Final Report

Mechanical

# Mechanical Alternative for Twin Rivers Elementary/Intermediate


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# TWIN RIVERS ELEMENTARY/INTERMEDIATE

McKeesport, Pa

## The Building

Name: Twin Rivers Elementary/Intermediate
Location:1600 Cornell St, McKeesport, PA
Size: 127, 000 sq.ft.
Overall cost: $28 million
Stories: 2
Projected Date of Completion: Jan 2014

## The Team

**Owner:** Mckeesport Area School District
**Architect:** J C Pierce
**General Contractor:** PJ Dick.
**Civil Engineers:** Phillips & Associates, Inc.
**Structural & MEP Engineers:** Loftus Engineers
**Environmental Engineers:** American Geosciences, Inc.

## Architecture

The building is a red brick that stands out against the expansive glass curtain walls. The k-6th grade students experience large naturally lit common areas. The school is expected to gain a Silver LEED certification. The building includes: Classrooms, offices, a library, a gymnasium, and a cafeteria.

## Mechanical

- Vertical closed loop, earth coupled geothermal system utilizing heat pumps for heating and cooling
- Supplemental floor heating will be provided in kindergarden rooms and the library
- Ventilation system consistis of Dedicated Outside Air Ssytems and rooftop heat pump units

## Structural

- Continuous Wall Footing foundation placed12 to 18 inches below grade
- Steel beam framing and Steel column system. coulumns will either be a wideflang or a HSS
- Interior waslll are metal stud construction with gypsum board.

## Electrical

- Power source is 208/120V, 3-phase, 4 wire and will provide approx. 10 W/ft^2.
- A UPS will be provided in case of an emergency and main power is lost.
- A 3000 A switchboard
typical transformer is 75 kVa located in various electrical rooms

Tessa Bauman | Mechanical | http://www.engr.psu.edu/ae/thesis/portfolios/2014/tlb5271

# Acknowledgments

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# Executive Summary

The Twin Rivers Elementary/Intermediate School is a two story 127,000 sqft K-6 grade school in Mckeesport, Pa. It is 20 miles west of Pittsburgh, Pa. It is currently on track to gain LEED Gold accreditation.

The current mechanical system includes a geothermal heat pump system with accompanying air handling units to service smaller and occupancy driven areas of the building. The AHUs are supplied with energy from a condenser chiller which in turn is supported by the geothermal heat pump system. The current system contains a auxiliary loop for more extreme cases of heating and cooling that cannot be serviced by the geo system. This loop, contains a boiler and evaporative cooling towers. The natural gas boiler expends 1000 MBH into the heating load.

The domestic hot water is currently supplied by two natural gas water heaters. The hot water is to be supplied to the building at 120°F. The Cafeteria demands hot water of 140°F. The two water heaters use 285 MBH each for the DHW load.

It is suggested to install a solar hot water system using flat plate collectors in order to service the boiler and the water heaters. The location of the site and the roof area applicable to a solar array are considered for solar gain and shading. The Array will be able to support 15% of the required load. The system will pay itself back after 13 years of use. The addition of more collectors could be justified and would be possible with a larger storage tank. Currently there is not enough room in the Mechanical space for the large storage tank that would be needed.

The array will increase the dead load on the roof of the cafeteria and the gymnasium. This requires the structural design to change the roof joists to larger LH-series joists.

Since the building is complete the cost of refurbishing the site to include a solar energy conversion system would have to be taken into consideration. The gain from the solar collectors may not be the best investment to make for the Mckeesport Area School District.

The Mechanical space is enclosed with a glass wall to allow students and visitors to learn about the inner workings of the building. It is suggested to use a wall with an STC of 60 to divide a mechanical space from an ancillary learning spaces. The current design only has a STC of 29. To decrease the amount of sound entering the space it is suggested to include a sound proof window system which would have as small of an STC of 56.

Twin Rivers Elementary/Intermediate is a well designed school with little to improve upon. However, there are a few things that can increase the educational value. The solar array would increase renewable energy awareness and the sound proof glass would allow that awareness to become knowledge.

# Existing Building and Mechanical Systems Background

## Existing Building and Site Summary

The Twin Rivers Elementary/Intermediate School will house 800 students of the Mckeesport Area School District. It is a two story building of 127,000 sq. ft. The Mechanical system is designed to save 30% of energy when compared to ASHRAE standard 90.1-2007 requirements. ASHRAEs Advanced Energy Design Guide for K-12 School Buildings also had a major impact on the design. The building has many different rooms with different functions, including the following types of areas:

- Cafeteria
- Classroom
- Computer Lab
- Corridor
- Gymnasium
- Kitchen
- Library
- Mechanical & Electrical
- Nurse's area
- Offices
- Water Closets

The school is currently on track to receive LEED Gold accreditation since its completion in February 2014. The Building has no neighboring buildings since it takes an entire block. this fact allows for and excess of sunlight onto the school. There are sustainable sunshades on the exterior curtain walls and windows. Both perforated metal sunshades and metal awnings will be used on the exterior to control day lighting. This will reduce the load needed to cool the building.

### Building Envelope

Twin Rivers Elementary/Intermediate is designed to have typical exterior walls to be 14-1/8". The finish will be modular brick veneer extending from grade to the height of the building. The wall coping is a pre-finished aluminum coping incorporated with a aluminum composite metal panel system. Ground face CMU is used for the window sills and heads. It will also work architecturally to separate the brick veneer from the above pre-finished horizontal metal siding. Also, the ground face cmu will be used as accent bands at various heights. Molded cellular weep vents will be placed 24" o.c. and a copper laminate fabric with stainless steel drip edge will be used as the through wall flashing. 2" polystyrene board insulation will extend below grade to protect the foundation at the frost line, as well as continuously run the length of the exterior walls. The framing is that of a steel thermal efficient panel in connection with a continuous vapor barrier.

Typical windows will have a stationary pane at the top with a awing opening lower pane. The glazing is to be low-E insulated triple glazed system. The exterior storefront glazing utilized in the clerestory windows and the southern hallway.

## Existing Mechanical Systems Summary

The main heating and cooling for the classrooms currently comes from a geothermal heat pump system. This will be an earth coupled water, or heat pump water(HPW), loop directly connected to water-to-air heat pumps located in the individual rooms. An auxiliary boiler will be used in case the geothermal wells cannot produce appropriate fluid temperatures. There will be 2 well fields located slightly north of the building's foundation. The earth coupled water loop will also be connected to a chiller, serving air handling units, variable volume reheat boxes, and radiant floor systems for the kindergarten, pre-school rooms, and library story room. The AHUs produce heating for the cafeteria, the gym, the library, and the offices.

The ventilation system consists of 2 dedicated outside air systems (DOAS) which serve the classrooms and most of the building. The library, cafeteria, gymnasium, and offices each have individual air handling units (AHU). The library and office AHUs will have zone reheat coils. The gym and cafeteria AHUs will consist of just a single zone. The additional AHU are necessary to allow the building to lower the building load during low occupancy time periods, such as the summer months when school is not in session.

### Design Objectives

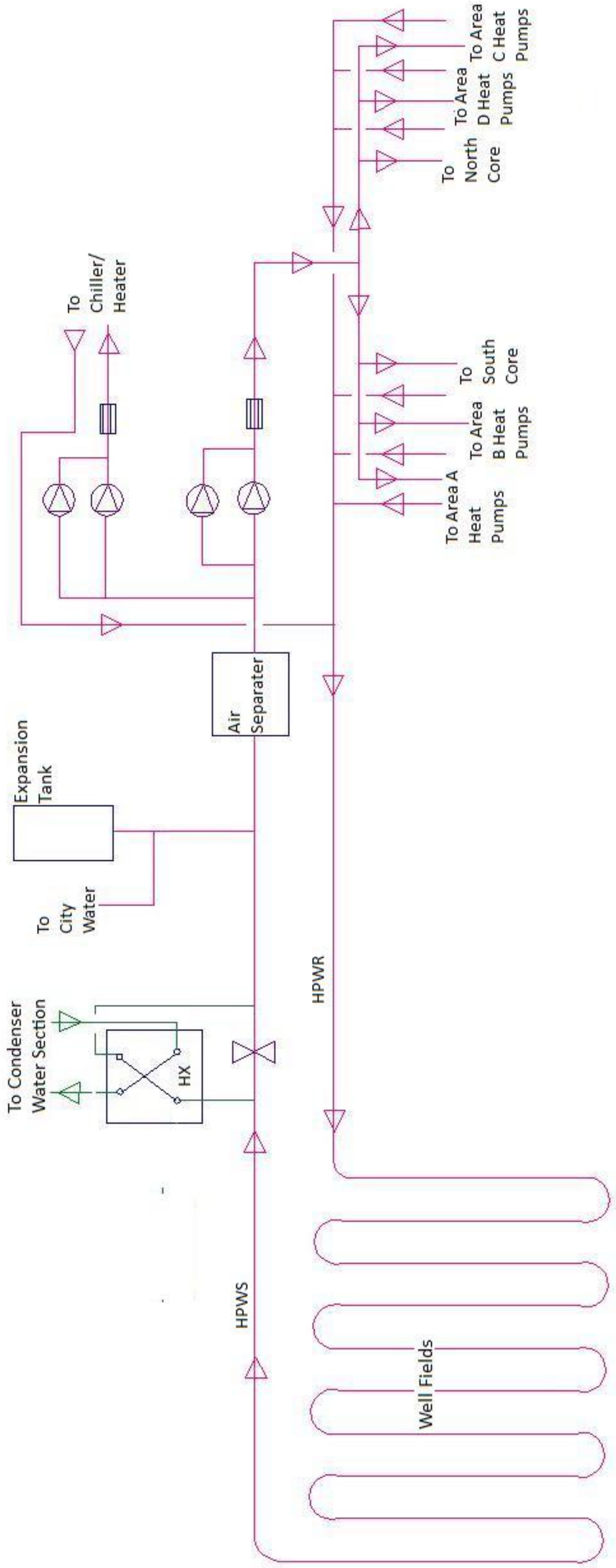
Twin Rivers Elementary/Intermediate was designed to be a state of the art educational building. It is to be a example for other school districts in the area to follow. LEED considerations heavily influenced the design. Once completed, the school is to be LEED Gold certified. The HVAC design references the following standards:ASHRAE 15-2010,62-2007,90.1-2007, and 55-2004,and uses ASHRAEs 2006 Advanced Energy Design Guide for K-12 School Building as a guideline.

### Ventilation

Two DOAS's, four AHU's supply the building, one kitchen make-up air unit, and one fan coil unit provide the building with the appropriate ventilation as required by ASHREA Standard 62.1.

The DOAS's return air, including that from the restrooms and from the classrooms, is used within the DOAS for heat recovery. It is then exhausted out of the system near the outside air intake. Since restroom exhaust is considered a Class 2 exhaust, it is allowed to be recirculated into the system. The AHU supplying the cafeteria and support area is placed at least 18 feet away from the kitchen exhaust. This is more than the 15 feet required for

Figure 1: Current Heat Pump Water Loop



a Class 3 exhaust. The Kitchen will have specific exhausts to the rooftop. Because of this, there is a kitchen makeup air unit.

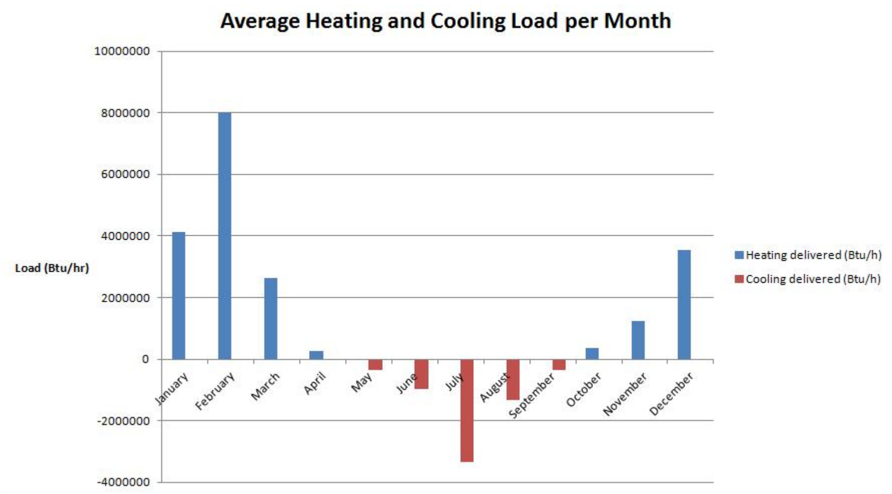
A ventilation calculation was performed in order to determine outdoor air intake flow for optimal ventilation system for breathing zone. All systems met the required outdoor air minimums.

### Heating and Cooling Loads

Twin Rivers Elementary/Intermediate is designed for 99.6% winter conditions due to the lack of occupancy during the summer months. This means that most of the load is for heating purposes.

A Load simulation was preformed in the TRANE Trace program. To do this, a block load energy analysis was applied. Within Trace, templates for different zone types were created. A block load analysis is for simplicity and estimation.

The following graph is the load for each month of the year. February has the highest average load due to extreme winter conditions. December and January do not have a high load as it may be expected. This is because these months have school holidays that lessen the load needed during those times. The peak heating load is 10,998 MBh. This is typical for western Pennsylvania design conditions.




### Geothermal Auxiliary Loop and Domestic Hot Water

The Geothermal Auxiliary Loop (also called the condenser water loop, CW) and Domestic Hot Water (DHW) are the main focus of the proposed renovations. The goal will be to reduce the dependency on natural gas for heating purposes.

The heating for the building is supplied by the geothermal system. However, the energy gained may not be enough to meet the demand loads of the building. In this case, the system requires backup energy. This backup energy is supplied by the condenser water loop.

The set point of the loop is to be 65°F rising to a max of 80°F. The system consists of 1 hot water boiler, 2 circulating water pumps (1 stand-by, 1 primary), 1 closed circuit evaporative cooler, cooler by-pass valve and a glycol injection unit. The condeneser water pump with the lowest run time energizes when any air handling unit or room heat pump is in operation. the lead pump will start and run continuously. Whenever the system is no longer needed, the lead water pump will run for a period of time to dissipate the heat in the system. When either evaporative cooler pumps (CDWP-1,2) is started, the supply valve from the Heat Pump Water Supply line shall open allowing flow through the heat exchanger. A condenser supply water temperature controller shall; open/close the evaporative cooler by-pass valve, cycle the cooler fan speeds, and cycle the spray pump, and energize the boiler to maintain set-point as follows:

If the condenser temperature is below setpoint, (65 ° F)

- The boiler shall be enabled
- The fan shall be de-energized and the spray pump shall be de-energized
- the by-pass valve closed

On a rise in condenser water temperature (over 80 °F)

- the boiler shall be shut off
- temperature the cooler by-pass valve shall open to the tower

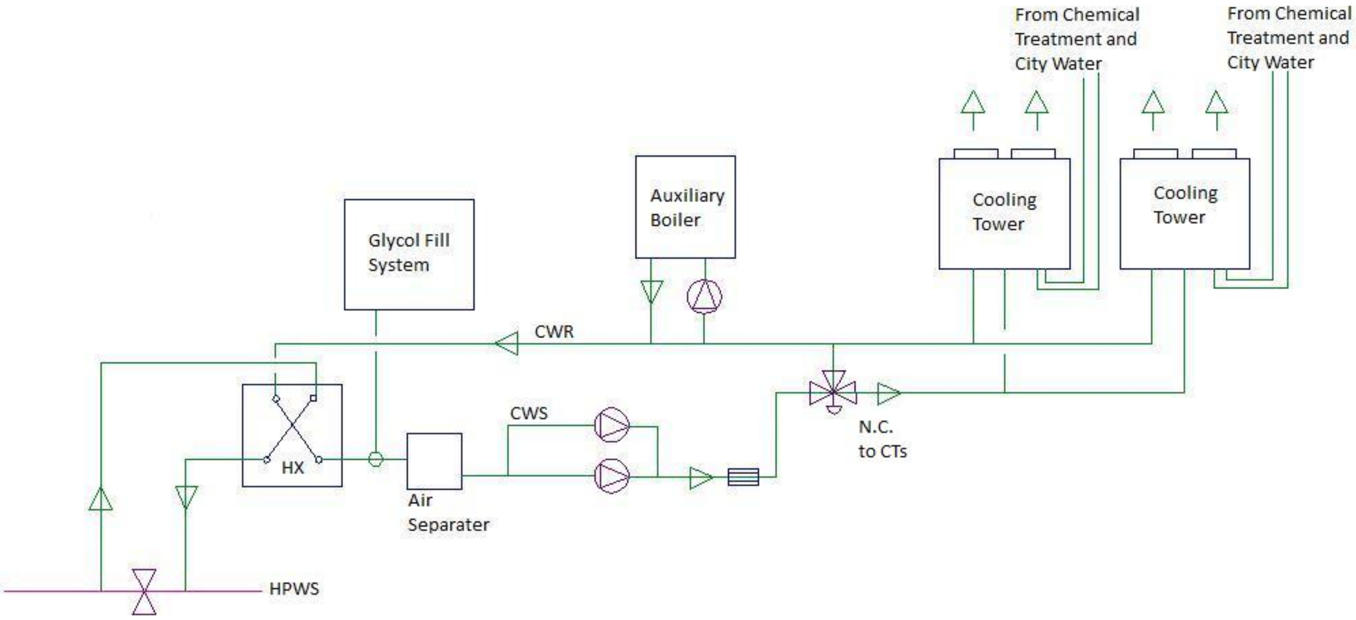
On a further rise in temperature (over 90 °F)

- the cooler spray pump shall energize
- the cooler fan shall energize

The following diagram is a simplified version of the existing system.

The current DHW is supplied from two natural gas water heaters. The peak demand for hot water is during meals when the cafeteria's kitchen will be in full use. The commercial dishwasher is the only device that demands 140°F water. The rest of the building will be supplied with 120°F DHW. The city water line comes into the building at a temperature of 49 °F. This demands a temperature rise of 91 °F.

Figure 2: Current Condenser Water loop




**Current Boiler and Water Heater**

The current boiler is a Futera Fusion boiler (1000MBH). This is auxiliary heating for the geothermal heat pump system. The boiler is to be turned on anytime the classroom heat pumps are in use. The geothermal wells are to supply water at 52°F at 1010 gpm. In 8" diameter piping. The exiting temperature of the boiler is to be 180°F.

Table 1: Current Boiler Size

| Auxilary Hot Water Boiler | | | | | | |
|---|---|---|---|---|---|---|
| | type | Input MBH | Output MBH | Max GPM | EWT (F) | LWT (F) |
| HWB-1 | finned tube | 1000 | 970 | 58 | 150 | 180 |

There are currently two 125 gallon water heaters that supply the building with domestic hot water. The exiting temperature is to be 140°F. The water heaters are able to produce 285 MBH for the building's hot water.

Table 2: Catalog of Futera Fusion From RBI Water Heaters

**Dimensions and Ratings**

| | Input | | Output | | Flue Vent | | | | Connections | | Weight | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cat IV Positive (Up to 60') | | Cat II | | | | | |
| Model | MBH | kW | MBH | kW | UL Listed Stainless Steel | PVC/PP Option | Negative | Air Intake | Gas | Water | Lbs | Kg |
| CB/CW 500 | 500 | 147 | 476 | 139 | 7" | 8" | | 8" | 1" | 2" | 850 | 386 |
| CB/CW 750 | 750 | 220 | 713 | 209 | 7" | 8" | Common | 8" | 1" | 2" | 900 | 408 |
| CB/CW 1000 | 1,000 | 293 | 952 | 279 | 7" | 8" | Vent | 8" | 1-1/4" | 2" | 1050 | 476 |
| CB/CW 1250 | 1,250 | 366 | 1189 | 348 | 8" | 8" | Engineered | 10" | 1-1/4" | 2-1/2" | 1235 | 560 |
| CB/CW 1500 | 1,500 | 440 | 1430 | 419 | 8" | 8" | Systems* | 10" | 1-1/4" | 2-1/2" | 1275 | 578 |
| CB/CW 1750 | 1,750 | 513 | 1668 | 489 | 10" | 10" | | 12" | 1-1/2" | 2-1/2" | 1365 | 619 |
| CB/CW 2000 | 1,999 | 586 | 1904 | 558 | 10" | 10" | | 12" | 1-1/2" | 2-1/2" | 1447 | 656 |

* Diameters may vary based on system design.

**Delta T/Boiler Recovery Table - Fahrenheit**

| Model | 500 | | 750 | | 1000 | | 1250 | | 1500 | | 1750 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inlet Temp (°F) | Flow Rate (gph) | Δt (°F) | Flow Rate (gph) | Δt (°F) | Flow Rate (gph) | Δt (°F) | Flow Rate (gph) | Δt (°F) | Flow Rate (gph) | Δt (°F) | Flow Rate (gph) | Δt (°F) | Flow Rate (gph) | Δt (°F) |
| 60 | 614 | 96 | 833 | 106 | 1050 | 112 | 1460 | 101 | 1664 | 106 | 1859 | 111 | 2118 | 111 |
| 80 | 753 | 76 | 998 | 86 | 1245 | 92 | 1768 | 81 | 2000 | 86 | 2205 | 91 | 2520 | 91 |
| 100 | 999 | 56 | 1268 | 66 | 1546 | 72 | 2293 | 61 | 2530 | 66 | 2758 | 71 | 3136 | 71 |
| 120 | 1513 | 36 | 1770 | 46 | 2083 | 52 | 3320 | 41 | 3532 | 46 | 3737 | 51 | 4247 | 51 |
| 140 | 3336 | 16 | 3072 | 26 | 3321 | 32 | 6354 | 21 | 6130 | 26 | 6026 | 31 | 6855 | 31 |

Table 3: Water Heater Schedule

| Hot Water Heaters | | | | | |
|---|---|---|---|---|---|
| | Size (Gal) | Input BTU | Input Temp(F) | Output Temp(F) | GPH |
| WH-1 | 125 | 285,000 | 100 | 140 | 332 |
| WH-1 | 125 | 285,000 | 100 | 140 | 332 |

# Mechanical Proposal

## Solar Thermal Auxiliary

The most likely solution to extracting on-site energy would be to involve adding an optocaloric auxiliary system to the condenser water loop. The proposed renovation would connect the solar thermal energy into the heat pump water system and remove the scheduled auxiliary boiler. There is adequate space available on top of the cafeteria roof, which are in close proximity to the mechanical spaces on the first floor. The solar thermal system should be able to provide enough auxiliary heat to the heat pump system and also have additional heat when auxiliary heat is not needed. This additional energy will be used to heat the domestic hot water.

