306
Lighting				
Lighting	443,475	47.2 %	1,513,580	4,541,195
Receptacle				
Receptacles	8,761	0.9 %	29,900	89,708
Cogeneration				
Cogeneration		0.0 %	0	0
Totals				
Totals**	940,329	100.0 %	3,209,342	9,628,990

Geothermal Monthly Energy Consumption

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----													
Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 1 AMIC													
Electric													
On-Pk Cons. (kWh)	12,061	11,282	12,152	12,003	16,408	18,179	19,064	20,033	15,562	12,872	11,302	11,028	171,946
Off-Pk Cons. (kWh)	48,055	45,622	40,249	37,267	38,334	39,027	51,712	39,983	39,703	36,372	36,861	47,674	500,858
Mid-Pk Cons. (kWh)	23,758	22,270	22,820	18,439	22,787	25,915	26,615	26,992	20,645	19,923	19,363	21,938	271,467
On-Pk Demand (kW)	101	104	109	127	151	173	193	177	160	128	114	99	193
Off-Pk Demand (kW)	130	139	123	102	127	141	163	149	135	102	106	124	163
Mid-Pk Demand (kW)	128	136	118	120	147	166	185	167	145	109	105	121	185
Energy Consumption													
Building	63,660 Btu/(ft2-year)												
Source	191,000 Btu/(ft2-year)												
Floor Area	50,625 ft2												
Environmental Impact Analysis													
	CO2 1,140,698 lbm/year												
	SO2 8,875 gm/year												
	NOX 1,706 gm/year												