Originally, it was assumed that this would not be a more cost effective revision to the mechanical system. Solar panels in Pennsylvania are not the least costly form of energy. While it is a fashionable renewable energy source, natural gas is by far less expensive in the initial cost and in the lifecycle cost. To add the solar hot water heating to Twin Rivers is suggested purely for it's educational value. The school had dedicated much of the design to the education of the inner-workings of sustainable design. The main corridor encases the mechanical room, electrical room, and the rain water harvesting room in glass with educational led screens depicting the sustainable aspects of the newest building in the district.

The initial cost of the system may be high but natural gas fuel savings could make the installation of a solar energy system worthwhile. A appropriate life cycle cost evaluation must be done to determine if the project is cost efficient idea.

The proposed system is to look similar to the following diagram. A 30% propylene glycol to water solution will be used within the loop. This is will not affect the existing condenser water loop due to the same solution being used in the original design with the boiler. The mechanical system is designed to have propylene glycol fill stations. One provides solution to the AHU heating coils and the other to the condenser water loop. The solution will ensure that the piping on the roof, which connects the panels to the DHW heater, will not freeze during the winter.

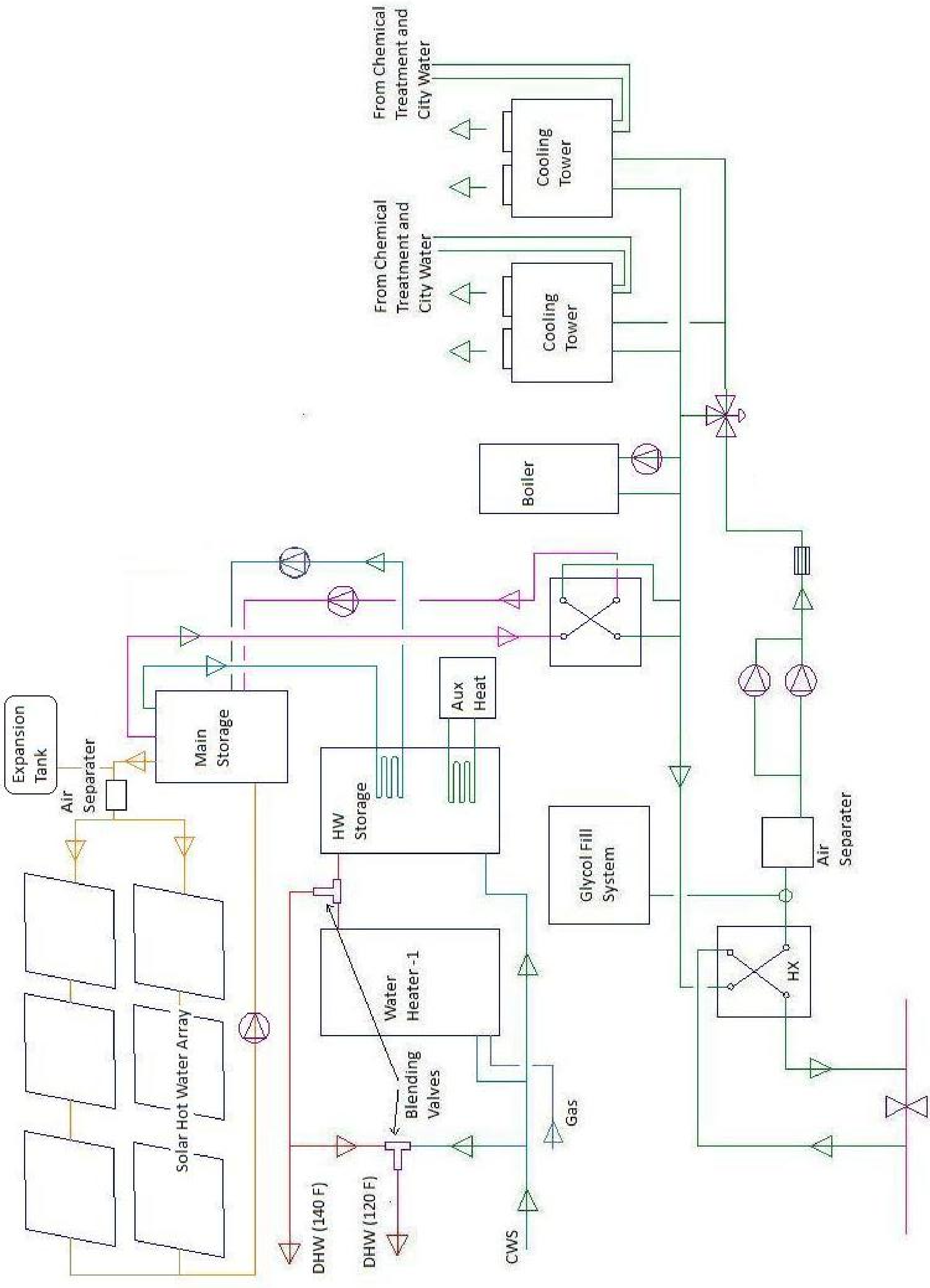



Figure 3: Revised Condenser Water Loop with Solar Water Heating

The solar hot water panels will produce an outlet temperature of 150°F. This is less than what is necessary for the DHW load, however, it is more beneficial to operate the collectors at this temperature than it is at 180°. The main use of the solar energy conversion system (SECS) is during the winter months when the GA loop is needed to be heated. The lower temperature difference between the collector inlet temp and the atmospheric temp is beneficial to the collector efficiency.

The geothermal system is a reliable system and the boiler is only in use during extreme winter conditions when the necessary load is not met. If the SECS is to be efficient, other loads must be added to the loop to ensure that the solar energy is being fully utilized. The domestic hot water currently receives the load from two identical water heaters in parallel. It is proposed to remove one of the water heaters and to replace it with a indirect solar system with the heat exchanger in the tank. This would be an additional benefit for installing the solar-based system.

## Load Analysis

### CW loop Load

The boiler runs at 58 gpm producing a 30°F temperature rise. The solution running through the system is to be 30% propylene glycol. To determine the load of the boiler the following calculation* was done.

$$Q = m_{dot} c_p \rho \Delta T$$

$$Q = \left(58\frac{gal}{min}\right)\left(60\frac{min}{hr}\right)\left(.947\frac{btu}{lbF}\right)\left(64.7\frac{lb}{ft^3}\right)\left(\frac{1ft^3}{7.48gal}\right)(30F)$$

$$Q = 855.171MBH$$

*Calculation based on 30% propylene glycol solution. Property values from Dow's Engineering and Operating Guide for Dowfrost HD at 80°F

This is a very large amount of energy to be provided. It is suggested to not remove the boiler but change the controls so that a solar heat exchanger would add as much energy to the system as possible and use the boiler for half the load necessary. The calculations will assume that the collector is to produce only 427.6 MBH for the GA loop.

### DHW Load

To determine the size of the water heaters. Pro-Size Water Heater Sizing Program for Schools was used to find the peak hot water demand. This added up all the classroom sinks, restrooms, and food services loads. The peak DHW demand is 667 gph. This can be checked by comparing it to the current water heater capability of 332 gph each.

$$Q = 8.36 m_{dot} \Delta T$$

$$Q = 8.36 \frac{lb}{gal}(332gph)(140°F - 49°F)$$

$$Q = 252.6 MBH\ each$$

The water sizing program accurately calculated the demand of the school. The value used in calculations is to be 252.6 MBH.

### Total Load

The total load that the SECS is expected to meet is 680.2 MBH. This is half of the total building load for the DHW and GA. Due to the very cold winters the collectors are not expected to work above 50% efficiency. This means that a large array area would be needed to produce the same amount of energy if it were a warmer climate. The cost of a very large array is not deemed necessary for the loads needed to be met. The unshaded area of the cafeteria and gymnasium also limits the size of the array possible.

## Solar Analysis

Mckeesport, Pa is located at 40.34° north and 79.8489° west. The proposed site of the optocaloric panels is atop the cafeteria and gymnasium roof. The is adequately near the mechanical space where the current boiler and water heaters are located. The rooftop has adequate access to maintain the panels. Project north for the building, where the front entrance faces East, is 11° NE of true north. This benefits the design of a solar array. There will not be an issue with directing the panels due south and the roof space can be utilized in a efficient manner.

The panels will be flat plate collectors(FPC). Evacuated tube collectors could be used but are more costly. Evacuated tube collectors have a higher efficiency at higher differential temperatures. This is to be a closed loop system and the return glycol solution will retain a high inlet temperature for the collector, therefore the ΔT will be relatively small. A FPC array will provide adequate load to the condenser water loop and the domestic hot water line with an adequate efficiency.

### Shading

The highest points of the roof include the southern and northern wings, the gymnasium, the library, and the cafeteria. The cafeteria roof and the gymnasium both have adequate height and space to house the array. The commons roof south east of the gymnasium roof, however, cast minor shadows which reduce the efficiency of the array when those times are encountered. It was decided that both the cafeteria roof and the gymnasium are to be utilized for the panels. The proposed location can be seen in the rough Google Sketchup model below. The exact location of the site was used from google earth so that the shading analysis would be as exact as possible. The rendering pictures the roof top during the winter solstice at 9 am (sunrise is at 7:43 am).

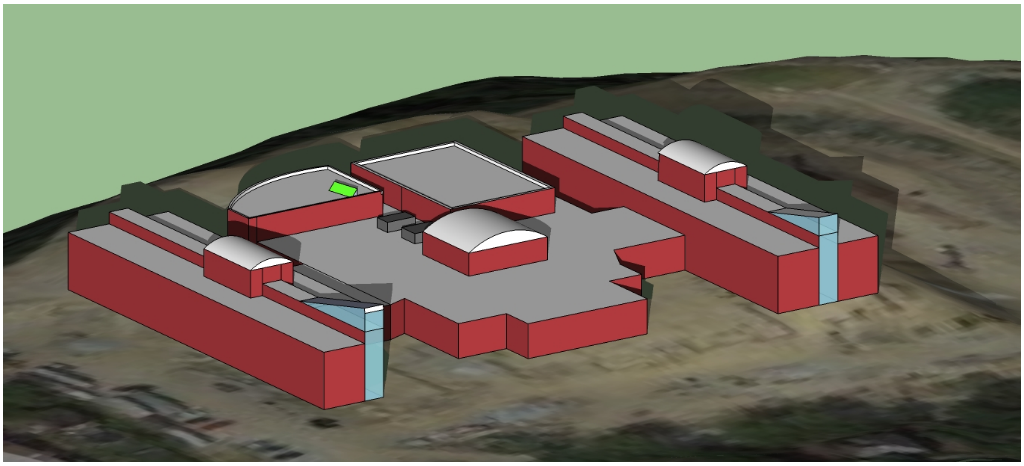


Figure 4: Location of Solar Panels

Some shading occurs in the early morning and late day during the winter solstice. The collector also does not gain direct sunlight during the summer solstice due to the positioning of the sun. These times were taken into account when sizing the collector. The benefit of constant direct gain will not produce enough of an increase in load to justify a more expensive tracking solar panel. A fixed system will be used in this project. The other key dates of the year, spring and fall equinoxes and summer solstice show no shading.

The collector chosen is the NAS10410 from Caleffi its dimensions are 4' by 10'. This is a relatively large collector. The tilt of the collector is to be 40°. The shading analysis for the collectors was done to minimize the amount of shading caused by other panels in the array. The height of the collector and the area of the roof taken by the collector were determined by the sine and cosine of the tilt. The following table was produce to show the shadow of the collector at different times of the day and year.

Table 4: Shading produced by Collectors

| Azmuith Angle | 0 | 50 | 75 | 0 | 50 | 75 | 0 | 50 | 75 |
|---|---|---|---|---|---|---|---|---|---|
| | Solar Altitude at lat=40 | | | Length of Shadow | | | Length of shadow due north | | |
| December | 25 | 8 | 0 | 5.514 | 18.295 | - | 5.514 | 11.760 | - |
| September/March | 51 | 40 | 15 | 2.082 | 3.064 | 9.596 | 2.082 | 1.970 | 2.484 |
| June | 75 | 67 | 50 | 0.689 | 1.091 | 2.157 | 0.689 | 0.702 | 0.558 |

During the winter months the shading caused by the array will be the most drastic. To ensure that the collectors recieve full sun exposure it is suggested to place the collectors 6 ft apart. This will not remove the possibility of shading but will reduce it to a minor variable. Early morning in the winter, the collectors will be slightly shaded.

### Solar Angles and Irradiance

The panels are to be directed due south with a tilt,$\beta$, of 40°. This is the optimum tilt for the location due to its latitude,$\phi$, being 40.34° north. The best collector azimuth $\gamma$ is 0°, due south. Angle of incidence, $\theta$, is key to collector design. This is an instantaneous value. For each hour, $\theta$ was calculated using the mid-hour angle, $\omega_{mid}$.

The declination of the earth was determined for each day analyzed using the following equation, where n is the day of the year.

$$\delta = 23.45^{\circ} sin\left(\frac{360}{365}(284+n)\right)$$

After all the solar angles were found, this equation can be used to find the instantaneous angle of incidence.

$$cos\theta = sin\phi sin\delta cos\beta - cos\phi sin\delta sin\beta cos\gamma +$$

$$cos\phi cos\delta cos\beta cos\omega + sin\phi cos\delta sin\beta cos\gamma cos\omega +$$

$$cos\delta sin\beta sin\omega sin\gamma$$

where:
$\theta =$ angle of incidence
$\phi =$ latitude
$\delta =$declination
$\beta =$ collector tilt
$\gamma =$ collector azimuth
$\omega =$hour angle

Since $\gamma = 0°$, the equation reduces to:

$$cos\theta = sin(\phi - \beta)sin\delta + cos(\phi - \beta)cos\delta cos\omega$$

### Collector and Array Design

For calculations, TMY3 data was used from Allegheny Co. Airport (5 miles west of Twin Rivers site). This data is the most up to date data for the area. Pittsburgh International airport only offered TMY2 data and is located 25 miles south-west of the site. Global horizontal irradiance(GHI), diffuse horizontal irradiance(DHI), Direct normal irradiance (DNI), and dry-bulb temperature were used in the solar analysis. The data collected suggested that the average day is partially cloudy with moderate temperatures. These values were offered in SI units and had to be converted into customary units.

The array will consist of 90 panels. They will be situated in 3 panels in series. 30 of these 3 panel series will be connected in parallel. The system is to produce enough energy to heat the DHW and add auxiliary heat into the condenser water loop. To design the array, the following procedure was used.

The irradiance on a tilted plane,$G_T$, was calculated for every hour in question. The ground reflectance,$\rho_g$, was estimated to be 0.2.

$$G_T = DNI cos\theta + DHI\left(\frac{1+cos\beta}{2}\right) + \rho_g GHI\left(\frac{1-cos\beta}{2}\right)$$

On average, $G_T = 235\frac{btu}{hr°F}$ around noon.

The first collector inlet temperature is the temperature of the main storage tank,150°F. The tank temp changes with every hour according to the load taken and the heat loss from the tank. An excel workbook was completed which iterated the tank temp for every hour.

Collector information was taken from the System Adviser Model (SAM) program's library of hot water solar collectors. Two collectors were chosen, one FPC and one ETC. The differences in the two calculations were minimal(the FPC actually outpreformed the ETC), therefore the FPC will be the focus of the report. The values obtained for collector area, mass flow rate, $F_r\tau\alpha$, and $F_rU_L$ gave way to easier calculations. The useful energy gained from the collector was calculated using the following equation.

$$Q_u = A_c\left(F_r\tau\alpha G_T - F_rU_L(T_i - T_a)\right)$$

For ease of calculations, $F_r\tau\alpha$ and $F_rU_L$ were considered constants. In reality, they vary with temperature.

The outlet temperature, equal to the inlet temperature of the proceeding collector, was found by rearranging the familiar formula:

$$Q = m_{dot}c_p\Delta T$$

$$T_o = \frac{Q_u}{m_{dot}c_p} + T_i$$

Depending on the inlet temperature, the specific heat of the 30% propylene glycol solution fluctuated. The change was accounted for with an if-then function incorporated into the equation.

This process continued for each successive collector in the series. The useful energy of each collector was added together to get the total useful energy of the series. Then to find the total energy of the array, the total energy from a single series was multiplied by the total number of series in parallel(30 parallel series of 3 panels). As expected, the system did not gain as much energy in the winter months as it does in the summer. This is due to the shorter day during the winter.

To calculate the load obtained for the array, the system calculation was made. Iteration was necessary to obtain the Useful energy $Q_u$ and the Tank temperature, $T_s$. The following equations were used to model the system.

$$T_s' = T_s + \left(\frac{1}{c_p V_{tank}}\right)(Q_u - L_{tank} - L_{DHW} - L_{GA})$$

where

- $T_s'$= new tank temperature
- $T_s$= initial tank temperature
- $c_p$=specific heat of propylene glycol solution
- $V_{tank}$=Volume of tank
- $L_{tank}$=the heat loss from the tank
- $L_{DHW}$= the load gained from the array for the DHW
- $L_{GA}$= the load gained from the array for the GA

$$L_{tank} = UA(T_s - T_{a,mech})$$

$$L_{DHW} = \epsilon_{HX} m_{DHW} c_p (T_s - T_{r,DHW})$$

$$L_{GA} = \epsilon_{HX} m_{GA} c_p (T_s - T_{r,GA})$$

The system modeling was done in excel. A computer program was not used due to the original system design. The system model is not without its flaws but produces adequately accurate results and provides enough information as to whether it will be beneficial to the overall building design. The first of the excel snapshots is the constants for the FPC collector. These were used in the array calculations. The second excel snapshot is the constants for the system calculations. This contains the main storage tank characteristics. All other variables vary by hour or by date.The third excel snapshot is one of the calculated days (9/23) for the useful energy supplied by the array. The last excel snapshot is of the system calculations for the same day.

| Company | Model | Weight | working temp | Cost/panel | type |
|---|---|---|---|---|---|
| Caleffi | NAS10410 | 153.0 | .-40 to 350 | 3625.0 | FPC |

Constants

| | | | |
|---|---|---|---|
| $\gamma$= | 0.0 | $\rho$= | 0.2 |
| $\phi$= | 40.0 | $\beta$= | 40.0 |
| A($Ft^2$)= | 39.9 | $F_r$*$\tau\alpha$= | 0.691 |
| $m_{dot}$ (Lb/H)= | 345.9 | $F_r$*Ul(btu/hr $ft^2$ °F)= | 0.5988 |
| Number of Series in Array | 30.000 | | |

30% propylene glycol solution

| T (°F) | $C_p$(btu/lbF)= |
|---|---|
| 165.0 | 0.943 |
| 180.0 | 0.947 |
| 195.0 | 0.952 |
| 210.0 | 0.958 |

| | |
|---|---|
| Freezing point | 7.0 |
| Boiling Point | 216.0 |
| orage Tank Ten | 150.0 |

Figure 5: Constants used for Array Useful Energy

| Tank Characteristics | | | |
|---|---|---|---|
| $V_{tank}$(gal) | 940.00 | R of foam | 16 |
| h (Ft) | 10.67 | R of fg | 13 |
| Dia (Ft) | 4.33 | U | 0.0345 |
| SA (ft2) | 174.71 | | |

| | |
|---|---|
| cp (btu/galF) | 8.191 |
| $\epsilon_{hx\ (estimated)}$ | 0.650 |
| $UA_{tank}$ (Btu/hrF) | 6.024 |

Figure 6: System Calculation Constants

Assumptions had to be made for ease of calculation. As previously stated,$F_r\tau\alpha$, and $F_rU_L$ are considered constants. Since not everyday of the year was considered in this calculation, the initial tank temperature was assumed to be 150° F. It was assumed that the control logic would not allow over heating and extreme cooling to affect the tank. This was done manually to the calculations when the event occurred. The system is designed with a school in mind. The dates considered are 3 winter dates, the equinoxes, and the summer solstice. The 3 winter dates include times close to school winter break and also the winter solstice. This makes the results favor the winter mode of the system. This was done purposely because of the low occupancy and need for the load in the summer months.

The heat exchanger effectiveness for both the water heater and the GA heat exchanger were assumed to be .7. The data from the vendors was not available so a reasonable effectiveness was chosen.

Another assumption made was that the control logic would change the mass flow rates to the DHW and the GA as the useful energy increased and decreased. This was done by assuming a specific mass flow rate for an entire day, however the rate varied throughout the year. When there was more energy obtained from the array, more energy at a faster rate would be taken to the loads. This assumes two variable speed pumps in the system.

Lastly, it is assumed to be a fully mixed storage tank. In reality, the hotter solution would rise to the top and the colder solution would remain at the bottom of the tank. The solution returning to the collectors is to be taken from the bottom of the tank. Therefore the inlet temperature to the collectors is modeled higher than it would be in reality. This raises the efficiency of the array.

Full calculations can be seen in the appendix.

| 9/23 | | n | 281.0 | | δ | -7.0 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TMY3 Data | | | | | | Solar Calculations | | | Typical Series Collector 1 | | Typical Series Collector 2 | | Typical Series Collector 3 | | Array Calculations | | |
| Start Time | End Time | Ta(°F) | GHI (Btu/HrFt²) | DNI (Btu/HrFt²) | DHI (Btu/HrFt²) | Hour, $\omega_{mid}$ (Deg) | Incedent, θ (deg) | Gt (Btu/HrFt2) | Ti (°F) | Qu (Btu/Hr) | Ti (°F) | Qu (Btu/Hr) | Ti (°F) | Qu (Btu/Hr) | Tsupply (°F) | Δ T of Array (F) | Total Qu of Array (Btu/Hr) |
| 6:00 AM | 7:00 AM | 55.4 | 3.8 | 0.0 | 3.8 | -82.5 | 82.6 | 3.4 | 149.9374 | -2161.91 | 143.3103 | -2003.7 | 137.1681 | -1857.07 | 131.4755 | 18.4619568 | -180680.57 |
| 7:00 AM | 8:00 AM | 55.4 | 14.9 | 0.0 | 14.9 | -67.5 | 67.7 | 13.5 | 149.8749 | -1883.36 | 144.1016 | -1745.53 | 138.7509 | -1617.79 | 133.7917 | 16.0831804 | -157400.34 |
| 8:00 AM | 9:00 AM | 57.2 | 37.1 | 24.1 | 26.3 | -52.5 | 52.8 | 38.7 | 149.8124 | -1145.88 | 146.2998 | -1062.03 | 143.0442 | -984.306 | 140.0269 | 9.78542395 | -95766.447 |
| 9:00 AM | 10:00 AM | 62.6 | 164.5 | 127.8 | 89.1 | -37.5 | 38.0 | 183.1 | 43.49821 | 5500.769 | 60.36028 | 5098.218 | 75.98837 | 4725.126 | 90.47279 | -46.974574 | 459723.37 |
| 10:00 AM | 11:00 AM | 64.4 | 213.7 | 200.3 | 73.9 | -22.5 | 23.5 | 254.0 | 22.45463 | 7997.738 | 46.97091 | 7412.457 | 69.69308 | 6870.007 | 90.75242 | -68.297788 | 668406.04 |
| 11:00 AM | 12:00 PM | 66.2 | 242.8 | 253.9 | 49.8 | -7.5 | 10.2 | 299.5 | 46.93288 | 8711.761 | 73.63794 | 8074.227 | 98.38869 | 7483.348 | 121.3282 | -74.395284 | 728080.06 |
| 12:00 PM | 1:00 PM | 69.8 | 230.5 | 207.6 | 70.1 | 7.5 | 10.2 | 271.6 | 79.95843 | 7240.008 | 102.152 | 6710.178 | 122.7214 | 6219.121 | 141.7855 | -61.827045 | 605079.19 |
| 1:00 PM | 2:00 PM | 69.8 | 236.5 | 266.0 | 42.2 | 22.5 | 23.5 | 286.7 | 122.4157 | 6641.701 | 142.7752 | 6155.656 | 161.6447 | 5705.18 | 179.1334 | -56.717726 | 555076.11 |
| 2:00 PM | 3:00 PM | 71.6 | 201.6 | 254.2 | 38.4 | 37.5 | 38.0 | 238.8 | 153.3494 | 4627.334 | 167.534 | 4288.702 | 180.6251 | 3976.177 | 192.6984 | -39.349063 | 386766.36 |
| 3:00 PM | 4:00 PM | 69.8 | 150.6 | 232.0 | 32.3 | 52.5 | 52.8 | 172.3 | 167.088 | 2424.144 | 174.4876 | 2247.493 | 181.348 | 2083.714 | 187.675 | -20.586999 | 202660.54 |
| 4:00 PM | 5:00 PM | 69.8 | 89.1 | 189.6 | 24.1 | 67.5 | 67.7 | 95.4 | 167.7177 | 289.7811 | 168.6022 | 268.6643 | 169.4223 | 249.0862 | 170.1826 | -2.4649539 | 24225.95 |
| 5:00 PM | 6:00 PM | 66.2 | 29.5 | 99.5 | 13.9 | 82.5 | 82.6 | 25.9 | 167.6412 | -1708.1 | 162.4273 | -1583.62 | 157.5729 | -1467.73 | 153.0737 | 14.5675314 | -142783.67 |
| 6:00 PM | 7:00 PM | 64.4 | 0.6 | 3.5 | 0.6 | 97.5 | 97.4 | 0.1 | 167.5648 | -2459.48 | 160.0573 | -2280.26 | 153.0674 | -2113.39 | 146.5891 | 20.9757546 | -205593.87 |
| | | | | | | | | | | | | | | | | Hourly Average: | 453752.2 |

Figure 7: Example of Excel Calculations for Array Useful Energy

| 9/23 | $m_{dhw}$ (gph) | 2400 | $m_{ga}$ (gph) | 2400 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Time | End Time | Qu,array (MBH) | tank Loss (MBH) | DHW load (MBH) | GA load (MBH) | Ts (F) | Tr,dhw (F) | Tr,ga (F) | Tr (F) | | Aux needed, DHW (MBH) | Aux needed, GA (MBH) | Solar Fraction |
| 6:00 AM | 7:00 AM | 0.00 | 0.48 | 0.00 | 0.00 | 149.94 | 119.94 | 79.94 | 114.94 | | 252.57 | 427.59 | 0.00 |
| 7:00 AM | 8:00 AM | 0.00 | 0.48 | 0.00 | 0.00 | 149.87 | 119.87 | 79.87 | 114.87 | | 252.57 | 427.59 | 0.00 |
| 8:00 AM | 9:00 AM | 0.00 | 0.48 | 0.00 | 0.00 | 149.81 | 119.81 | 79.81 | 114.81 | | 252.57 | 427.59 | 0.00 |
| 9:00 AM | 10:00 AM | 459.72 | 0.48 | 383.35 | 894.49 | 43.50 | 24.00 | -2.00 | 11.00 | | -130.78 | -466.90 | 1.88 |
| 10:00 AM | 11:00 AM | 668.41 | -0.16 | 249.18 | 581.42 | 22.45 | 9.78 | -7.12 | 1.33 | | 3.39 | -153.83 | 1.22 |
| 11:00 AM | 12:00 PM | 728.08 | -0.29 | 161.97 | 377.92 | 46.93 | 38.69 | 27.71 | 33.20 | | 90.61 | 49.66 | 0.79 |
| 12:00 PM | 1:00 PM | 605.08 | -0.14 | 105.28 | 245.65 | 79.96 | 74.60 | 67.46 | 71.03 | | 147.29 | 181.94 | 0.52 |
| 1:00 PM | 2:00 PM | 555.08 | 0.06 | 68.43 | 159.67 | 122.42 | 118.93 | 114.29 | 116.61 | | 184.14 | 267.91 | 0.34 |
| 2:00 PM | 3:00 PM | 386.77 | 0.32 | 44.48 | 103.79 | 153.35 | 151.09 | 148.07 | 149.58 | | 208.09 | 323.80 | 0.22 |
| 3:00 PM | 4:00 PM | 202.66 | 0.50 | 28.91 | 67.46 | 167.09 | 165.62 | 163.66 | 164.64 | | 223.66 | 360.12 | 0.14 |
| 4:00 PM | 5:00 PM | 24.23 | 0.58 | 18.79 | 0.00 | 167.72 | 166.76 | 126.76 | 166.76 | | 233.78 | 427.59 | 0.03 |
| 5:00 PM | 6:00 PM | 0.00 | 0.59 | 0.00 | 0.00 | 167.64 | 137.64 | 97.64 | 132.64 | | 252.57 | 427.59 | 0.00 |
| 6:00 PM | 7:00 PM | 0.00 | 0.59 | 0.00 | 0.00 | 167.56 | 137.56 | 97.56 | 132.56 | | 252.57 | 427.59 | 0.00 |
| | | | | | | | | | | Hourly Average | 171.0036705 | 240.6319144 | 0.394794184 |

Figure 8: System Calculation and Solar Fraction

## Revised System

The components for the system can be seen in the appendix. The full system contains 90 flat plate collectors, 3 small variable speed pumps(solar array pump, HX pump, DHW pump), 1 storage tank, 1 air separator, 1 expansion tank, and 1 drainback tank(not diagrammed). The 30% propylene glycol solution will first travel into the solar array where it will gain a variable amount of energy. This energy will then be delivered to the storage tank. If the solution rises above boiling point or falls below freezing point the solar array pump will turn off and the drainback system will activate. The energy enters the main storage tank. This will be controlled by a temperature sensor. If the energy supplied to the tank is adequate the DHW load will be met, followed by the GA load. Because the load for the geothermal is nearly double that of the DHW, the DHW is first priority.

When the solar hot water heater is active the DHW pump on the return side of the water heater exchanger will turn on. This will return the water to the main storage tank. If the temperature of the water drops below 140°F, the auxiliary heaters will activate to heat the water to an adequate temperature.

When the heat exchanger is active, the GA pump will turn on and return the GA solution to the main storage tank. This will supply the load to the condenser water loop. If the temperature sensor in the CW loop indicates the load is not sufficient to raise the CW temperature in a timely manner, the boiler will active. The loop varies between 65-80°F. The control logic for the geothermal heat pump system will determine when load is necessary for the loop.

The main storage tank then delivers water to the to the collectors by means of the solar array pump. The solution also passes through a air separator and a expansion tank. These are precautionary components.

### Domestic Hot Water

The Strato-Therm+ solar hot water heater, manufactured by Lochinvar, would be sufficiently large to supply the entire building with hot water. The second water heater can be inactive while the solar hot water tank's auxiliary heaters work to maintain the water temperature if the solar gain is not adequate. However, the load supplied by the collectors rarely exceeds that needed from one water heater. Therefore the system was only modeled to serve the load equal to that of one water heater. Two sets of coils will heat the tank, one from the solar collector array and the other from an auxiliary heating device.

Table 5: Suggested WH replacement Performance Data

| Stored Water Temp. | DHW Output Temp. | | 150 |
|---|---|---|---|
| 180°F | 140°F | Continuous Draw Rating (GPM) | 16 |
| | | BTU/Hr input of Boiler for DHW | 675,925 |
| | | First Hour Rating Gallons | 1,035 |

**Geothermal Auxilary**

The Boiler will not be replaced. The Array cannot fully provide the load needed to heat the condenser water loop. A heat exchanger will be placed before the boiler so that the boiler will not have to be activated as much as it originally had to. The heat exchanger will have the following characteristics.

Table 6: Geothermal Auxiliary Heat Exchanger

Heat Exchanger

| | | | Hot Side | | | Cold Side | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MFG | Efectiveness | GPM | ET (F) | LT (F) | GPM | ET (F) | LT (F) | HX MBH |
| HX-GA | Mueller | 0.7 | 30 | 150 | 121 | 58 | 64 | 79 | 430 |

## Cost Analysis

In order to be able to suggest this system it must be economically beneficial. A life cycle cost analysis was preformed. The cost of the system was determined by the following equation.

$$C = (Number\ of\ Collectors)(Cost\ per\ collector) + (Estimated\ Price\ of\ additional\ Components)$$

$$+(Average\ Cost\ of\ Installation\ per\ sqft\ of\ Collector\ Area)(Total\ Collector\ Area)$$

The cost of each Califfi FPC is \$3,625. It was assumed for all of the additional components the cost would be \$20,000. The cost of installation is assumed to be \$7 per sqft of collector area. This is the high end of the installation average, however it is a large system and exact placement and tilt is necessary for the system to work as designed. The total cost of the system is \$371,450.

The boiler and the current water heaters are fueled by natural gas. The local gas company's current rate is \$0.48 per therm, or \$.48 per 100,000 Btu. The fuel savings is the load supplied to the DHW and the GA multiplied by this rate. Average hourly gain was used and it is assumed that the load is only needed for 12 hours of the day for %80 of the year.

The fuel cost per year for the DHW and the GA is $12,371.40. The yearly fuel savings is $3,686.60.

SPP(simple payback period)= $\frac{Cost of System}{Solar Savings}$

$SPP = \frac{371,450}{12,371.40} = 100 years$

A simple payback period calculation is not sufficient to determine the true cost cycle of the system. Many assumptions were made in order to complete the extensive life cycle cost analysis. The market dicount rate is assumed to be 6%. The interest rate is 5.75%. The cost of NG is assumed to increase at a rate of 3% a year. The cost of maintenence is to be 1% of the total cost of the system and is to increase at a rate of 1% a year. The down payment is to be 20% of the total cost. All of this leads to the table on the next page of lifecycle cost. The payback period is to be 13 years. After 13 the system begins exceeds the initial cost of the system.

## Mechanical Results

Table 8: Comparison of Evacuated Tube and Flat Plate Collectors

ETC

| Date | Total $Q_{u,avg}$ (MBH) | Axilliary For DHW (MBH) | Axilliary for GA (MBH) | Solar Fraction |
|---|---|---|---|---|
| 12/21 | 35.27 | 218.83 | 427.59 | 5% |
| 3/20 | 237.68 | 185.04 | 296.14 | 29% |
| 6/21 | 225.06 | 203.56 | 328.31 | 22% |
| 9/23 | 257.93 | 190.69 | 308.40 | 27% |
| 11/30 | 45.52 | 204.45 | 402.34 | 11% |
| 1/12 | 141.05 | 194.71 | 278.87 | 30% |
| Hourly Average: | 157.09 | 199.55 | 340.28 | 21% |

FPC

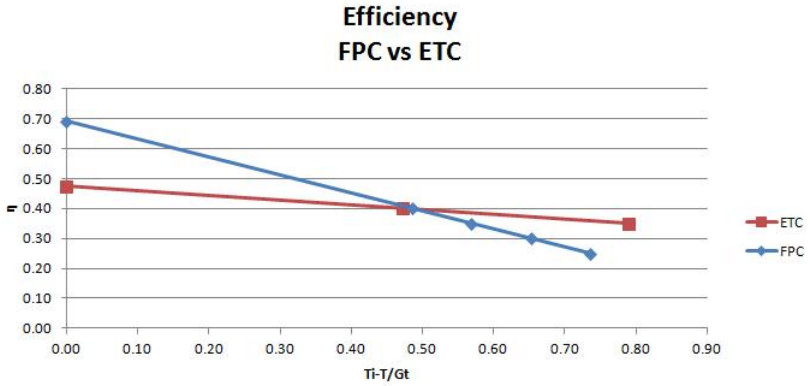
| Date | Total $Q_{u,avg}$ (MBH) | Axilliary For DHW (MBH) | Axilliary for GA (MBH) | Solar Fraction |
|---|---|---|---|---|
| 12/21 | 2.13 | 252.57 | 427.59 | 0% |
| 3/20 | 418.05 | 197.34 | 221.40 | 38% |
| 6/21 | 353.77 | 110.39 | 206.37 | 53% |
| 9/23 | 453.75 | 171.00 | 240.63 | 39% |
| 11/30 | 93.65 | 208.30 | 394.04 | 11% |
| 1/12 | 419.23 | 182.59 | 252.63 | 36% |
| Hourly Average: | 290.10 | 187.03 | 290.44 | 30% |

This system is adequate to supply the building with additional "free" energy. However, It does not meet the necessary loads required of it. The array is limited in size do to the area available on the cafeteria roof and the gymnasium roof. If the system were to increase in collector area and install a much larger storage tank, the system would be able to handle the given loads. However, this is not a realistic design. The proposed system would save enough energy to be able to pay for itself, but the amount of energy saved compared to what the building uses is minuscule. The average annual solar fraction for this system is 30%. This is 30% of half of the amount of energy required for both the DHW and the GA.

Table 7: Lifecycle Cost of Solar Array

| Year | Extra mortgage payment ($) : fixed | Fuel savings ($) : projected to increase by 1.03 each year | Extra insurance, maintenance, and parasitic cost ($) : projected to increase by 1.01 each year | Annual Solar savings ($) | PW of annual solar savings ($) : must use PW for each year | Cumulative Solar Savings ($) | Yearly Interest Payment ($) : need to multiply balance by 1.0575 | Principle Payment | Principle Balance (total system cost, less 20% Down Payment) | Periodic Payment Present Worth Factor (15, 0, 0.0575) | Present Worth for Savings (n, 0, d) : must use 1/(1+d)^n |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | $3,686.60 | | -$74,290.00 | -$74,290.00 | $0.00 | | $297,160.00 | $297,160.00 | 9.87288553 | 1.0000 |
| 1 | -$30,098.60 | $3,797.19 | -$3,714.50 | -$30,015.90 | -$28,316.89 | -$102,606.89 | $0.00 | -$30,098.60 | $267,061.40 | | 0.9434 |
| 2 | -$30,098.60 | $3,911.11 | -$3,751.65 | -$29,939.13 | -$26,645.72 | -$129,252.61 | $15,356.03 | -$14,742.57 | $252,318.84 | | 0.8900 |
| 3 | -$30,098.60 | $4,028.44 | -$3,789.16 | -$29,859.31 | -$25,070.46 | -$154,323.07 | $14,508.33 | -$15,590.26 | $236,728.57 | | 0.8396 |
| 4 | -$30,098.60 | $4,149.30 | -$3,827.05 | -$29,776.35 | -$23,585.66 | -$177,908.73 | $13,611.89 | -$16,486.70 | $220,241.87 | | 0.7921 |
| 5 | -$30,098.60 | $4,273.78 | -$3,865.32 | -$29,690.14 | -$22,186.20 | -$200,094.93 | $12,663.91 | -$17,434.69 | $202,807.18 | | 0.7473 |
| 6 | -$30,098.60 | $4,401.99 | -$3,903.98 | -$29,600.58 | -$20,867.24 | -$220,962.17 | $11,661.41 | -$18,437.18 | $184,370.00 | | 0.7050 |
| 7 | -$30,098.60 | $4,534.05 | -$3,943.02 | -$29,507.56 | -$19,624.22 | -$240,586.39 | $10,601.27 | -$19,497.32 | $164,872.68 | | 0.6651 |
| 8 | -$30,098.60 | $4,670.07 | -$3,982.45 | -$29,410.97 | -$18,452.81 | -$259,039.20 | $9,480.18 | -$20,618.42 | $144,254.26 | | 0.6274 |
| 9 | -$30,098.60 | $4,810.17 | -$4,022.27 | -$29,310.70 | -$17,348.96 | -$276,388.15 | $8,294.62 | -$21,803.98 | $122,450.28 | | 0.5919 |
| 10 | -$30,098.60 | $4,954.48 | -$4,062.49 | -$29,206.61 | -$16,308.82 | -$292,696.97 | $7,040.89 | -$23,057.71 | $99,392.57 | | 0.5584 |
| 11 | -$30,098.60 | $5,103.11 | -$4,103.12 | -$29,098.60 | -$15,328.78 | -$308,025.75 | $5,715.07 | -$24,383.52 | $75,009.05 | | 0.5268 |
| 12 | -$30,098.60 | $5,256.21 | -$4,144.15 | -$28,986.54 | -$14,405.42 | -$322,431.18 | $4,313.02 | -$25,785.58 | $49,223.47 | | 0.4970 |
| 13 | -$30,098.60 | $5,413.89 | -$4,185.59 | -$28,870.30 | -$13,535.52 | -$335,966.70 | $2,830.35 | -$27,268.25 | $21,955.23 | | 0.4688 |
| 14 | -$30,098.60 | $5,576.31 | -$4,227.45 | -$28,749.74 | -$12,716.04 | -$348,682.73 | $1,262.43 | -$28,836.17 | -$6,880.94 | | 0.4423 |
| 15 | -$30,098.60 | $5,743.60 | -$4,269.72 | -$28,624.72 | -$11,944.10 | -$360,626.83 | -$395.65 | -$30,494.25 | -$37,375.19 | | 0.4173 |
| 15 | | | | **Totals:** | $2,002.87 | -$358,623.96 | -$2,149.0737 | | | | |

Figure 9: Efficiency of Two Different Collector Types




# Breadth Topics

## Structural Load Breadth Evaluation of Collectors

The suggested placement of the collector is to be on the cafeteria roof and the gymnasium roof. This is a large enough area but, the roof is not designed to hold the extra weight that a solar collectors would entail. The two roofs are supported by a LH-series joist system. The cafeteria spans 57' with a 32LH06 and the gymnasium spans 64' with a 32LH07. To determine if these joists are adequate the Load and Resistance Factor Design (LRFD) method was used. The loads on the roof are to be a dead load of 7 psf(2.5 psf metal decking and 1.5 psf per inch of the 3" rigid insulation). The snow load was assumed to be the same as that in the original design, 19.25 psf. The roof live load is assumed to be 20 psf. The collectors are 153 lbs each. The projected area onto the roof, taking into consideration the tilt, is 30.64 sqft. The implies almost 5.5 psf additional dead load. To ensure the calculations were correct, the formulas were applied to the current design.

$$w_{LL} = (1.2D + 1.6S + L_r)(joist\ spacing) + 1.2(joist\ weight)$$

$$w_{TL} = 1.2(D + S(or\ L_r))(joist\ spacing) + (joist\ weight)$$

where

- D = Dead Load
- S = Snow Load
- $L_r$= Roof Live Load

Figure 10: Placement of Solar Array on Cafe and Gym Roofs

For the cafeteria the span is 57' at 4' joist spacing.

$$w_{LL} = (1.2(12.5) + 1.6(19.25) + 20)(4) + 1.2(14) = 280\ plf$$

$$w_{TL} = 1.2(12.5 + 20))(4) + (14) = 167.6\ plf$$

From the Standard Specifications; Load Tables and Weight Tables for Steel Joists and Joist Girders catalog, specifically from the Standard LRFD Load Table for Longspan Steel Joists, LH-Series, a 32LH06 can support up to a $w_{LL}$=388 plf and a $w_{TL}$=145 plf. With the additional dead load, the joist cannot support the the total load. It is suggested to change the type of joist to either a 32LH08 or a 28LH06. A re-evaluation of the calculation with the new joist weight is preformed. Each suggested member still is sufficient to support the load.

For the Gymnasium, the same procedure was applied. The spacing remains the same, 4' O.C..The calculated values for $w_{LL}$ and $w_{TL}$ remain the same. 32LH07 can support up to a $w_{LL}$=360 plf and a $w_{TL}$=116 plf. Once again the joist system does not meet the requirement to support the additional dead load. It is suggested to change the member to a 32LH10 or a 36LH09. A re-evaluation of the calculation with the new joist weight is preformed. Each suggested member still is sufficient to support the load.

## Acoustics Breadth Evaluation

The current design has the mechanical room encased by a exposing glass wall. This was decided so that students of Twin Rivers Elementary/Intermediate would have a clearer understanding on mechanical and electrical systems at a young age. However, This proposed wall system could lead to loud HVAC noise entering the corridor and other adjacent spaces. 28% of the mechanical space perimeter wall is constructed of of an interior storefront glazing.

Figure 11: Mechanical Space in Relation to Ancillary Space


The background noise level (BNL) is a clear indication as to how much acoustical treatment is needed to reduce the mechanical room noise entering the corridor. If the BNL is too high for a corridor it will be assumed that the sound will be transferred into core learning spaces, which would interrupt the learning process. According to the American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools S12.60, The BNL for a corridor shall not exceed 45 dBA. 45 dBA corresponds to a Noise Criterion curve of NC-45. However, The corridor is considered to be a ancillary learning space due to the informative LCD screens. The space will be used in tours of the building. This means that the sound transmission class (STC) of the partition between the Mech. room and the corridor must meet a value of 55. The following Chart describes partition STC for ancillary learning spaces adjacent to Mechanical spaces. The STC requirement is more restrictive. This is the design goal to be met.

Table 9: STC for Ancillary Learning Spaces from ANSI-ASA

**Table B.1 — Minimum STC ratings recommended between an ancillary space and an adjacent space**

| Receiving ancillary learning space | Adjacent space: Corridor or staircase [a)], common-use, and public-use toilet and bathing room [b)] | Music room | Office or conference room [a)] | Mechanical equipment room [f)], cafeteria, gymnasium, or indoor swimming pool |
|---|---|---|---|---|
| Corridor used as ancillary learning space | 45 | 60[c)] | 45[d)] | 55[c)] |
| Music room | 45 | 60 | 60[e)] | 60 |
| Office or conference room | 45 [d)] | 60[g)] | 45[d)] | 60 |

c) When the corridor will not be used as an ancillary learning space, the minimum STC rating may be reduced to not less than 45. Use of corridors as ancillary learning spaces should be avoided when they are located next to the noisy spaces indicated in the table by the high STC ratings.

Ancillary spaces are defined as "spaces where good communication is important to a students educational progress but for which the primary educational functions are informal learning, social interaction, or similar activity other than formal instruction. Ancillary learning spaces include corridors, cafeterias, and gymnasia." The Wall separating the two spaces contains a large pane of clear 1/4" annealed float glass. The STC value is 29. In order to reach a STC of at least 60, a special kind of sound proofing glass must be installed. This system is much like those used in recording studios. A similar design to the below figure, a sound proof window can reach 56-62 STC. This is more costly but simply adding another sheet of glass, to create a duel pane window, raises the STC of the to no more than 32.

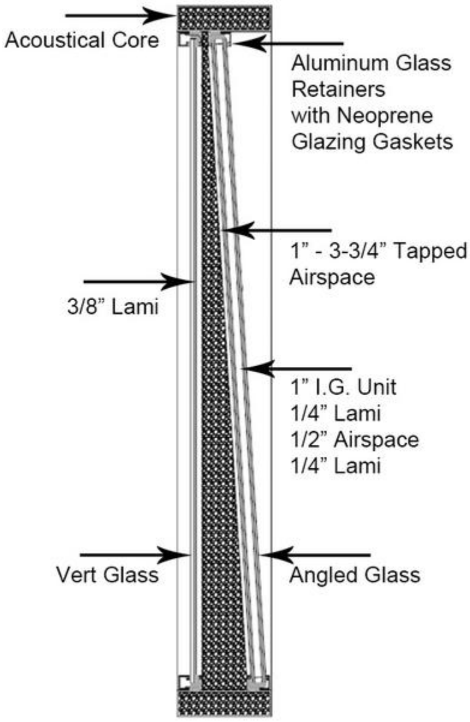



Figure 12: Soundproof Glass System

# Conclusions

The system is *not* recommended to Mckeesport Area School District, unless the client specifically states that the educational gain from the system out weighs the overall cost of the system. The benefit of the system is fairly small compared to the total building load. The load that it is reducing is the auxiliary load itself. This means this load is not constantly needed like the system model implies. The domestic hot water load will be sufficiently reduced which is the large positive to the proposed system. The needed changes to the structural system are too large to easily fix. The system would cost much more than the life cycle analysis suggests.

The acoustic treatment in the commons area is very important if the corridor is to be considered a space for learning. The mechanical room can be very noisy and can impact how the students and faculty feel about that particular space in the building.

# Appednix A

ECT Array Sizing

| Company | Model | Weight | working temp | Cost/panel | type | Size |
|---|---|---|---|---|---|---|
| erican Solarw | ASW52B | | | | ETC | 40000.0 |

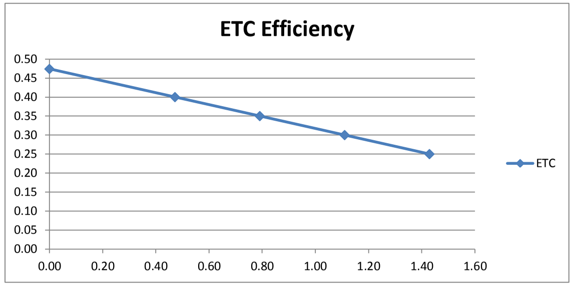
Constants

| | | | |
|---|---|---|---|
| γ= | 0.0 | ρ= | 0.2 |
| ϕ= | 40.0 | β= | 40.0 |
| $A(Ft^2)$= | 30.8 | $F_r$*τα= | 0.474 |
| $m_{dot}$ (Lb/H)= | 452.4 | $F_r$*Ul(btu/hr $ft^2$ °F)= | 0.1567 |
| Number of Series in Array | 30.000 | | |

30% propylene glycol solution

| T (°F) | $C_p$(btu/lbF)= |
|---|---|
| 165.0 | 0.943 |
| 180.0 | 0.947 |
| 195.0 | 0.952 |
| 210.0 | 0.958 |

| | |
|---|---|
| Freezing point | 7.0 |
| Boiling Point | 216.0 |
| torage Tank Tem | 150.0 |



# ECT Array Sizing
## Equinox and Solstice

12/21 | n 335.0 | δ -22.1 | η at noon 0.2

| | | TMY3 Data | | | | | | | | Solar Calculations | | | Typical Series Collector 1 | | Collector 2 | | Collector 3 | | Array Calculations | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Time | End Time | DB Temp(°C ) | Ta(°F) | GHI (Wh/m^2) | GHI (Btu/HrFt$^2$) | DNI (Wh/m^2) | DNI (Btu/HrFt$^2$) | DHI (Wh/m^2) | DHI (Btu/HrFt$^2$) | Hour, $\omega_{mid}$ (Deg) | Incedent, θ (deg) | Gt (Btu/HrFt2) | Ti (°F) | Qu | Ti (°F) | Qu | Ti (°F) | Qu | Tsupply (°F) | Δ T of Array (F) | Total Qu of Array |
| 7:00 AM | 8:00 AM | 2.0 | 35.6 | 1.0 | 0.3 | 0.0 | 0.0 | 1.0 | 0.3 | -67.5 | 69.2 | 0.3 | 150 | -547.719 | 148.7161 | -541.525 | 147.4467 | -535.4 | 146.1916 | 3.80840411 | -48739.309 |
| 8:00 AM | 9:00 AM | 1.0 | 33.8 | 42.0 | 13.3 | 13.0 | 4.1 | 40.0 | 12.7 | -52.5 | 55.7 | 13.8 | 149.9374 | -358.481 | 149.0971 | -354.427 | 148.2662 | -350.419 | 147.4448 | 2.4925937 | -31899.791 |
| 9:00 AM | 10:00 AM | 1.0 | 33.8 | 81.0 | 25.7 | 15.0 | 4.8 | 77.0 | 24.4 | -37.5 | 42.7 | 25.6 | 149.8749 | -185.773 | 149.4394 | -183.672 | 149.0088 | -181.595 | 148.5831 | 1.29171663 | -16531.17 |
| 10:00 AM | 11:00 AM | 2.0 | 35.6 | 103.0 | 32.7 | 34.0 | 10.8 | 90.0 | 28.5 | -22.5 | 31.1 | 35.2 | 149.8124 | -37.7104 | 149.724 | -37.2839 | 149.6366 | -36.8623 | 149.5502 | 0.26220825 | -3355.6966 |
| 11:00 AM | 12:00 PM | 2.0 | 35.6 | 178.0 | 56.4 | 40.0 | 12.7 | 161.0 | 51.0 | -7.5 | 23.3 | 58.0 | 149.7499 | 295.9977 | 150.4438 | 292.6502 | 151.1298 | 289.3406 | 151.8081 | -2.05813463 | 26339.658 |
| 12:00 PM | 1:00 PM | 2.0 | 35.6 | 135.0 | 42.8 | 23.0 | 7.3 | 125.0 | 39.6 | 7.5 | 23.3 | 42.7 | 134.4381 | 145.9736 | 134.7803 | 144.3228 | 135.1186 | 142.6906 | 135.4531 | -1.01498528 | 12989.609 |
| 1:00 PM | 2:00 PM | 3.0 | 37.4 | 277.0 | 87.8 | 118.0 | 37.4 | 229.0 | 72.6 | 22.5 | 31.1 | 98.2 | 123.9391 | 1014.823 | 126.318 | 1003.347 | 128.67 | 991.9997 | 130.9954 | -7.05628162 | 90305.094 |
| 2:00 PM | 3:00 PM | 3.0 | 37.4 | 123.0 | 39.0 | 24.0 | 7.6 | 115.0 | 36.5 | 37.5 | 42.7 | 38.7 | 127.7369 | 128.7261 | 128.0387 | 127.2703 | 128.337 | 125.831 | 128.632 | -0.89505958 | 11454.821 |
| 3:00 PM | 4:00 PM | 4.0 | 39.2 | 68.0 | 21.6 | 17.0 | 5.4 | 65.0 | 20.6 | 52.5 | 55.7 | 21.7 | 124.0521 | -92.2029 | 123.836 | -91.1602 | 123.6223 | -90.1292 | 123.411 | 0.64110639 | -8204.7707 |
| 4:00 PM | 5:00 PM | 4.0 | 39.2 | 21.0 | 6.7 | 1.0 | 0.3 | 21.0 | 6.7 | 67.5 | 69.2 | 6.1 | 124.0098 | -319.482 | 123.2609 | -315.869 | 122.5205 | -312.296 | 121.7884 | 2.2214235 | -28429.401 |

Hourly Average: 35272.295

3/20 | n 335.0 | δ -22.1 | η at noon 0.5

| | | TMY3 Data | | | | | | | | Solar Calculations | | | Typical Series Collector 1 | | Collector 2 | | Collector 3 | | Array Calculations | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Time | End Time | DB Temp(°C ) | Ta(°F) | GHI (Wh/m^2) | GHI (Btu/HrFt$^2$) | DNI (Wh/m^2) | DNI (Btu/HrFt$^2$) | DHI (Wh/m^2) | DHI (Btu/HrFt$^2$) | Hour, $\omega_{mid}$ (Deg) | Incedent, θ (deg) | Gt (Btu/HrFt2) | Ti (°F) | Qu | Ti (°F) | Qu | Ti (°F) | Qu | Tsupply (°F) | Δ T of Array (F) | Total Qu of Array |
| 6:00 AM | 7:00 AM | -7.0 | 19.4 | 1.0 | 0.3 | 64.0 | 20.3 | 1.0 | 0.3 | -82.5 | 83.1 | 2.7 | 150 | -590.079 | 148.6168 | -583.406 | 147.2492 | -576.808 | 145.8971 | 4.10294562 | -52508.801 |
| 7:00 AM | 8:00 AM | -5.0 | 23.0 | 158.0 | 50.1 | 344.0 | 109.0 | 90.0 | 28.5 | -67.5 | 69.2 | 65.0 | 149.9374 | 336.3313 | 150.7258 | 332.5277 | 151.5053 | 328.7671 | 152.276 | -2.33858286 | 29928.786 |
| 8:00 AM | 9:00 AM | -3.0 | 26.6 | 362.0 | 114.8 | 641.0 | 203.2 | 118.0 | 37.4 | -52.5 | 55.7 | 150.3 | 116.4214 | 1759.778 | 120.5466 | 1739.876 | 124.6251 | 1720.2 | 128.6575 | -12.2361065 | 156595.61 |
| 9:00 AM | 10:00 AM | -1.0 | 30.2 | 532.0 | 168.6 | 747.0 | 236.8 | 130.0 | 41.2 | -37.5 | 42.7 | 214.4 | 38.39285 | 3088.333 | 45.63236 | 3053.407 | 52.78999 | 3018.876 | 59.86668 | -21.4738346 | 274818.49 |
| 10:00 AM | 11:00 AM | 2.0 | 35.6 | 669.0 | 212.1 | 806.0 | 255.5 | 139.0 | 44.1 | -22.5 | 31.1 | 262.6 | 10.19477 | 3953.36 | 19.46203 | 3908.651 | 28.62448 | 3864.448 | 37.68331 | -27.488546 | 351793.74 |
| 11:00 AM | 12:00 PM | 4.0 | 39.2 | 768.0 | 243.5 | 850.0 | 269.5 | 147.0 | 46.6 | -7.5 | 23.3 | 294.3 | 14.3858 | 4414.161 | 24.73324 | 4364.241 | 34.96366 | 4314.885 | 45.07839 | -30.6925921 | 392798.58 |
| 12:00 PM | 1:00 PM | 6.0 | 42.8 | 799.0 | 253.3 | 864.0 | 273.9 | 147.0 | 46.6 | 7.5 | 23.3 | 298.7 | 38.4395 | 4378.314 | 48.70291 | 4328.799 | 58.85025 | 4279.844 | 68.88284 | -30.4433406 | 389608.7 |
| 1:00 PM | 2:00 PM | 7.0 | 44.6 | 765.0 | 242.5 | 789.0 | 250.1 | 191.0 | 60.5 | 22.5 | 31.1 | 273.2 | 71.51143 | 3856.417 | 80.55144 | 3812.804 | 89.48921 | 3769.685 | 98.32591 | -26.8144798 | 343167.16 |
| 2:00 PM | 3:00 PM | 8.0 | 46.4 | 597.0 | 189.2 | 535.0 | 169.6 | 249.0 | 78.9 | 37.5 | 42.7 | 198.8 | 104.6693 | 2619.083 | 110.8089 | 2589.463 | 116.8789 | 2560.179 | 122.8804 | -18.2110365 | 233061.75 |
| 3:00 PM | 4:00 PM | 7.0 | 44.6 | 509.0 | 161.4 | 583.0 | 184.8 | 202.0 | 64.0 | 52.5 | 55.7 | 164.6 | 127.4948 | 2000.858 | 132.1851 | 1978.23 | 136.8223 | 1955.858 | 141.4072 | -13.9123883 | 178048.38 |
| 4:00 PM | 5:00 PM | 7.0 | 44.6 | 186.0 | 59.0 | 69.0 | 21.9 | 161.0 | 51.0 | 67.5 | 69.2 | 54.2 | 145.7531 | 302.7786 | 146.4629 | 299.3545 | 147.1646 | 295.9691 | 147.8584 | -2.10528391 | 26943.066 |
| 5:00 PM | 6:00 PM | 6.0 | 42.8 | 123.0 | 39.0 | 266.0 | 84.3 | 74.0 | 23.5 | 82.5 | 83.1 | 31.8 | 148.4197 | -45.2598 | 148.3136 | -44.7479 | 148.2087 | -44.2419 | 148.105 | 0.31470088 | -4027.4884 |

Hourly Average: 237676.43

6/21 | n 183.0 | δ 23.0 | η at noon 0.5

| | | TMY3 Data | | | | | | | | Solar Calculations | | | Typical Series Collector 1 | | Collector 2 | | Collector 3 | | Array Calculations | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Time | End Time | DB Temp(°C ) | Ta(°F) | GHI (Wh/m^2) | GHI (Btu/HrFt$^2$) | DNI (Wh/m^2) | DNI (Btu/HrFt$^2$) | DHI (Wh/m^2) | DHI (Btu/HrFt$^2$) | Hour, $\omega_{mid}$ (Deg) | Incedent, θ (deg) | Gt (Btu/HrFt2) | Ti (°F) | Qu | Ti (°F) | Qu | Ti (°F) | Qu | Tsupply (°F) | Δ T of Array (F) | Total Qu of Array |
| 5:00 AM | 6:00 AM | 19.0 | 66.2 | 59.0 | 18.7 | 43.0 | 13.6 | 54.0 | 17.1 | -97.5 | 96.9 | 13.9 | 150 | -201.254 | 149.5282 | -198.978 | 149.0618 | -196.728 | 148.6006 | 1.39936235 | -17908.802 |
| 6:00 AM | 7:00 AM | 19.0 | 66.2 | 209.0 | 66.3 | 345.0 | 109.4 | 111.0 | 35.2 | -82.5 | 83.1 | 45.8 | 149.9374 | 263.5892 | 150.5553 | 260.6082 | 151.1662 | 257.661 | 151.7702 | -1.83279123 | 23455.751 |
| 7:00 AM | 8:00 AM | 20.0 | 68.0 | 391.0 | 123.9 | 546.0 | 173.1 | 138.0 | 43.7 | -67.5 | 69.4 | 102.5 | 119.3148 | 1247.537 | 122.2392 | 1233.429 | 125.1305 | 1219.48 | 127.9891 | -8.67439065 | 111013.38 |
| 8:00 AM | 9:00 AM | 22.0 | 71.6 | 540.0 | 171.2 | 537.0 | 170.2 | 202.0 | 64.0 | -52.5 | 55.9 | 155.9 | 42.7284 | 2413.884 | 48.38691 | 2386.586 | 53.98141 | 2359.595 | 59.51265 | -16.7842484 | 214801.96 |
| 9:00 AM | 10:00 AM | 24.0 | 75.2 | 727.0 | 230.5 | 684.0 | 216.8 | 200.0 | 63.4 | -37.5 | 43.1 | 219.7 | 11.51923 | 3512.049 | 19.75199 | 3472.331 | 27.89165 | 3433.062 | 35.93925 | -24.4200185 | 312523.25 |
| 10:00 AM | 11:00 AM | 22.0 | 71.6 | 848.0 | 268.8 | 730.0 | 231.4 | 209.0 | 66.3 | -22.5 | 31.8 | 261.5 | 13.72048 | 4094.72 | 23.31911 | 4048.413 | 32.80919 | 4002.629 | 42.19194 | -28.4714562 | 364372.86 |
| 11:00 AM | 12:00 PM | 24.0 | 75.2 | 932.0 | 295.4 | 782.0 | 247.9 | 197.0 | 62.4 | -7.5 | 24.2 | 288.2 | 36.1054 | 4393.484 | 46.40437 | 4343.797 | 56.58687 | 4294.673 | 66.65422 | -30.5488201 | 390958.61 |
| 12:00 PM | 1:00 PM | 26.0 | 78.8 | 936.0 | 296.7 | 714.0 | 226.3 | 253.0 | 80.2 | 7.5 | 24.2 | 284.2 | 70.66906 | 4186.323 | 80.48242 | 4138.979 | 90.1848 | 4092.171 | 99.77745 | -29.1083853 | 372524.17 |
| 1:00 PM | 2:00 PM | 26.0 | 78.8 | 928.0 | 294.2 | 790.0 | 250.4 | 196.0 | 62.1 | 22.5 | 31.8 | 274.6 | 108.4948 | 3863.698 | 117.5519 | 3820.003 | 126.5065 | 3776.803 | 135.3599 | -26.8651117 | 343815.14 |
| 2:00 PM | 3:00 PM | 25.0 | 77.0 | 831.0 | 263.4 | 752.0 | 238.4 | 192.0 | 60.9 | 37.5 | 43.1 | 233.9 | 146.2565 | 3078.876 | 153.4739 | 3044.057 | 160.6096 | 3009.631 | 167.6646 | -21.4080744 | 273976.9 |
| 3:00 PM | 4:00 PM | 26.0 | 78.8 | 683.0 | 216.5 | 701.0 | 222.2 | 168.0 | 53.3 | 52.5 | 55.9 | 176.6 | 177.3198 | 2100.795 | 182.2236 | 2077.137 | 187.0467 | 2053.868 | 191.8157 | -14.4959095 | 186954 |
| 4:00 PM | 5:00 PM | 25.0 | 77.0 | 514.0 | 162.9 | 661.0 | 209.5 | 127.0 | 40.3 | 67.5 | 69.4 | 113.1 | 198.6176 | 1064.042 | 201.0728 | 1052.198 | 203.5007 | 1040.484 | 205.9015 | -7.28396368 | 94701.734 |
| 5:00 PM | 6:00 PM | 25.0 | 77.0 | 335.0 | 106.2 | 557.0 | 176.6 | 105.0 | 33.3 | 82.5 | 83.1 | 53.1 | 210.3637 | 131.0644 | 210.6661 | 129.6054 | 210.9652 | 128.1626 | 211.2609 | -0.89720904 | 11664.975 |
| 6:00 PM | 7:00 PM | 24.0 | 75.2 | 148.0 | 46.9 | 243.0 | 77.0 | 91.0 | 28.8 | 97.5 | 96.9 | 17.3 | 211.4748 | -404.774 | 210.5408 | -400.268 | 209.6172 | -395.813 | 208.7039 | 2.77090595 | -36025.66 |
| 7:00 PM | 8:00 PM | 22.0 | 71.6 | 12.0 | 3.8 | 0.0 | 0.0 | 12.0 | 3.8 | 112.5 | 110.6 | 3.4 | 211.3641 | -623.972 | 209.9243 | -617.026 | 208.5006 | -610.157 | 207.0927 | 4.27143435 | -55534.632 |

Hourly Average: 225063.56

| 9/23 | n | 281.0 | δ | -7.0 | η at noon | 0.5 | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TMY3 Data | | | | | | | | | | Solar Calculations | | | Typical Series Collector 1 | | Collector 2 | | Collector 3 | | Array Calculations | | |
| Start Time | End Time | DB Temp(°C ) | Ta(°F) | GHI (Wh/m^2) | GHI (Btu/HrFt$^2$) | DNI (Wh/m^2) | DNI (Btu/HrFt$^2$) | DHI (Wh/m^2) | DHI (Btu/HrFt$^2$) | Hour, $\omega_{mid}$ (Deg) | Incedent, θ (deg) | Gt (Btu/HrFt2) | Ti (°F) | Qu | Ti (°F) | Qu | Ti (°F) | Qu | Tsupply (°F) | Δ T of Array (F) | Total Qu of Array |
| 6:00 AM | 7:00 AM | 13.0 | 55.4 | 12.0 | 3.8 | 0.0 | 0.0 | 12.0 | 3.8 | -82.5 | 82.6 | 3.4 | 150 | -406.082 | 149.0481 | -401.49 | 148.1069 | -396.949 | 147.1764 | 2.82357592 | -36135.645 |
| 7:00 AM | 8:00 AM | 13.0 | 55.4 | 47.0 | 14.9 | 0.0 | 0.0 | 47.0 | 14.9 | -67.5 | 67.7 | 13.5 | 149.9374 | -259.056 | 149.3301 | -256.126 | 148.7297 | -253.23 | 148.1361 | 1.8012697 | -23052.344 |
| 8:00 AM | 9:00 AM | 14.0 | 57.2 | 117.0 | 37.1 | 76.0 | 24.1 | 83.0 | 26.3 | -52.5 | 52.8 | 38.7 | 149.8749 | 116.9265 | 150.149 | 115.6041 | 150.4199 | 114.2968 | 150.6879 | -0.81301445 | 10404.821 |
| 9:00 AM | 10:00 AM | 17.0 | 62.6 | 519.0 | 164.5 | 403.0 | 127.8 | 281.0 | 89.1 | -37.5 | 38.0 | 183.1 | 113.8233 | 2424.422 | 119.5065 | 2397.004 | 125.1254 | 2369.896 | 130.6808 | -16.8575188 | 215739.66 |
| 10:00 AM | 11:00 AM | 18.0 | 64.4 | 674.0 | 213.7 | 632.0 | 200.3 | 233.0 | 73.9 | -22.5 | 23.5 | 254.0 | 43.47797 | 3805.997 | 52.39979 | 3762.955 | 61.22071 | 3720.399 | 69.94188 | -26.4639047 | 338680.56 |
| 11:00 AM | 12:00 PM | 19.0 | 66.2 | 766.0 | 242.8 | 801.0 | 253.9 | 157.0 | 49.8 | -7.5 | 10.2 | 299.5 | 23.56988 | 4575.56 | 34.29567 | 4523.814 | 44.90016 | 4472.654 | 55.38472 | -31.814835 | 407160.86 |
| 12:00 PM | 1:00 PM | 21.0 | 69.8 | 727.0 | 230.5 | 655.0 | 207.6 | 221.0 | 70.1 | 7.5 | 10.2 | 271.6 | 34.94115 | 4130.685 | 44.62409 | 4083.971 | 54.19752 | 4037.785 | 63.66268 | -28.7215276 | 367573.23 |
| 1:00 PM | 2:00 PM | 21.0 | 69.8 | 746.0 | 236.5 | 839.0 | 266.0 | 133.0 | 42.2 | 22.5 | 23.5 | 286.7 | 55.70267 | 4250.444 | 65.66634 | 4202.376 | 75.51733 | 4154.851 | 85.25691 | -29.5542388 | 378230.13 |
| 2:00 PM | 3:00 PM | 22.0 | 71.6 | 636.0 | 201.6 | 802.0 | 254.2 | 121.0 | 38.4 | 37.5 | 38.0 | 238.8 | 87.28333 | 3408.346 | 95.27299 | 3369.801 | 103.1723 | 3331.692 | 110.9823 | -23.6989517 | 303295.16 |
| 3:00 PM | 4:00 PM | 21.0 | 69.8 | 475.0 | 150.6 | 732.0 | 232.0 | 102.0 | 32.3 | 52.5 | 52.8 | 172.3 | 115.2506 | 2294.443 | 120.6291 | 2268.495 | 125.9468 | 2242.84 | 131.2043 | -15.9537464 | 204173.34 |
| 4:00 PM | 5:00 PM | 21.0 | 69.8 | 281.0 | 89.1 | 598.0 | 189.6 | 76.0 | 24.1 | 67.5 | 67.7 | 95.4 | 134.3159 | 1080.132 | 136.8479 | 1067.916 | 139.3513 | 1055.839 | 141.8263 | -7.5103844 | 96116.624 |
| 5:00 PM | 6:00 PM | 19.0 | 66.2 | 93.0 | 29.5 | 314.0 | 99.5 | 44.0 | 13.9 | 82.5 | 82.6 | 25.9 | 145.5587 | -4.94402 | 145.5471 | -4.88811 | 145.5357 | -4.83283 | 145.5244 | 0.03437682 | -439.94877 |
| 6:00 PM | 7:00 PM | 18.0 | 64.4 | 2.0 | 0.6 | 11.0 | 3.5 | 2.0 | 0.6 | 97.5 | 97.4 | 0.1 | 145.4996 | -389.464 | 144.5867 | -385.059 | 143.684 | -380.705 | 142.7916 | 2.70802473 | -34656.841 |
| | | | | | | | | | | | | | | | | | | | | Hourly Average: | 257930.49 |

## Beginning and End of Winter Break

| 11/30 | n | 334.0 | δ | -22.0 | η at noon | 0.5 | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TMY3 Data | | | | | | | | | | Solar Calculations | | | Typical Series Collector 1 | | Collector 2 | | Collector 3 | | Array Calculations | | |
| Start Time | End Time | DB Temp(°C ) | Ta(°F) | GHI (Wh/m^2) | GHI (Btu/HrFt2) | DNI (Wh/m^2) | DNI (Btu/HrFt2) | DHI (Wh/m^2) | DHI (Btu/HrFt2) | Hour, ωmid (Deg) | Incedent, θ (deg) | Gt (Btu/HrFt2) | Ti (°F) | Qu | Ti (°F) | Qu | Ti (°F) | Qu | Tsupply (°F) | Δ T of Array (F) | Total Qu of Array |
| 6:00 AM | 7:00 AM | 0.0 | 32.0 | 3.0 | 1.0 | 43.0 | 13.6 | 2.0 | 0.6 | -82.5 | 83.0 | 2.2 | 150 | -536.713 | 148.7419 | -530.643 | 147.498 | -524.642 | 146.2681 | 3.73188042 | -47759.972 |
| 7:00 AM | 8:00 AM | 1.0 | 33.8 | 133.0 | 42.2 | 174.0 | 55.2 | 103.0 | 32.7 | -67.5 | 69.2 | 49.4 | 149.9374 | 160.3393 | 150.3133 | 158.526 | 150.6849 | 156.7332 | 151.0523 | -1.11487292 | 14267.954 |
| 8:00 AM | 9:00 AM | 2.0 | 35.6 | 91.0 | 28.8 | 0.0 | 0.0 | 91.0 | 28.8 | -52.5 | 55.6 | 26.1 | 133.0577 | -88.6907 | 132.8498 | -87.6876 | 132.6442 | -86.696 | 132.441 | 0.61668484 | -7892.2278 |
| 9:00 AM | 10:00 AM | 2.0 | 35.6 | 103.0 | 32.7 | 0.0 | 0.0 | 103.0 | 32.7 | -37.5 | 42.6 | 29.6 | 133.0083 | -38.1471 | 132.9189 | -37.7157 | 132.8305 | -37.2891 | 132.7431 | 0.26524473 | -3394.557 |
| 10:00 AM | 11:00 AM | 3.0 | 37.4 | 117.0 | 37.1 | 0.0 | 0.0 | 117.0 | 37.1 | -22.5 | 31.0 | 33.6 | 132.959 | 29.46447 | 133.0281 | 29.13125 | 133.0964 | 28.8018 | 133.1639 | -0.20487268 | 2621.9258 |
| 11:00 AM | 12:00 PM | 4.0 | 39.2 | 202.0 | 64.0 | 18.0 | 5.7 | 194.0 | 61.5 | -7.5 | 23.2 | 61.0 | 133.2503 | 436.9458 | 134.2746 | 432.0043 | 135.2872 | 427.1187 | 136.2885 | -3.03817629 | 38882.064 |
| 12:00 PM | 1:00 PM | 4.0 | 39.2 | 235.0 | 74.5 | 89.0 | 28.2 | 197.0 | 62.4 | 7.5 | 23.2 | 82.8 | 119.5803 | 820.6371 | 121.504 | 811.3564 | 123.406 | 802.1807 | 125.2864 | -5.70606311 | 73025.227 |
| 1:00 PM | 2:00 PM | 4.0 | 39.2 | 222.0 | 70.4 | 216.0 | 68.5 | 149.0 | 47.2 | 22.5 | 31.0 | 102.0 | 116.8899 | 1113.64 | 119.5005 | 1101.045 | 122.0815 | 1088.593 | 124.6333 | -7.743371 | 99098.347 |
| 2:00 PM | 3:00 PM | 4.0 | 39.2 | 115.0 | 36.5 | 106.0 | 33.6 | 92.0 | 29.2 | 37.5 | 42.6 | 51.3 | 89.05351 | 508.3437 | 90.24514 | 502.5948 | 91.4233 | 496.9109 | 92.58813 | -3.53462144 | 45235.485 |
| 3:00 PM | 4:00 PM | 4.0 | 39.2 | 15.0 | 4.8 | 8.0 | 2.5 | 15.0 | 4.8 | 52.5 | 55.6 | 5.7 | 89.78617 | -160.278 | 89.41046 | -158.465 | 89.03899 | -156.673 | 88.67173 | 1.11444365 | -14262.461 |
| | | | | | | | | | | | | | | | | | | | | Hourly Average: | 45521.834 |

| 1/12 | n | 12.0 | δ | -21.8 | η at noon | 0.5 | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TMY3 Data | | | | | | | | | | Solar Calculations | | | Typical Series Collector 1 | | Collector 2 | | Collector 3 | | Array Calculations | | |
| Start Time | End Time | DB Temp(°C ) | Ta(°F) | GHI (Wh/m^2) | GHI (Btu/HrFt2) | DNI (Wh/m^2) | DNI (Btu/HrFt2) | DHI (Wh/m^2) | DHI (Btu/HrFt2) | Hour, ωmid (Deg) | Incedent, θ (deg) | Gt (Btu/HrFt2) | Ti (°F) | Qu | Ti (°F) | Qu | Ti (°F) | Qu | Tsupply (°F) | Δ T of Array (F) | Total Qu of Array |
| 8:00 AM | 9:00 AM | 0.0 | 32.0 | 29.0 | 9.2 | 0.0 | 0.0 | 29.0 | 9.2 | -52.5 | 55.6 | 8.3 | 150 | -447.707 | 148.9505 | -442.644 | 147.9129 | -437.638 | 146.887 | 3.11300102 | -39839.658 |
| 9:00 AM | 10:00 AM | 1.0 | 33.8 | 114.0 | 36.1 | 49.0 | 15.5 | 101.0 | 32.0 | -37.5 | 42.6 | 40.5 | 149.9374 | 31.25396 | 150.0107 | 30.9005 | 150.0831 | 30.55105 | 150.1547 | -0.21731538 | 2781.1654 |
| 10:00 AM | 11:00 AM | 2.0 | 35.6 | 164.0 | 52.0 | 68.0 | 21.6 | 139.0 | 44.1 | -22.5 | 31.0 | 58.6 | 150.2361 | 301.8177 | 150.9436 | 298.4044 | 151.6431 | 295.0297 | 152.3347 | -2.09860233 | 26857.556 |
| 11:00 AM | 12:00 PM | 2.0 | 35.6 | 427.0 | 135.4 | 779.0 | 246.9 | 84.0 | 26.6 | -7.5 | 23.2 | 253.7 | 128.7677 | 3252.384 | 136.3918 | 3215.603 | 143.9297 | 3179.237 | 151.3823 | -22.6145166 | 289416.74 |
| 12:00 PM | 1:00 PM | 3.0 | 37.4 | 338.0 | 107.1 | 449.0 | 142.3 | 131.0 | 41.5 | 7.5 | 23.2 | 170.0 | 76.06988 | 2294.33 | 81.44812 | 2268.383 | 86.76555 | 2242.73 | 92.02284 | -15.9529631 | 204163.31 |
| 1:00 PM | 2:00 PM | 4.0 | 39.2 | 425.0 | 134.7 | 773.0 | 245.0 | 89.0 | 28.2 | 22.5 | 31.0 | 238.0 | 43.92488 | 3449.747 | 52.0116 | 3410.733 | 60.00686 | 3372.161 | 67.9117 | -23.9868171 | 306979.21 |
| 2:00 PM | 3:00 PM | 4.0 | 39.2 | 339.0 | 107.5 | 714.0 | 226.3 | 80.0 | 25.4 | 37.5 | 42.6 | 191.4 | 45.68752 | 2761.665 | 52.16127 | 2730.433 | 58.56181 | 2699.554 | 64.88996 | -19.2024411 | 245749.58 |
| 3:00 PM | 4:00 PM | 4.0 | 39.2 | 92.0 | 29.2 | 31.0 | 9.8 | 85.0 | 26.9 | 52.5 | 55.6 | 30.0 | 52.84084 | 372.2214 | 53.71338 | 368.0119 | 54.57605 | 363.8501 | 55.42897 | -2.58813429 | 33122.503 |
| 4:00 PM | 5:00 PM | 4.0 | 39.2 | 69.0 | 21.9 | 3.0 | 1.0 | 68.0 | 21.6 | 67.5 | 69.2 | 19.9 | 54.2676 | 217.405 | 54.77723 | 214.9463 | 55.2811 | 212.5155 | 55.77927 | -1.51166268 | 19346.002 |
| | | | | | | | | | | | | 235.0 | | | | | | | | Hourly Average: | 141052.01 |

| Company | Model | Weight | working temp | Cost/panel | type |
|---|---|---|---|---|---|
| Caleffi | NAS10410 | 153.0 | .-40 to 350 | 3625.0 | FPC |

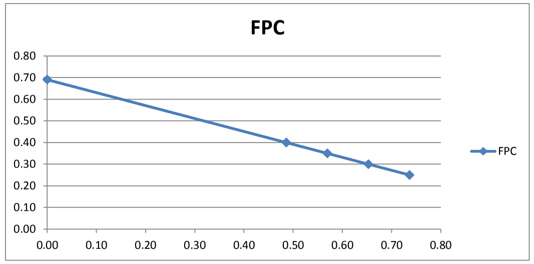
Constants

| | | | |
|---|---|---|---|
| γ= | 0.0 | ρ= | 0.2 |
| ϕ= | 40.0 | β= | 40.0 |
| $A(Ft^2)$= | 39.9 | $F_r$*τα= | 0.691 |
| $m_{dot}$ (Lb/H)= | 345.9 | $F_r$*Ul(btu/hr $ft^2$ °F)= | 0.5988 |
| Number of Series in Array | 30.000 | | |

30% propylene glycol solution

| T (°F) | $C_p$(btu/lbF)= |
|---|---|
| 165.0 | 0.943 |
| 180.0 | 0.947 |
| 195.0 | 0.952 |
| 210.0 | 0.958 |

| | |
|---|---|
| Freezing point | 7.0 |
| Boiling Point | 216.0 |
| torage Tank Tem | 150.0 |



# Collector Sizing
## Equinox and Solstice

| 12/21 | n | 335.0 | δ | -22.1 | η at noon | 0.0 | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Typical Series | | | | | | | | |
| TMY3 Data | | | | | | | | | | Solar Calculations | | | Collector 1 | | Collector 2 | | Collector 3 | | Array Calculations | | |
| Start Time | End Time | DB Temp(°C ) | Ta(°F) | GHI (Wh/m^2) | GHI (Btu/HrFt$^2$) | DNI (Wh/m^2) | DNI (Btu/HrFt$^2$) | DHI (Wh/m^2) | DHI (Btu/HrFt$^2$) | Hour, $\omega_{mid}$ (Deg) | Incedent, θ (deg) | Gt (Btu/HrFt2) | Ti (°F) | Qu | Ti (°F) | Qu | Ti (°F) | Qu | Tsupply (°F) | Δ T of Array (F) | Total Qu of Array |
| 7:00 AM | 8:00 AM | 2.0 | 35.6 | 1.0 | 0.3 | 0.0 | 0.0 | 1.0 | 0.3 | -67.5 | 69.2 | 0.3 | 150 | -2723.173 | 141.6524 | -2523.889 | 133.9156 | -2339.189 | 126.7451 | 23.2549148 | -227587.54 |
| 8:00 AM | 9:00 AM | 1.0 | 33.8 | 42.0 | 13.3 | 13.0 | 4.1 | 40.0 | 12.7 | -52.5 | 55.7 | 13.8 | 149.9374 | -2391.48 | 142.6066 | -2216.469 | 135.8122 | -2054.266 | 129.515 | 20.4223732 | -199866.47 |
| 9:00 AM | 10:00 AM | 1.0 | 33.8 | 81.0 | 25.7 | 15.0 | 4.8 | 77.0 | 24.4 | -37.5 | 42.7 | 25.6 | 149.8749 | -2064.427 | 143.5466 | -1913.35 | 137.6814 | -1773.33 | 132.2454 | 17.629458 | -172533.2 |
| 10:00 AM | 11:00 AM | 2.0 | 35.6 | 103.0 | 32.7 | 34.0 | 10.8 | 90.0 | 28.5 | -22.5 | 31.1 | 35.2 | 149.8124 | -1757.34 | 144.4254 | -1628.737 | 139.4327 | -1509.544 | 134.8053 | 15.0070519 | -146868.65 |
| 11:00 AM | 12:00 PM | 2.0 | 35.6 | 178.0 | 56.4 | 40.0 | 12.7 | 161.0 | 51.0 | -7.5 | 23.3 | 58.0 | 149.7499 | -1126.268 | 146.2975 | -1043.847 | 143.0976 | -967.4575 | 140.132 | 9.61792472 | -94127.192 |
| 12:00 PM | 1:00 PM | 2.0 | 35.6 | 135.0 | 42.8 | 23.0 | 7.3 | 125.0 | 39.6 | 7.5 | 23.3 | 42.7 | 149.6875 | -1547.565 | 144.9436 | -1434.312 | 140.5469 | -1329.348 | 136.4719 | 13.2156409 | -129336.75 |
| 1:00 PM | 2:00 PM | 3.0 | 37.4 | 277.0 | 87.8 | 118.0 | 37.4 | 229.0 | 72.6 | 22.5 | 31.1 | 98.2 | 149.6252 | 25.52379 | 149.7034 | 23.65593 | 149.7759 | 21.92477 | 149.8431 | -0.21796391 | 2133.13486 |
| 2:00 PM | 3:00 PM | 3.0 | 37.4 | 123.0 | 39.0 | 24.0 | 7.6 | 115.0 | 36.5 | 37.5 | 42.7 | 38.7 | 149.8399 | -1618.246 | 144.8793 | -1499.822 | 140.2818 | -1390.063 | 136.0207 | 13.8192369 | -135243.93 |
| 3:00 PM | 4:00 PM | 4.0 | 39.2 | 68.0 | 21.6 | 17.0 | 5.4 | 65.0 | 20.6 | 52.5 | 55.7 | 21.7 | 149.7774 | -2040.936 | 143.5212 | -1891.579 | 137.7227 | -1753.152 | 132.3486 | 17.4288576 | -170570 |
| 4:00 PM | 5:00 PM | 4.0 | 39.2 | 21.0 | 6.7 | 1.0 | 0.3 | 21.0 | 6.7 | 67.5 | 69.2 | 6.1 | 149.715 | -2469.008 | 142.1465 | -2288.324 | 135.1319 | -2120.863 | 128.6306 | 21.0844363 | -206345.84 |
| | | | | | | | | | | | | | | | | | | | | Hourly Average: | 2133.13486 |

| 3/20 | n | 335.0 | δ | -22.1 | η at noon | 0.6 | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Typical Series | | | | | | | | |
| TMY3 Data | | | | | | | | | | Solar Calculations | | | Collector 1 | | Collector 2 | | Collector 3 | | Array Calculations | | |
| Start Time | End Time | DB Temp(°C ) | Ta(°F) | GHI (Wh/m^2) | GHI (Btu/HrFt$^2$) | DNI (Wh/m^2) | DNI (Btu/HrFt$^2$) | DHI (Wh/m^2) | DHI (Btu/HrFt$^2$) | Hour, $\omega_{mid}$ (Deg) | Incedent, θ (deg) | Gt (Btu/HrFt2) | Ti (°F) | Qu | Ti (°F) | Qu | Ti (°F) | Qu | Tsupply (°F) | Δ T of Array (F) | Total Qu of Array |
| 6:00 AM | 7:00 AM | -7.0 | 19.4 | 1.0 | 0.3 | 64.0 | 20.3 | 1.0 | 0.3 | -82.5 | 83.1 | 2.7 | 149.9374 | -3040.832 | 140.616 | -2818.301 | 131.9768 | -2612.056 | 123.9698 | 25.9676057 | -254135.68 |
| 7:00 AM | 8:00 AM | -5.0 | 23.0 | 158.0 | 50.1 | 344.0 | 109.0 | 90.0 | 28.5 | -67.5 | 69.2 | 65.0 | 149.8749 | -1237.395 | 146.0817 | -1146.842 | 142.5662 | -1062.915 | 139.308 | 10.5669087 | -103414.56 |
| 8:00 AM | 9:00 AM | -3.0 | 26.6 | 362.0 | 114.8 | 641.0 | 203.2 | 118.0 | 37.4 | -52.5 | 55.7 | 150.3 | 43.17922 | 3745.515 | 54.66073 | 3471.415 | 65.30201 | 3217.374 | 75.16456 | -31.9853405 | 313029.096 |
| 9:00 AM | 10:00 AM | -1.0 | 30.2 | 532.0 | 168.6 | 747.0 | 236.8 | 130.0 | 41.2 | -37.5 | 42.7 | 214.4 | 15.40574 | 6259.608 | 34.59395 | 5801.525 | 52.37796 | 5376.964 | 68.86052 | -53.4547869 | 523142.895 |
| 10:00 AM | 11:00 AM | 2.0 | 35.6 | 669.0 | 212.1 | 806.0 | 255.5 | 139.0 | 44.1 | -22.5 | 31.1 | 262.6 | 32.53098 | 7307.063 | 54.93007 | 6772.326 | 75.68997 | 6276.721 | 94.93065 | -62.399672 | 610683.288 |
| 11:00 AM | 12:00 PM | 4.0 | 39.2 | 768.0 | 243.5 | 850.0 | 269.5 | 147.0 | 46.6 | -7.5 | 23.3 | 294.3 | 71.70737 | 7333.269 | 94.18679 | 6796.614 | 115.0211 | 6299.232 | 134.3308 | -62.6234663 | 612873.483 |
| 12:00 PM | 1:00 PM | 6.0 | 42.8 | 799.0 | 253.3 | 864.0 | 273.9 | 147.0 | 46.6 | 7.5 | 23.3 | 298.7 | 115.8043 | 6485.122 | 135.6838 | 6010.535 | 154.1085 | 5570.679 | 171.1849 | -55.3805973 | 541990.113 |
| 1:00 PM | 2:00 PM | 7.0 | 44.6 | 765.0 | 242.5 | 789.0 | 250.1 | 191.0 | 60.5 | 22.5 | 31.1 | 273.2 | 152.4425 | 4952.801 | 167.6248 | 4590.351 | 181.6366 | 4255.844 | 194.5592 | -42.1167132 | 413969.905 |
| 2:00 PM | 3:00 PM | 8.0 | 46.4 | 597.0 | 189.2 | 535.0 | 169.6 | 249.0 | 78.9 | 37.5 | 42.7 | 198.8 | 168.9625 | 2550.567 | 176.748 | 2364.703 | 183.9662 | 2192.383 | 190.6232 | -21.6606427 | 213229.601 |
| 3:00 PM | 4:00 PM | 7.0 | 44.6 | 509.0 | 161.4 | 583.0 | 184.8 | 202.0 | 64.0 | 52.5 | 55.7 | 164.6 | 176.6586 | 1380.793 | 180.8734 | 1280.172 | 184.7606 | 1187.374 | 188.366 | -11.7073219 | 115450.173 |
| 4:00 PM | 5:00 PM | 7.0 | 44.6 | 186.0 | 59.0 | 69.0 | 21.9 | 161.0 | 51.0 | 67.5 | 69.2 | 54.2 | 176.5752 | -1657.41 | 171.516 | -1536.632 | 166.8255 | -1424.655 | 162.4768 | 14.098363 | -138560.9 |
| 5:00 PM | 6:00 PM | 6.0 | 42.8 | 123.0 | 39.0 | 266.0 | 84.3 | 74.0 | 23.5 | 82.5 | 83.1 | 31.8 | 176.4918 | -2314.912 | 169.4256 | -2146.22 | 162.8744 | -1989.821 | 156.7748 | 19.7170052 | -193528.58 |
| | | | | | | | | | | | | | | | | | | | | Hourly Average: | 418046.069 |

| 6/21 | n | 183.0 | δ | 23.0 | η at noon | 0.6 |
|---|---|---|---|---|---|---|

| Start Time | End Time | DB Temp(°C ) | Ta(°F) | GHI (Wh/m^2) | GHI (Btu/HrFt²) | DNI (Wh/m^2) | DNI (Btu/HrFt²) | DHI (Wh/m^2) | DHI (Btu/HrFt²) | Hour, $\omega_{mid}$ (Deg) | Incedent, θ (deg) | Gt (Btu/HrFt2) | Collector 1 Ti (°F) | Collector 1 Qu | Collector 2 Ti (°F) | Collector 2 Qu | Collector 3 Ti (°F) | Collector 3 Qu | Tsupply (°F) | Δ T of Array (F) | Total Qu of Array |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TMY3 Data | | | | | | | | Solar Calculations | | | Typical Series | | | | | | Array Calculations | | |
| 5:00 AM | 6:00 AM | 19.0 | 66.2 | 59.0 | 18.7 | 43.0 | 13.6 | 54.0 | 17.1 | -97.5 | 96.9 | 13.9 | 149.9 | -1615.7 | 145.0 | -1497.5 | 140.4 | -1387.9 | 136.1 | 13.8 | -135030.2 |
| 6:00 AM | 7:00 AM | 19.0 | 66.2 | 209.0 | 66.3 | 345.0 | 109.4 | 111.0 | 35.2 | -82.5 | 83.1 | 45.8 | 149.9 | -737.0 | 147.6 | -683.1 | 145.5 | -633.1 | 143.6 | 6.3 | -61593.5 |
| 7:00 AM | 8:00 AM | 20.0 | 68.0 | 391.0 | 123.9 | 546.0 | 173.1 | 138.0 | 43.7 | -67.5 | 69.4 | 102.5 | 42.0 | 3444.3 | 52.5 | 3192.3 | 62.3 | 2958.6 | 71.4 | -29.4 | 287856.3 |
| 8:00 AM | 9:00 AM | 22.0 | 71.6 | 540.0 | 171.2 | 537.0 | 170.2 | 202.0 | 64.0 | -52.5 | 55.9 | 155.9 | 10.2 | 5762.0 | 27.8 | 5340.3 | 44.2 | 4949.5 | 59.4 | -49.2 | 481553.6 |
| 9:00 AM | 10:00 AM | 24.0 | 75.2 | 727.0 | 230.5 | 684.0 | 216.8 | 200.0 | 63.4 | -37.5 | 43.1 | 219.7 | 27.0 | 7201.9 | 49.1 | 6674.9 | 69.6 | 6186.4 | 88.5 | -61.5 | 601894.0 |
| 10:00 AM | 11:00 AM | 22.0 | 71.6 | 848.0 | 268.8 | 730.0 | 231.4 | 209.0 | 66.3 | -22.5 | 31.8 | 261.5 | 66.7 | 7322.8 | 89.1 | 6786.9 | 109.9 | 6290.3 | 129.2 | -62.5 | 612000.0 |
| 11:00 AM | 12:00 PM | 24.0 | 75.2 | 932.0 | 295.4 | 782.0 | 247.9 | 197.0 | 62.4 | -7.5 | 24.2 | 288.2 | 116.3 | 6959.5 | 137.6 | 6450.2 | 157.4 | 5978.1 | 175.7 | -59.4 | 581633.6 |
| 12:00 PM | 1:00 PM | 26.0 | 78.8 | 936.0 | 296.7 | 714.0 | 226.3 | 253.0 | 80.2 | 7.5 | 24.2 | 284.2 | 162.7 | 5828.7 | 180.5 | 5402.2 | 196.9 | 5010.6 | 212.1 | -49.4 | 487243.7 |
| 1:00 PM | 2:00 PM | 26.0 | 78.8 | 928.0 | 294.2 | 790.0 | 250.4 | 196.0 | 62.1 | 22.5 | 31.8 | 274.6 | 201.9 | 4626.9 | 215.9 | 4293.6 | 228.8 | 3984.3 | 240.9 | -38.9 | 387147.2 |
| 2:00 PM | 3:00 PM | 25.0 | 77.0 | 831.0 | 263.4 | 752.0 | 238.4 | 192.0 | 60.9 | 37.5 | 43.1 | 233.9 | 185.0 | 3866.6 | 196.7 | 3586.3 | 207.6 | 3327.9 | 217.6 | -32.6 | 323422.8 |
| 3:00 PM | 4:00 PM | 26.0 | 78.8 | 683.0 | 216.5 | 701.0 | 222.2 | 168.0 | 53.3 | 52.5 | 55.9 | 176.6 | 146.2 | 3256.5 | 156.1 | 3018.2 | 165.4 | 2797.3 | 173.9 | -27.8 | 272158.5 |
| 4:00 PM | 5:00 PM | 25.0 | 77.0 | 514.0 | 162.9 | 661.0 | 209.5 | 127.0 | 40.3 | 67.5 | 69.4 | 113.1 | 93.8 | 2715.6 | 102.1 | 2516.9 | 109.9 | 2332.7 | 117.0 | -23.2 | 226956.0 |
| 5:00 PM | 6:00 PM | 25.0 | 77.0 | 335.0 | 106.2 | 557.0 | 176.6 | 105.0 | 33.3 | 82.5 | 83.1 | 53.1 | 60.7 | 1850.4 | 66.4 | 1715.0 | 71.7 | 1589.5 | 76.6 | -15.8 | 154646.3 |
| 6:00 PM | 7:00 PM | 24.0 | 75.2 | 148.0 | 46.9 | 243.0 | 77.0 | 91.0 | 28.8 | 97.5 | 96.9 | 17.3 | 40.4 | 1307.7 | 44.4 | 1212.0 | 48.1 | 1123.3 | 51.6 | -11.2 | 109287.8 |
| 7:00 PM | 8:00 PM | 22.0 | 71.6 | 12.0 | 3.8 | 0.0 | 0.0 | 12.0 | 3.8 | 112.5 | 110.6 | 3.4 | 38.9 | 876.1 | 41.6 | 812.0 | 44.1 | 752.5 | 46.4 | -7.5 | 73217.8 |
| | | | | | | | | | | | | | | | | | | | | Hourly Average: | 353770.585 |

| 9/23 | n | 281.0 | 281.0 | -7.0 | δ | 0.7 | -7.0 |
|---|---|---|---|---|---|---|---|

| Start Time | End Time | DB Temp(°C ) | Ta(°F) | GHI (Wh/m^2) | GHI (Btu/HrFt²) | DNI (Wh/m^2) | DNI (Btu/HrFt²) | DHI (Wh/m^2) | DHI (Btu/HrFt²) | Hour, $\omega_{mid}$ (Deg) | Incedent, θ (deg) | Gt (Btu/HrFt2) | Collector 1 Ti (°F) | Collector 1 Qu (Btu/Hr) | Collector 2 Ti (°F) | Collector 2 Qu (Btu/Hr) | Collector 3 Ti (°F) | Collector 3 Qu (Btu/Hr) | Tsupply (°F) | Δ T of Array (F) | Total Qu of Array (Btu/Hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TMY3 Data | | | | | | | | Solar Calculations | | | Typical Series | | | | | | Array Calculations | | |
| 6:00 AM | 7:00 AM | 13.0 | 55.4 | 12.0 | 3.8 | 0.0 | 0.0 | 12.0 | 3.8 | -82.5 | 82.6 | 3.4 | 149.9374 | -2161.913 | 143.3103 | -2003.703 | 137.1681 | -1857.07 | 131.4755 | 18.4619568 | -180680.57 |
| 7:00 AM | 8:00 AM | 13.0 | 55.4 | 47.0 | 14.9 | 0.0 | 0.0 | 47.0 | 14.9 | -67.5 | 67.7 | 13.5 | 149.8749 | -1883.356 | 144.1016 | -1745.531 | 138.7509 | -1617.791 | 133.7917 | 16.0831804 | -157400.34 |
| 8:00 AM | 9:00 AM | 14.0 | 57.2 | 117.0 | 37.1 | 76.0 | 24.1 | 83.0 | 26.3 | -52.5 | 52.8 | 38.7 | 149.8124 | -1145.883 | 146.2998 | -1062.026 | 143.0442 | -984.3061 | 140.0269 | 9.78542395 | -95766.447 |
| 9:00 AM | 10:00 AM | 17.0 | 62.6 | 519.0 | 164.5 | 403.0 | 127.8 | 281.0 | 89.1 | -37.5 | 38.0 | 183.1 | 43.49821 | 5500.769 | 60.36028 | 5098.218 | 75.98837 | 4725.126 | 90.47279 | -46.9745743 | 459723.37 |
| 10:00 AM | 11:00 AM | 18.0 | 64.4 | 674.0 | 213.7 | 632.0 | 200.3 | 233.0 | 73.9 | -22.5 | 23.5 | 254.0 | 22.45463 | 7997.738 | 46.97091 | 7412.457 | 69.69308 | 6870.007 | 90.75242 | -68.2977875 | 668406.037 |
| 11:00 AM | 12:00 PM | 19.0 | 66.2 | 766.0 | 242.8 | 801.0 | 253.9 | 157.0 | 49.8 | -7.5 | 10.2 | 299.5 | 46.93288 | 8711.761 | 73.63794 | 8074.227 | 98.38869 | 7483.348 | 121.3282 | -74.3952843 | 728080.059 |
| 12:00 PM | 1:00 PM | 21.0 | 69.8 | 727.0 | 230.5 | 655.0 | 207.6 | 221.0 | 70.1 | 7.5 | 10.2 | 271.6 | 79.95843 | 7240.008 | 102.152 | 6710.178 | 122.7214 | 6219.121 | 141.7855 | -61.8270447 | 605079.19 |
| 1:00 PM | 2:00 PM | 21.0 | 69.8 | 746.0 | 236.5 | 839.0 | 266.0 | 133.0 | 42.2 | 22.5 | 23.5 | 286.7 | 122.4157 | 6641.701 | 142.7752 | 6155.656 | 161.6447 | 5705.18 | 179.1334 | -56.7177258 | 555076.111 |
| 2:00 PM | 3:00 PM | 22.0 | 71.6 | 636.0 | 201.6 | 802.0 | 254.2 | 121.0 | 38.4 | 37.5 | 38.0 | 238.8 | 153.3494 | 4627.334 | 167.534 | 4288.702 | 180.6251 | 3976.177 | 192.6984 | -39.3490633 | 386766.363 |
| 3:00 PM | 4:00 PM | 21.0 | 69.8 | 475.0 | 150.6 | 732.0 | 232.0 | 102.0 | 32.3 | 52.5 | 52.8 | 172.3 | 167.088 | 2424.144 | 174.4876 | 2247.493 | 181.348 | 2083.714 | 187.675 | -20.5869985 | 202660.537 |
| 4:00 PM | 5:00 PM | 21.0 | 69.8 | 281.0 | 89.1 | 598.0 | 189.6 | 76.0 | 24.1 | 67.5 | 67.7 | 95.4 | 167.7177 | 289.7811 | 168.6022 | 268.6643 | 169.4223 | 249.0862 | 170.1826 | -2.46495386 | 24225.9496 |
| 5:00 PM | 6:00 PM | 19.0 | 66.2 | 93.0 | 29.5 | 314.0 | 99.5 | 44.0 | 13.9 | 82.5 | 82.6 | 25.9 | 167.6412 | -1708.097 | 162.4273 | -1583.625 | 157.5729 | -1467.734 | 153.0737 | 14.5675314 | -142783.67 |
| 6:00 PM | 7:00 PM | 18.0 | 64.4 | 2.0 | 0.6 | 11.0 | 3.5 | 2.0 | 0.6 | 97.5 | 97.4 | 0.1 | 167.5648 | -2459.485 | 160.0573 | -2280.258 | 153.0674 | -2113.387 | 146.5891 | 20.9757546 | -205593.87 |
| | | | | | | | | | | | | | | | | | | | | Hourly Average: | 453752.202 |

## Beginning and End of Winter Break

| 11/30 | n | 334.0 | δ | -22.0 | η at noon | -0.4 | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TMY3 Data | | | | | | | | | | Solar Calculations | | | Typical Series Collector 1 | | Collector 2 | | Collector 3 | | Array Calculations | | |
| Start Time | End Time | DB Temp(°C) | Ta(°F) | GHI (Wh/m^2) | GHI (Btu/HrFt2) | DNI (Wh/m^2) | DNI (Btu/HrFt2) | DHI (Wh/m^2) | DHI (Btu/HrFt2) | Hour, ωmid (Deg) | Incedent, θ (deg) | Gt (Btu/HrFt2) | Ti (°F) | Qu | Ti (°F) | Qu | Ti (°F) | Qu | Tsupply (°F) | Δ T of Array (F) | Total Qu of Array |
| 6:00 AM | 7:00 AM | 0.0 | 32.0 | 3.0 | 1.0 | 43.0 | 13.6 | 2.0 | 0.6 | -82.5 | 83.0 | 2.2 | 149.9374 | -2754.044 | 141.4952 | -2552.501 | 133.6707 | -2365.707 | 126.4189 | 23.5185413 | -230167.56 |
| 7:00 AM | 8:00 AM | 1.0 | 33.8 | 133.0 | 42.2 | 174.0 | 55.2 | 103.0 | 32.7 | -67.5 | 69.2 | 49.4 | 149.8749 | -1410.284 | 145.5518 | -1307.079 | 141.5451 | -1211.425 | 137.8315 | 12.0433177 | -117863.65 |
| 8:00 AM | 9:00 AM | 2.0 | 35.6 | 91.0 | 28.8 | 0.0 | 0.0 | 91.0 | 28.8 | -52.5 | 55.6 | 26.1 | 149.8124 | -2006.244 | 143.6624 | -1859.425 | 137.9625 | -1723.351 | 132.6798 | 17.1325965 | -167670.6 |
| 9:00 AM | 10:00 AM | 2.0 | 35.6 | 103.0 | 32.7 | 0.0 | 0.0 | 103.0 | 32.7 | -37.5 | 42.6 | 29.6 | 149.7499 | -1909.76 | 143.8957 | -1770.002 | 138.47 | -1640.472 | 133.4413 | 16.3086569 | -159607 |
| 10:00 AM | 11:00 AM | 3.0 | 37.4 | 117.0 | 37.1 | 0.0 | 0.0 | 117.0 | 37.1 | -22.5 | 31.0 | 33.6 | 149.6875 | -1754.473 | 144.3094 | -1626.079 | 139.3248 | -1507.081 | 134.705 | 14.9825632 | -146628.99 |
| 11:00 AM | 12:00 PM | 4.0 | 39.2 | 202.0 | 64.0 | 18.0 | 5.7 | 194.0 | 61.5 | -7.5 | 23.2 | 61.0 | 149.6252 | -954.2992 | 146.6999 | -884.4628 | 143.9886 | -819.7371 | 141.4758 | 8.14937021 | -79754.974 |
| 12:00 PM | 1:00 PM | 4.0 | 39.2 | 235.0 | 74.5 | 89.0 | 28.2 | 197.0 | 62.4 | 7.5 | 23.2 | 82.8 | 149.5629 | -352.811 | 148.4814 | -326.992 | 147.479 | -303.0624 | 146.55 | 3.01287806 | -29485.961 |
| 1:00 PM | 2:00 PM | 4.0 | 39.2 | 222.0 | 70.4 | 216.0 | 68.5 | 149.0 | 47.2 | 22.5 | 31.0 | 102.0 | 88.75282 | 1627.692 | 93.74235 | 1508.576 | 98.36675 | 1398.177 | 102.6527 | -13.8999012 | 136033.365 |
| 2:00 PM | 3:00 PM | 4.0 | 39.2 | 115.0 | 36.5 | 106.0 | 33.6 | 92.0 | 29.2 | 37.5 | 42.6 | 51.3 | 72.7421 | 613.3311 | 74.6222 | 568.447 | 76.36472 | 526.8476 | 77.97972 | -5.23762547 | 51258.7685 |
| 3:00 PM | 4:00 PM | 4.0 | 39.2 | 15.0 | 4.8 | 8.0 | 2.5 | 15.0 | 4.8 | 52.5 | 55.6 | 5.7 | 72.73995 | -642.5191 | 70.77037 | -595.499 | 68.94493 | -551.9199 | 67.25307 | 5.4868807 | -53698.14 |
| | | | | | | | | | | | | | | | | | | | | Hourly Average: | 93646.0667 |

| 1/12 | n | 12.0 | δ | -21.8 | η at noon | 0.6 | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TMY3 Data | | | | | | | | | | Solar Calculations | | | Typical Series Collector 1 | | Collector 2 | | Collector 3 | | Array Calculations | | |
| Start Time | End Time | DB Temp(°C) | Ta(°F) | GHI (Wh/m^2) | GHI (Btu/HrFt2) | DNI (Wh/m^2) | DNI (Btu/HrFt2) | DHI (Wh/m^2) | DHI (Btu/HrFt2) | Hour, ωmid (Deg) | Incedent, θ (deg) | Gt (Btu/HrFt2) | Ti (°F) | Qu | Ti (°F) | Qu | Ti (°F) | Qu | Tsupply (°F) | Δ T of Array (F) | Total Qu of Array |
| 8:00 AM | 9:00 AM | 0.0 | 32.0 | 29.0 | 9.2 | 0.0 | 0.0 | 29.0 | 9.2 | -52.5 | 55.6 | 8.3 | 149.9374 | -2585.971 | 142.0104 | -2396.728 | 134.6634 | -2221.333 | 127.8541 | 22.0832588 | -216120.96 |
| 9:00 AM | 10:00 AM | 1.0 | 33.8 | 114.0 | 36.1 | 49.0 | 15.5 | 101.0 | 32.0 | -37.5 | 42.6 | 40.5 | 149.8749 | -1654.04 | 144.8046 | -1532.996 | 140.1053 | -1420.81 | 135.75 | 14.1249004 | -138235.35 |
| 10:00 AM | 11:00 AM | 2.0 | 35.6 | 164.0 | 52.0 | 68.0 | 21.6 | 139.0 | 44.1 | -22.5 | 31.0 | 58.6 | 149.8124 | -1112.34 | 146.4026 | -1030.938 | 143.2424 | -955.4934 | 140.3134 | 9.49898431 | -92963.165 |
| 11:00 AM | 12:00 PM | 2.0 | 35.6 | 427.0 | 135.4 | 779.0 | 246.9 | 84.0 | 26.6 | -7.5 | 23.2 | 253.7 | 89.64146 | 5700.189 | 107.1148 | 5283.044 | 123.3095 | 4896.426 | 138.319 | -48.6775487 | 476389.772 |
| 12:00 PM | 1:00 PM | 3.0 | 37.4 | 338.0 | 107.1 | 449.0 | 142.3 | 131.0 | 41.5 | 7.5 | 23.2 | 170.0 | 56.2928 | 4233.7 | 69.2708 | 3923.874 | 81.29905 | 3636.722 | 92.44707 | -36.1542675 | 353828.895 |
| 1:00 PM | 2:00 PM | 4.0 | 39.2 | 425.0 | 134.7 | 773.0 | 245.0 | 89.0 | 28.2 | 22.5 | 31.0 | 238.0 | 68.37978 | 5860.682 | 86.34513 | 5431.792 | 102.9958 | 5034.289 | 118.4279 | -50.0481025 | 489802.892 |
| 2:00 PM | 3:00 PM | 4.0 | 39.2 | 339.0 | 107.5 | 714.0 | 226.3 | 80.0 | 25.4 | 37.5 | 42.6 | 191.4 | 81.23515 | 4270.518 | 94.326 | 3957.998 | 106.4589 | 3668.348 | 117.7038 | -36.468679 | 356905.927 |
| 3:00 PM | 4:00 PM | 4.0 | 39.2 | 92.0 | 29.2 | 31.0 | 9.8 | 85.0 | 26.9 | 52.5 | 55.6 | 30.0 | 81.22636 | -176.1574 | 80.68636 | -163.266 | 80.18589 | -151.3181 | 79.72204 | 1.50432011 | -14722.243 |
| 4:00 PM | 5:00 PM | 4.0 | 39.2 | 69.0 | 21.9 | 3.0 | 1.0 | 68.0 | 21.6 | 67.5 | 69.2 | 19.9 | 81.21757 | -455.294 | 79.82191 | -421.9752 | 78.52839 | -391.0947 | 77.32953 | 3.88804568 | -38050.913 |
| | | | | | | | | | | | | 235.0 | | | | | | | | Hourly Average: | 419231.871 |

| | Original Design Load Calc | | | | | | Self-Designed Load Calc | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | mdot (gal/hr) | cp (btu/lbF) | density (lb/gal) | weight of water (lb/gal) | temp rise(F) | Load (MBH) | Set Tank temp | Mdot Chosen(gal/hr) | To (F) | mixed temp |
| DHW | 332 | - | | 8.36 | 91 | 252.5723 | 150 | 1800 | 132.87 | 126.9349 |
| Geo auxiliary | 3480 | 0.947 | 8.649733 | - | 30 | 855.1714 | 150 | 1800 | 121 | |
| *assumed pipe loss is negligable | | | | | | 427.5857 | | | | |

| | |
|---|---|
| $\varepsilon_{hx\,(estimated)}$ | 0.65 |
| $UA_{tank}$ (Btu/h | 6.024395 |
| $V_{tank}$(gal) | 940 |
| Ts(F) | 150 |
| Ta,mech.rm. | 70 |
| Ts,return | 126.9349 |

| | |
|---|---|
| cp (btu/gal | 8.1912968 |

Tank Dimensions

| | | | |
|---|---|---|---|
| V(gal) | 940 | SA (ft2) | 174.7075 |
| h (Ft) | 10.66666667 | R of foam | 16 |
| D (Ft) | 4.333333333 | R of fg | 13 |
| | | U | 0.034483 |

| 12/21 | m,dhw (gph) | 900 | m, ga (gph) | 300 |
|---|---|---|---|---|

| Start Time | End Time | Qu,array (MBH) | tank Loss (MBH) | DHW load (MBH) | GA load (MBH) | Ts (F) | Tr,dhw (F) | Tr,ga (F) | Tr (F) | Aux needed, DHW (MBH) | Aux needed, GA (MBH) | Solar Fraction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7:00 AM | 8:00 AM | 0 | 0.481952 | 0 | 0 | 149.9374 | 119.9374 | 79.93741 | 114.9374 | 252.5723 | 427.5856925 | 0 |
| 8:00 AM | 9:00 AM | 0 | 0.481575 | 0 | 0 | 149.8749 | 119.8749 | 79.87486 | 114.8749 | 252.5723 | 427.5856925 | 0 |
| 9:00 AM | 10:00 AM | 0 | 0.481198 | 0 | 0 | 149.8124 | 119.8124 | 79.81237 | 114.8124 | 252.5723 | 427.5856925 | 0 |
| 10:00 AM | 11:00 AM | 0 | 0.480821 | 0 | 0 | 149.7499 | 119.7499 | 79.74992 | 114.7499 | 252.5723 | 427.5856925 | 0 |
| 11:00 AM | 12:00 PM | 26.33966 | 0.480445 | 143.7573 | 0 | 134.4381 | 114.9381 | 74.93813 | 114.9381 | 108.8151 | 427.5856925 | 0.21135862 |
| 12:00 PM | 1:00 PM | 12.98961 | 0.388201 | 93.44222 | 0 | 123.9391 | 111.2641 | 71.26408 | 111.2641 | 159.1301 | 427.5856925 | 0.137383103 |
| 1:00 PM | 2:00 PM | 90.30509 | 0.32495 | 60.73744 | 0 | 127.7369 | 119.4982 | 79.49817 | 119.4982 | 191.8349 | 427.5856925 | 0.089299017 |
| 2:00 PM | 3:00 PM | 11.45482 | 0.34783 | 39.47934 | 0 | 124.0521 | 118.6969 | 78.69692 | 118.6969 | 213.093 | 427.5856925 | 0.058044361 |
| 3:00 PM | 4:00 PM | 0 | 0.325631 | 0 | 0 | 124.0098 | 94.00982 | 54.00982 | 89.00982 | 252.5723 | 427.5856925 | 0 |
| 4:00 PM | 5:00 PM | 0 | 0.325376 | 0 | 0 | 123.9676 | 93.96756 | 53.96756 | 88.96756 | 252.5723 | 427.5856925 | 0 |
| | | | | | | | | | | 218.8307 | 427.5856925 | 0.04960851 |

| 3/20 | m,dhw (gph) | 1800 | m, ga (gph) | 1800 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Time | End Time | Qu,array (MBH) | tank Loss (MBH) | DHW load (MBH) | GA load (MBH) | Ts (F) | IF Max Temp of Tank obtained, Reduce to | Tr,dhw (F) | Tr,ga (F) | Tr (F) | Aux needed, DHW (MBH) | Aux needed, GA (MBH) | Solar Fraction |
| 6:00 AM | 7:00 AM | 0 | 0.481952 | 0 | 0 | 149.9374 | | 119.9374 | 79.93741 | 114.9374 | 252.5723 | 427.5856925 | 0 |
| 7:00 AM | 8:00 AM | 29.92879 | 0.481575 | 287.5145 | 0 | 116.4214 | | 96.92139 | 56.92139 | 96.92139 | -34.9422 | 427.5856925 | 0.422717239 |
| 8:00 AM | 9:00 AM | 156.5956 | 0.279661 | 186.8844 | 570.23713 | 38.39285 | | 25.71785 | -0.282152 | 12.71785 | 65.68788 | -142.6514336 | 1.113155397 |
| 9:00 AM | 10:00 AM | 274.8185 | -0.190414 | 121.4749 | 370.65413 | 10.19477 | | 1.956018 | -14.94398 | -6.493982 | 131.0974 | 56.93156052 | 0.723551008 |
| 10:00 AM | 11:00 AM | 351.7937 | -0.36029 | 78.95867 | 240.92519 | 14.3858 | | 9.030611 | -1.954389 | 3.538111 | 173.6136 | 186.6605067 | 0.470308155 |
| 11:00 AM | 12:00 PM | 392.7986 | -0.335042 | 51.32314 | 156.60137 | 38.4395 | | 34.95862 | 27.81837 | 31.3885 | 201.2492 | 270.9843217 | 0.305700301 |
| 12:00 PM | 1:00 PM | 389.6087 | -0.190133 | 33.36004 | 101.79089 | 71.51143 | | 69.24886 | 64.6077 | 66.92828 | 219.2123 | 325.7948015 | 0.198705196 |
| 1:00 PM | 2:00 PM | 343.1672 | 0.009105 | 21.68403 | 66.164079 | 104.6693 | 185 | 103.1987 | 100.1819 | 101.6903 | 230.8883 | 361.4216134 | 0.129158377 |
| 2:00 PM | 3:00 PM | 233.0618 | 0.208862 | 14.09462 | 43.006651 | 127.4948 | | 126.5388 | 124.5779 | 125.5584 | 238.4777 | 384.5790411 | 0.083952945 |
| 3:00 PM | 4:00 PM | 178.0484 | 0.346371 | 9.161501 | 27.954323 | 145.7531 | | 145.1318 | 143.8572 | 144.4945 | 243.4108 | 399.6313691 | 0.054569414 |
| 4:00 PM | 5:00 PM | 26.94307 | 0.456367 | 5.954976 | 0 | 148.4197 | | 148.0158 | 108.0158 | 148.0158 | 246.6173 | 427.5856925 | 0.008755283 |
| 5:00 PM | 6:00 PM | 0 | 0.472431 | 0 | 0 | 148.3583 | | 118.3583 | 78.35831 | 113.3583 | 252.5723 | 427.5856925 | 0 |
| | | | | | | | | | | | 185.0381 | 296.1412125 | 0.292547776 |

| 6/21 | m,dhw (gph) | 1620 | m, ga (gph) | 1680 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Time | End Time | Qu,array (MBH) | tank Loss (MBH) | DHW load (MBH) | GA load (MBH) | Ts (F) | IF Max Temp of Tank obtained, Reduce to | Tr,dhw (F) | Tr,ga (F) | Tr (F) | Aux needed, DHW (MBH) | Aux needed, GA (MBH) | Solar Fraction |
| 5:00 AM | 6:00 AM | 0 | 0.481952 | 0 | 0 | 149.9374 | | 119.9374 | 79.93741 | 114.9374 | 252.5723 | 427.5856925 | 0 |
| 6:00 AM | 7:00 AM | 23.45575 | 0.481575 | 258.7631 | 0 | 119.3148 | | 99.81475 | 59.81475 | 99.81475 | -6.190746 | 427.5856925 | 0.380445515 |
| 7:00 AM | 8:00 AM | 111.0134 | 0.297092 | 168.196 | 532.22132 | 42.7284 | | 30.0534 | 4.053405 | 16.81704 | 84.37633 | -104.6356252 | 1.029786164 |
| 8:00 AM | 9:00 AM | 214.802 | -0.164295 | 109.3274 | 345.94386 | 11.51923 | | 3.28048 | -13.61952 | -5.323156 | 143.2449 | 81.64183599 | 0.669361006 |
| 9:00 AM | 10:00 AM | 312.5233 | -0.352311 | 71.06281 | 224.86351 | 13.72048 | | 8.365295 | -2.619705 | 2.772932 | 181.5095 | 202.7221858 | 0.435084654 |
| 10:00 AM | 11:00 AM | 364.3729 | -0.33905 | 46.19082 | 146.16128 | 36.1054 | | 32.62453 | 25.48428 | 28.98949 | 206.3815 | 281.4244131 | 0.282805025 |
| 11:00 AM | 12:00 PM | 390.9586 | -0.204194 | 30.02404 | 95.004832 | 70.66906 | | 68.40649 | 63.76533 | 66.04372 | 222.5483 | 332.5808609 | 0.183823266 |
| 12:00 PM | 1:00 PM | 372.5242 | 0.004031 | 19.51562 | 61.753141 | 108.4948 | | 107.0241 | 104.0074 | 105.4883 | 233.0567 | 365.832552 | 0.119485123 |
| 1:00 PM | 2:00 PM | 343.8151 | 0.231908 | 12.68516 | 40.139541 | 146.2565 | | 145.3006 | 143.3397 | 144.7716 | 239.8872 | 387.4461512 | 0.07766533 |
| 2:00 PM | 3:00 PM | 273.9769 | 0.4594 | 8.245351 | 26.090702 | 177.3198 | | 176.6984 | 175.4239 | 176.0496 | 244.327 | 401.4949906 | 0.050482465 |
| 3:00 PM | 4:00 PM | 186.954 | 0.646537 | 5.359478 | 16.958956 | 198.6176 | | 198.2137 | 197.3852 | 197.7919 | 247.2128 | 410.6267363 | 0.032813602 |
| 4:00 PM | 5:00 PM | 94.70173 | 0.774843 | 3.483661 | 0 | 210.3637 | | 210.1012 | 170.1012 | 210.1012 | 249.0887 | 427.5856925 | 0.00512184 |
| 5:00 PM | 6:00 PM | 11.66497 | 0.845607 | 2.264379 | 0 | 211.4748 | | 211.3041 | 171.3041 | 211.3041 | 250.3079 | 427.5856925 | 0.003329196 |
| 6:00 PM | 7:00 PM | 0 | 0.8523 | 0 | 0 | 211.3641 | | 181.3641 | 141.3641 | 176.3641 | 252.5723 | 427.5856925 | 0 |
| 7:00 PM | 8:00 PM | 0 | 0.851633 | 0 | 0 | 211.2535 | | 181.2535 | 141.2535 | 176.2535 | 252.5723 | 427.5856925 | 0 |
| | | | | | | | | | | | 203.5645 | 328.3098837 | 0.218013546 |

| 9/23 | m,dhw (gph) | 1800 | m, ga (gph) | 1800 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Time | End Time | Qu,array (MBH) | tank Loss (MBH) | DHW load (MBH) | GA load (MBH) | Ts (F) | | Tr,dhw (F) | Tr,ga (F) | Tr (F) | Aux needed, DHW (MBH) | Aux needed, GA (MBH) | Solar Fraction |
| 6:00 AM | 7:00 AM | 0 | 0.481952 | 0 | 0 | 149.9374 | | 119.9374 | 79.93741 | 114.9374 | 252.5723 | 427.5856925 | 0 |
| 7:00 AM | 8:00 AM | 0 | 0.481575 | 0 | 0 | 149.8749 | | 119.8749 | 79.87486 | 114.8749 | 252.5723 | 427.5856925 | 0 |
| 8:00 AM | 9:00 AM | 10.40482 | 0.481198 | 287.5145 | 0 | 113.8233 | | 94.32325 | 54.32325 | 94.32325 | -34.9422 | 427.5856925 | 0.422717239 |
| 9:00 AM | 10:00 AM | 215.7397 | 0.264009 | 186.8844 | 570.23713 | 43.47797 | | 30.80297 | 4.802973 | 17.80297 | 65.68788 | -142.6514336 | 1.113155397 |
| 10:00 AM | 11:00 AM | 338.6806 | -0.159779 | 121.4749 | 370.65413 | 23.56988 | | 15.33113 | -1.568866 | 6.881134 | 131.0974 | 56.93156052 | 0.723551008 |
| 11:00 AM | 12:00 PM | 407.1609 | -0.279713 | 78.95867 | 240.92519 | 34.94115 | | 29.58597 | 18.60097 | 24.09347 | 173.6136 | 186.6605067 | 0.470308155 |
| 12:00 PM | 1:00 PM | 367.5732 | -0.211208 | 51.32314 | 156.60137 | 55.70267 | | 52.2218 | 45.08155 | 48.65167 | 201.2492 | 270.9843217 | 0.305700301 |
| 1:00 PM | 2:00 PM | 378.2301 | -0.086133 | 33.36004 | 101.79089 | 87.28333 | | 85.02076 | 80.3796 | 82.70018 | 219.2123 | 325.7948015 | 0.198705196 |
| 2:00 PM | 3:00 PM | 303.2952 | 0.104122 | 21.68403 | 66.164079 | 115.2506 | | 113.7799 | 110.7632 | 112.2716 | 230.8883 | 361.4216134 | 0.129158377 |
| 3:00 PM | 4:00 PM | 204.1733 | 0.272607 | 14.09462 | 43.006651 | 134.3159 | 185 | 133.36 | 131.3991 | 132.3795 | 238.4777 | 384.5790411 | 0.083952945 |
| 4:00 PM | 5:00 PM | 96.11662 | 0.387464 | 9.161501 | 0 | 145.5587 | | 144.9374 | 104.9374 | 144.9374 | 243.4108 | 427.5856925 | 0.013469666 |
| 5:00 PM | 6:00 PM | 0 | 0.455196 | 0 | 0 | 145.4996 | | 115.4996 | 75.49961 | 110.4996 | 252.5723 | 427.5856925 | 0 |
| 6:00 PM | 7:00 PM | 0 | 0.454839 | 0 | 0 | 145.4405 | | 115.4405 | 75.44054 | 110.4405 | 252.5723 | 427.5856925 | 0 |
| | | | | | | | | | | | 190.6911 | 308.402659 | 0.266209099 |

| 11/30 | m,dhw (gph) | 900 | m, ga (gph) | 900 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Time | End Time | Qu,array (MBH) | tank Loss (MBH) | DHW load (MBH) | GA load (MBH) | Ts (F) | Tr,dhw (F) | Tr,ga (F) | Tr (F) | Aux needed, DHW (MBH) | Aux needed, GA (MBH) | Solar Fraction |
| 6:00 AM | 7:00 AM | 0 | 0.481952 | 0 | 0 | 149.9374 | 119.9374 | 79.93741 | 114.9374 | 252.5723 | 427.5856925 | 0 |
| 7:00 AM | 8:00 AM | 14.26795 | 0.481575 | 143.7573 | 0 | 133.0577 | 113.5577 | 73.55768 | 113.5577 | 108.8151 | 427.5856925 | 0.21135862 |
| 8:00 AM | 9:00 AM | 0 | 0.379884 | 0 | 0 | 133.0083 | 103.0083 | 63.00834 | 98.00834 | 252.5723 | 427.5856925 | 0 |
| 9:00 AM | 10:00 AM | 0 | 0.379587 | 0 | 0 | 132.959 | 102.959 | 62.95904 | 97.95904 | 252.5723 | 427.5856925 | 0 |
| 10:00 AM | 11:00 AM | 2.621926 | 0.37929 | 0 | 0 | 133.2503 | 103.2503 | 63.2503 | 98.2503 | 252.5723 | 427.5856925 | 0 |
| 11:00 AM | 12:00 PM | 38.88206 | 0.381045 | 143.7573 | 0 | 119.5803 | 100.0803 | 60.08034 | 100.0803 | 108.8151 | 427.5856925 | 0.21135862 |
| 12:00 PM | 1:00 PM | 73.02523 | 0.298692 | 93.44222 | 0 | 116.8899 | 104.2149 | 64.21492 | 104.2149 | 159.1301 | 427.5856925 | 0.137383103 |
| 1:00 PM | 2:00 PM | 99.09835 | 0.282483 | 60.73744 | 252.41379 | 89.05351 | 80.81476 | 54.81476 | 67.81476 | 191.8349 | 175.1719058 | 0.460409527 |
| 2:00 PM | 3:00 PM | 45.23548 | 0.114786 | 39.47934 | 0 | 89.78617 | 84.43098 | 44.43098 | 84.43098 | 213.093 | 427.5856925 | 0.058044361 |
| 3:00 PM | 4:00 PM | 0 | 0.1192 | 0 | 0 | 89.77069 | 59.77069 | 19.77069 | 54.77069 | 252.5723 | 427.5856925 | 0 |
| | | | | | | | | | | 204.455 | 402.3443138 | 0.107855423 |

| 1/12 | m,dhw (gph) | 1200 | m, ga (gph) | 1800 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Time | End Time | Qu,array (MBH) | tank Loss (MBH) | DHW load (MBH) | GA load (MBH) | Ts (F) | Tr,dhw (F) | Tr,ga (F) | Tr (F) | Aux needed, DHW (MBH) | Aux needed, GA (MBH) | Solar Fraction |
| 8:00 AM | 9:00 AM | 0 | 0.481952 | 0 | 0 | 149.9374 | 119.9374 | 79.93741 | 114.9374 | 252.5723 | 427.5856925 | 0 |
| 9:00 AM | 10:00 AM | 2.781165 | 0.481575 | 0 | 0 | 150.2361 | 120.2361 | 80.23606 | 115.2361 | 252.5723 | 427.5856925 | 0 |
| 10:00 AM | 11:00 AM | 26.85756 | 0.483374 | 191.6763 | 0 | 128.7677 | 109.2677 | 69.26774 | 109.2677 | 60.89598 | 427.5856925 | 0.281811493 |
| 11:00 AM | 12:00 PM | 289.4167 | 0.35404 | 124.5896 | 570.23713 | 76.06988 | 63.39488 | 37.39488 | 47.79488 | 127.9827 | -142.6514336 | 1.021566662 |
| 12:00 PM | 1:00 PM | 204.1633 | 0.036567 | 80.98326 | 370.65413 | 43.92488 | 35.68613 | 18.78613 | 25.54613 | 171.5891 | 56.93156052 | 0.66401833 |
| 1:00 PM | 2:00 PM | 306.9792 | -0.157087 | 52.63912 | 240.92519 | 45.68752 | 40.33233 | 29.34733 | 33.74133 | 199.9332 | 186.6605067 | 0.431611915 |
| 2:00 PM | 3:00 PM | 245.7496 | -0.146468 | 34.21543 | 156.60137 | 52.84084 | 49.35997 | 42.21972 | 45.07582 | 218.3569 | 270.9843217 | 0.280547744 |
| 3:00 PM | 4:00 PM | 33.1225 | -0.103374 | 22.24003 | 0 | 54.2676 | 52.00504 | 12.00504 | 52.00504 | 230.3323 | 427.5856925 | 0.032698323 |
| 4:00 PM | 5:00 PM | 19.346 | -0.094778 | 14.45602 | 0 | 54.91499 | 53.44432 | 13.44432 | 53.44432 | 238.1163 | 427.5856925 | 0.02125391 |
| | | | | | | | | | | 194.7057 | 278.872602 | 0.303723153 |

| | Original Design Load Calc | | | | | | Self-Designed Load Calc | | |
|---|---|---|---|---|---|---|---|---|---|
| | mdot (gal/hr) | cp (btu/lbF) | density (lb/gal) | weight of water (lb/gal) | temp rise(F) | Load (MBH) | Mdot Chosen(gal/hr) | To (F) | mixed temp |
| DHW | 332 | - | | 8.36 | 91 | 252.5723 | 1800 | 132.87 | 126.9349 |
| Geo auxiliary | 3480 | 0.947 | 8.649733 | - | 30 | 855.1714 | 1800 | 121 | |
| *assumed pipe loss is negligable | | | | | | 427.5857 | | | |

| | |
|---|---|
| $V_{tank}$(gal) | 940 |
| Ts,i(F) | 150 |
| Ta,mech.rm. | 70 |
| cp (btu/galF) | 8.191 |
| $\varepsilon_{hx\ (estimated)}$ | 0.650 |
| $UA_{tank}$ (Btu/h | 6.024 |

| Tank Characteristics | | | |
|---|---|---|---|
| $V_{tank}$(gal) | 940.00 | R of foam | 16 |
| h (Ft) | 10.67 | R of fg | 13 |
| Dia (Ft) | 4.33 | U | 0.0345 |
| SA (ft2) | 174.71 | | |

| 12/21 | m,dhw (gph) | 600 | m, ga (gph) | 600 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Time | End Time | Qu,array (MBH) | tank Loss (MBH) | DHW load (MBH) | GA load (MBH) | Ts (F) | Tr,dhw (F) | Tr,ga (F) | Tr (F) | Aux needed, DHW (MBH) | Aux needed, GA (MBH) | Solar Fraction |
| 7:00 AM | 8:00 AM | 0 | 0.481952 | 0 | 0 | 149.9374 | 119.9374 | 79.93741 | 114.93741 | 252.57232 | 427.5856925 | 0 |
| 8:00 AM | 9:00 AM | 0 | 0.481575 | 0 | 0 | 149.8749 | 119.8749 | 79.87486 | 114.87486 | 252.57232 | 427.5856925 | 0 |
| 9:00 AM | 10:00 AM | 0 | 0.481198 | 0 | 0 | 149.8124 | 119.8124 | 79.81237 | 114.81237 | 252.57232 | 427.5856925 | 0 |
| 10:00 AM | 11:00 AM | 0 | 0.480821 | 0 | 0 | 149.7499 | 119.7499 | 79.74992 | 114.74992 | 252.57232 | 427.5856925 | 0 |
| 11:00 AM | 12:00 PM | 0 | 0.480445 | 0 | 0 | 149.6875 | 119.6875 | 79.68753 | 114.68753 | 252.57232 | 427.5856925 | 0 |
| 12:00 PM | 1:00 PM | 0 | 0.480069 | 0 | 0 | 149.6252 | 119.6252 | 79.62518 | 114.62518 | 252.57232 | 427.5856925 | 0 |
| 1:00 PM | 2:00 PM | 2.133135 | 0.479694 | 0 | 0 | 149.8399 | 119.8399 | 79.83992 | 114.83992 | 252.57232 | 427.5856925 | 0 |
| 2:00 PM | 3:00 PM | 0 | 0.480987 | 0 | 0 | 149.7774 | 119.7774 | 79.77745 | 114.77745 | 252.57232 | 427.5856925 | 0 |
| 3:00 PM | 4:00 PM | 0 | 0.480611 | 0 | 0 | 149.715 | 119.715 | 79.71503 | 114.71503 | 252.57232 | 427.5856925 | 0 |
| 4:00 PM | 5:00 PM | 0 | 0.480235 | 0 | 0 | 149.6527 | 119.6527 | 79.65266 | 114.65266 | 252.57232 | 427.5856925 | 0 |
| | | | | | | | | | | 252.57232 | 427.5856925 | 0 |

| 3/20 | m,dhw (gph) | 1500 | m, ga (gph) | 2400 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Time | End Time | Qu,array (MBH) | tank Loss (MBH) | DHW load (MBH) | GA load (MBH) | Ts (F) | Tr,dhw (F) | Tr,ga (F) | Tr (F) | Aux needed, DHW (MBH) | Aux needed, GA (MBH) | Solar Fraction |
| 6:00 AM | 7:00 AM | 0 | 0.481952 | 0 | 0 | 149.9374 | 119.9374 | 79.93741 | 114.93741 | 252.57232 | 427.5856925 | 0 |
| 7:00 AM | 8:00 AM | 0 | 0.481575 | 0 | 0 | 149.8749 | 119.8749 | 79.87486 | 114.87486 | 252.57232 | 427.5856925 | 0 |
| 8:00 AM | 9:00 AM | 313.0291 | 0.481198 | 239.5954 | 894.48961 | 43.17922 | 23.67922 | -2.32078 | 7.6792201 | 12.97688885 | -466.903917 | 1.667384666 |
| 9:00 AM | 10:00 AM | 523.1429 | -0.161579 | 155.737 | 581.41825 | 15.40574 | 2.730736 | -14.16926 | -7.669264 | 96.83528975 | -153.832554 | 1.083800033 |
| 10:00 AM | 11:00 AM | 610.6833 | -0.328897 | 101.2291 | 377.92186 | 32.53098 | 24.29223 | 13.30723 | 17.532227 | 151.3432503 | 49.66383245 | 0.704470022 |
| 11:00 AM | 12:00 PM | 612.8735 | -0.225728 | 65.7989 | 245.64921 | 71.70737 | 66.35218 | 59.21193 | 61.958179 | 186.7734247 | 181.9364835 | 0.457905514 |
| 12:00 PM | 1:00 PM | 541.9901 | 0.010286 | 42.76928 | 159.67199 | 115.8043 | 112.3234 | 107.6823 | 109.46735 | 209.8030381 | 267.9137066 | 0.297638584 |
| 1:00 PM | 2:00 PM | 413.9699 | 0.275943 | 27.80003 | 103.78679 | 152.4425 | 150.1799 | 147.1631 | 148.32344 | 224.7722867 | 323.7989017 | 0.19346508 |
| 2:00 PM | 3:00 PM | 213.2296 | 0.496666 | 18.07002 | 67.461414 | 168.9625 | 167.4919 | 165.531 | 166.28516 | 234.5022984 | 360.1242785 | 0.125752302 |
| 3:00 PM | 4:00 PM | 115.4502 | 0.596189 | 11.74551 | 43.849919 | 176.6586 | 175.7027 | 174.4281 | 174.91834 | 240.8268059 | 383.7357734 | 0.081738996 |
| 4:00 PM | 5:00 PM | 0 | 0.642554 | 0 | 0 | 176.5752 | 146.5752 | 106.5752 | 141.57518 | 252.57232 | 427.5856925 | 0 |
| 5:00 PM | 6:00 PM | 0 | 0.642051 | 0 | 0 | 176.4918 | 146.4918 | 106.4918 | 141.4918 | 252.57232 | 427.5856925 | 0 |
| | | | | | | | | | | 197.3435469 | 221.3982729 | 0.384346266 |

| 6/21 | m,dhw (gph) | 2100 | m, ga (gph) | 2100 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Time | End Time | Qu,array (MBH) | tank Loss (MBH) | DHW load (MBH) | GA load (MBH) | Ts (F) | Tr,dhw (F) | Tr,ga (F) | Tr (F) | Aux needed, DHW (MBH) | Aux needed, GA (MBH) | Solar Fraction |
| 5:00 AM | 6:00 AM | 0 | 0.481952 | 0 | 0 | 149.9374 | 119.9374 | 79.93741 | 114.93741 | 252.57232 | 427.5856925 | 0 |
| 6:00 AM | 7:00 AM | 0 | 0.481575 | 0 | 0 | 149.8749 | 119.8749 | 79.87486 | 114.87486 | 252.57232 | 427.5856925 | 0 |
| 7:00 AM | 8:00 AM | 287.8563 | 0.481198 | 335.4336 | 782.67841 | 41.98442 | 22.48442 | -3.515581 | 9.4844189 | -82.86128361 | -355.092716 | 1.643900375 |
| 8:00 AM | 9:00 AM | 481.5536 | -0.168777 | 218.0318 | 508.74097 | 10.15893 | -2.516066 | -19.41607 | -10.96607 | 34.54047765 | -81.155273 | 1.068535244 |
| 9:00 AM | 10:00 AM | 601.894 | -0.360506 | 141.7207 | 330.68163 | 27.02325 | 18.7845 | 7.799501 | 13.292001 | 110.8516225 | 96.90406495 | 0.694547909 |
| 10:00 AM | 11:00 AM | 612 | -0.258909 | 92.11845 | 214.94306 | 66.6602 | 61.30501 | 54.16476 | 57.73489 | 160.4538666 | 212.6426346 | 0.451456141 |
| 11:00 AM | 12:00 PM | 581.6336 | -0.02012 | 59.87699 | 139.71299 | 116.28 | 112.7992 | 108.158 | 110.47859 | 192.6953253 | 287.8727049 | 0.293446491 |
| 12:00 PM | 1:00 PM | 487.2437 | 0.278809 | 38.92005 | 90.813442 | 162.6748 | 160.4122 | 157.3955 | 158.90387 | 213.6522734 | 336.7722505 | 0.190740219 |
| 1:00 PM | 2:00 PM | 387.1472 | 0.55831 | 25.29803 | 59.028737 | 201.9306 | 200.4599 | 198.499 | 199.47944 | 227.2742897 | 368.5569552 | 0.123981143 |
| 2:00 PM | 3:00 PM | 323.4228 | 0.794802 | 16.44372 | 38.368679 | 236.7126 | 194.0441 | 192.7695 | 193.40678 | 236.1286003 | 389.2170133 | 0.080587743 |
| 3:00 PM | 4:00 PM | 272.1585 | 1.004343 | 477.0823 | 491.33354 | 146.157 | 118.4225 | 117.594 | 118.00823 | -224.5099953 | -63.7478465 | 1.423810109 |
| 4:00 PM | 5:00 PM | 226.956 | 0.4588 | 310.1035 | 319.3668 | 93.82163 | 75.79416 | 75.25565 | 75.524906 | -57.53118493 | 108.2188922 | 0.925476571 |
| 5:00 PM | 6:00 PM | 154.6463 | 0.143511 | 201.5673 | 207.58842 | 60.74904 | 49.03119 | 48.68116 | 48.856175 | 51.0050418 | 219.9972723 | 0.601559771 |
| 6:00 PM | 7:00 PM | 109.2878 | -0.055731 | 131.0187 | 134.93247 | 40.40991 | 32.79331 | 32.56579 | 32.679547 | 121.5535892 | 292.6532194 | 0.391013851 |
| 7:00 PM | 8:00 PM | 73.21783 | -0.178262 | 85.16218 | 0 | 38.88181 | 33.93102 | -6.068979 | 33.931021 | 167.410145 | 427.5856925 | 0.125209398 |
| | | | | | | | | | | 110.3871605 | 206.3730833 | 0.534284331 |

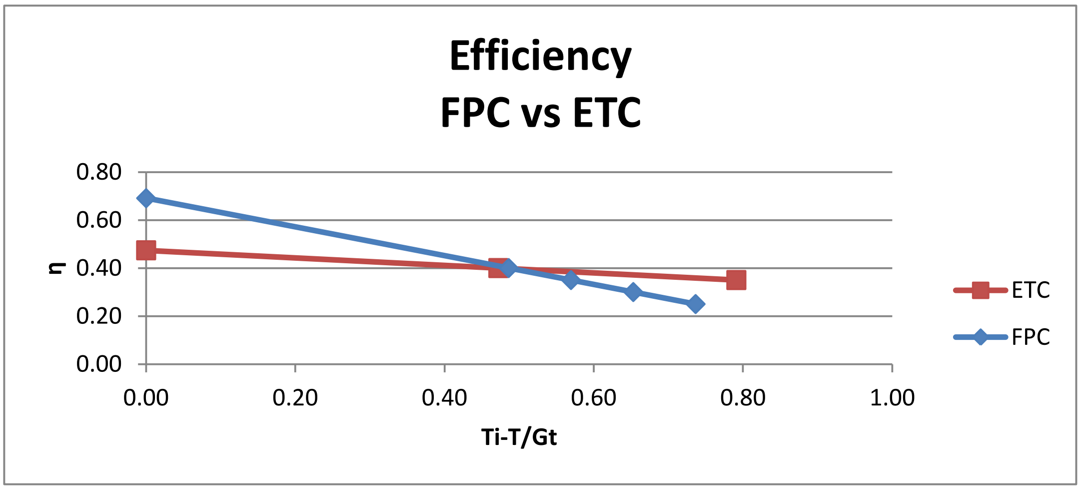
| 9/23 | $m_{dhw}$ (gph) | 2400 | $m_{ga}$ (gph) | 2400 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Time | End Time | Qu,array (MBH) | tank Loss (MBH) | DHW load (MBH) | GA load (MBH) | Ts (F) | Tr,dhw (F) | Tr,ga (F) | Tr (F) | Aux needed, DHW (MBH) | Aux needed, GA (MBH) | Solar Fraction |
| 6:00 AM | 7:00 AM | 0.00 | 0.48 | 0.00 | 0.00 | 149.94 | 119.94 | 79.94 | 114.94 | 252.57 | 427.59 | 0.00 |
| 7:00 AM | 8:00 AM | 0.00 | 0.48 | 0.00 | 0.00 | 149.87 | 119.87 | 79.87 | 114.87 | 252.57 | 427.59 | 0.00 |
| 8:00 AM | 9:00 AM | 0.00 | 0.48 | 0.00 | 0.00 | 149.81 | 119.81 | 79.81 | 114.81 | 252.57 | 427.59 | 0.00 |
| 9:00 AM | 10:00 AM | 459.72 | 0.48 | 383.35 | 894.49 | 43.50 | 24.00 | -2.00 | 11.00 | -130.78 | -466.90 | 1.88 |
| 10:00 AM | 11:00 AM | 668.41 | -0.16 | 249.18 | 581.42 | 22.45 | 9.78 | -7.12 | 1.33 | 3.39 | -153.83 | 1.22 |
| 11:00 AM | 12:00 PM | 728.08 | -0.29 | 161.97 | 377.92 | 46.93 | 38.69 | 27.71 | 33.20 | 90.61 | 49.66 | 0.79 |
| 12:00 PM | 1:00 PM | 605.08 | -0.14 | 105.28 | 245.65 | 79.96 | 74.60 | 67.46 | 71.03 | 147.29 | 181.94 | 0.52 |
| 1:00 PM | 2:00 PM | 555.08 | 0.06 | 68.43 | 159.67 | 122.42 | 118.93 | 114.29 | 116.61 | 184.14 | 267.91 | 0.34 |
| 2:00 PM | 3:00 PM | 386.77 | 0.32 | 44.48 | 103.79 | 153.35 | 151.09 | 148.07 | 149.58 | 208.09 | 323.80 | 0.22 |
| 3:00 PM | 4:00 PM | 202.66 | 0.50 | 28.91 | 67.46 | 167.09 | 165.62 | 163.66 | 164.64 | 223.66 | 360.12 | 0.14 |
| 4:00 PM | 5:00 PM | 24.23 | 0.58 | 18.79 | 0.00 | 167.72 | 166.76 | 126.76 | 166.76 | 233.78 | 427.59 | 0.03 |
| 5:00 PM | 6:00 PM | 0.00 | 0.59 | 0.00 | 0.00 | 167.64 | 137.64 | 97.64 | 132.64 | 252.57 | 427.59 | 0.00 |
| 6:00 PM | 7:00 PM | 0.00 | 0.59 | 0.00 | 0.00 | 167.56 | 137.56 | 97.56 | 132.56 | 252.57 | 427.59 | 0.00 |
| | | | | | | | | | Hourly Average | 171.0036705 | 240.6319144 | 0.394794184 |

| 11/30 | m,dhw (gph) | 1680 | m, ga (gph) | 900 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Time | End Time | Qu,array (MBH) | tank Loss (MBH) | DHW load (MBH) | GA load (MBH) | Ts (F) | Tr,dhw (F) | Tr,ga (F) | Tr (F) | Aux needed, DHW (MBH) | Aux needed, GA (MBH) | Solar Fraction |
| 6:00 AM | 7:00 AM | 0 | 0.481952 | 0 | 0 | 149.9374 | 119.9374 | 79.93741 | 114.93741 | 252.57232 | 427.5856925 | 0 |
| 7:00 AM | 8:00 AM | 0 | 0.481575 | 0 | 0 | 149.8749 | 119.8749 | 79.87486 | 114.87486 | 252.57232 | 427.5856925 | 0 |
| 8:00 AM | 9:00 AM | 0 | 0.481198 | 0 | 0 | 149.8124 | 119.8124 | 79.81237 | 114.81237 | 252.57232 | 427.5856925 | 0 |
| 9:00 AM | 10:00 AM | 0 | 0.480821 | 0 | 0 | 149.7499 | 119.7499 | 79.74992 | 114.74992 | 252.57232 | 427.5856925 | 0 |
| 10:00 AM | 11:00 AM | 0 | 0.480445 | 0 | 0 | 149.6875 | 119.6875 | 79.68753 | 114.68753 | 252.57232 | 427.5856925 | 0 |
| 11:00 AM | 12:00 PM | 0 | 0.480069 | 0 | 0 | 149.6252 | 119.6252 | 79.62518 | 114.62518 | 252.57232 | 427.5856925 | 0 |
| 12:00 PM | 1:00 PM | 0 | 0.479694 | 0 | 0 | 149.5629 | 119.5629 | 79.56288 | 114.56288 | 252.57232 | 427.5856925 | 0 |
| 1:00 PM | 2:00 PM | 136.0334 | 0.479318 | 268.3469 | 335.4336 | 88.75282 | 69.25282 | 43.25282 | 60.183053 | -15.77456289 | 92.1520889 | 0.887706203 |
| 2:00 PM | 3:00 PM | 51.25877 | 0.112974 | 174.4255 | 0 | 72.7421 | 60.0671 | 20.0671 | 60.067096 | 78.14684612 | 427.5856925 | 0.256448459 |
| 3:00 PM | 4:00 PM | 0 | 0.016519 | 0 | 0 | 72.73995 | 42.73995 | 2.739951 | 37.739951 | 252.57232 | 427.5856925 | 0 |
| | | | | | | | | | | 208.2950843 | 394.0423322 | 0.114415466 |

| 1/12 | m,dhw (gph) | 1680 | m, ga (gph) | 1800 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Time | End Time | Qu,array (MBH) | tank Loss (MBH) | DHW load (MBH) | GA load (MBH) | Ts (F) | Tr,dhw (F) | Tr,ga (F) | Tr (F) | Aux needed, DHW (MBH) | Aux needed, GA (MBH) | Solar Fraction |
| 8:00 AM | 9:00 AM | 0 | 0.481952 | 0 | 0 | 149.9374 | 119.9374 | 79.93741 | 114.93741 | 252.57232 | 427.5856925 | 0 |
| 9:00 AM | 10:00 AM | 0 | 0.481575 | 0 | 0 | 149.8749 | 119.8749 | 79.87486 | 114.87486 | 252.57232 | 427.5856925 | 0 |
| 10:00 AM | 11:00 AM | 0 | 0.481198 | 0 | 0 | 149.8124 | 119.8124 | 79.81237 | 114.81237 | 252.57232 | 427.5856925 | 0 |
| 11:00 AM | 12:00 PM | 476.3898 | 0.480821 | 268.3469 | 670.86721 | 89.64146 | 70.14146 | 44.14146 | 56.69318 | -15.77456289 | -243.281515 | 1.380876315 |
| 12:00 PM | 1:00 PM | 353.8289 | 0.118328 | 174.4255 | 436.06368 | 56.2928 | 43.6178 | 26.7178 | 34.876424 | 78.14684612 | -8.47799218 | 0.897569605 |
| 1:00 PM | 2:00 PM | 489.8029 | -0.082578 | 113.3766 | 283.4414 | 68.37978 | 60.14103 | 49.15603 | 54.459131 | 139.195762 | 144.1442975 | 0.583420243 |
| 2:00 PM | 3:00 PM | 356.9059 | -0.009761 | 73.69476 | 184.23691 | 81.23515 | 75.87996 | 68.73971 | 72.186727 | 178.8775573 | 243.3487857 | 0.379223158 |
| 3:00 PM | 4:00 PM | 0 | 0.067685 | 0 | 0 | 81.22636 | 51.22636 | 11.22636 | 46.226357 | 252.57232 | 427.5856925 | 0 |
| 4:00 PM | 5:00 PM | 0 | 0.067632 | 0 | 0 | 81.21757 | 51.21757 | 11.21757 | 46.217573 | 252.57232 | 427.5856925 | 0 |
| | | | | | | | | | | 182.5896892 | 252.6291154 | 0.360121036 |

| ETC | | | | |
|---|---|---|---|---|
| Date | Total $Q_{u,avg}$ (MBH) | Axililary For DHW (MBH) | Axililary for GA (MBH) | Solar Fraction |
| 12/21 | 35.27 | 218.83 | 427.59 | 5% |
| 3/20 | 237.68 | 185.04 | 296.14 | 29% |
| 6/21 | 225.06 | 203.56 | 328.31 | 22% |
| 9/23 | 257.93 | 190.69 | 308.40 | 27% |
| 11/30 | 45.52 | 204.45 | 402.34 | 11% |
| 1/12 | 141.05 | 194.71 | 278.87 | 30% |
| Hourly Average: | 157.09 | 199.55 | 340.28 | 21% |

| FPC | | | | |
|---|---|---|---|---|
| Date | Total $Q_{u,avg}$ (MBH) | Axililary For DHW (MBH) | Axililary for GA (MBH) | Solar Fraction |
| 12/21 | 2.13 | 252.57 | 427.59 | 0% |
| 3/20 | 418.05 | 197.34 | 221.40 | 38% |
| 6/21 | 353.77 | 110.39 | 206.37 | 53% |
| 9/23 | 453.75 | 171.00 | 240.63 | 39% |
| 11/30 | 93.65 | 208.30 | 394.04 | 11% |
| 1/12 | 419.23 | 182.59 | 252.63 | 36% |
| Hourly Average: | 290.10 | 187.03 | 290.44 | 30% |



## Solar Hot Water Collector

| | Company | type | Model | GPM | $F_r$*τα | $F_r$*Ul (btu/hr ft$^2$ °F) | CollectorArea (FT2) | working Temp (F) | Working Solution | Weight (Lb) |
|---|---|---|---|---|---|---|---|---|---|---|
| FPC-1 | Caleffi | FPC | NAS10410 | 0.593333 | 0.691 | 0.598775 | 39.9 | .-40 to 350 | 30% pg | 153.0 |

## Water Heater

| | MFG | Model | Draw Rate GPM | Temp Rise (F) | Max LT (F) | MBH input for DHW |
|---|---|---|---|---|---|---|
| WH-DHW | Lochnivar | STU150 | 16 | 91 | 140 | 676 |

## Heat Exchanger

| | | | Hot Side | | | Cold Side | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MFG | Efectiveness | GPM | ET (F) | LT (F) | GPM | ET (F) | LT (F) | HX MBH |
| HX-GA | Mueller | 0.7 | 30 | 150 | 121 | 58 | 64 | 79 | 430 |

## Water Pumps

| | | | | | Motor | | |
|---|---|---|---|---|---|---|---|
| | MFG | Model | Solution | GPM | RPM | Amps | Volts/ Phase |
| SHWP-1 | Bell & Gossett | NRF-25 | 30% pg | 0.6 | 3300 | 0.4 | 120/1 |
| GAWP-2 | Bell & Gossett | PL-30 | 30% pg | 30 | 2750 | 0.08 | 120/1 |
| DHWP-3 | Bell & Gossett | PL-30 | 30% pg | 25 | 2750 | 0.08 | 120/1 |

## Storage Tank

| | MFG | Model | Capacity | UA | Dimensions (in) |
|---|---|---|---|---|---|
| ST-1 | Lochnivar | RGA0 | 940 | 3.98 | 128x52 |

## Air Seperater

| | MFG | Model | Solution | GPM |
|---|---|---|---|---|
| AS-1 | Bell & Gossett | RL-1F | 30% pg | 0.6 |

### Expansion Tank

| | MFG | Model | Solution | GPM |
|---|---|---|---|---|
| ET-1 | Bell & Gossett | | 30% pg | 0.6 |

| | | |
|---|---|---|
| NG | $0.48 | per therm |
| Utility Cost of Original system | $12,371.40 | |
| FS | $3,686.60 | |

| | | | |
|---|---|---|---|
| C | 371450 | d | 0.06 |
| n | 16 | i_{fuel} | 0.03 |
| down payment | 74290 | C_{main} | 3714.5 |
| i | 0.0575 | i_{main} | 0.01 |
| FS_1 | $3,686.60 | V | 148580 |

| Year | Extra mortgage payment ($) : fixed | Fuel savings ($) : projected to increase by 1.03 each year | Extra insurance, maintenance, and parasitic cost ($) : projected to increase by 1.01 each year | Annual Solar savings ($) | PW of annual solar savings ($) : must use PW for each year | Cumulative Solar Savings ($) | Yearly Interest Payment ($) : need to multiply balance by 1.0575 | Principle Payment | Principle Balance (total system cost, less 20% Down Payment) | Periodic Payment Present Worth Factor (15, 0, 0.0575) | Present Worth for Savings (n, 0, d) : must use 1/(1+d)^n |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | $3,686.60 | | -$74,290.00 | -$74,290.00 | $0.00 | | $297,160.00 | $297,160.00 | 9.87288553 | 1.0000 |
| 1 | -$30,098.60 | $3,797.19 | -$3,714.50 | -$30,015.90 | -$28,316.89 | -$102,606.89 | $0.00 | -$30,098.60 | $267,061.40 | | 0.9434 |
| 2 | -$30,098.60 | $3,911.11 | -$3,751.65 | -$29,939.13 | -$26,645.72 | -$129,252.61 | $15,356.03 | -$14,742.57 | $252,318.84 | | 0.8900 |
| 3 | -$30,098.60 | $4,028.44 | -$3,789.16 | -$29,859.31 | -$25,070.46 | -$154,323.07 | $14,508.33 | -$15,590.26 | $236,728.57 | | 0.8396 |
| 4 | -$30,098.60 | $4,149.30 | -$3,827.05 | -$29,776.35 | -$23,585.66 | -$177,908.73 | $13,611.89 | -$16,486.70 | $220,241.87 | | 0.7921 |
| 5 | -$30,098.60 | $4,273.78 | -$3,865.32 | -$29,690.14 | -$22,186.20 | -$200,094.93 | $12,663.91 | -$17,434.69 | $202,807.18 | | 0.7473 |
| 6 | -$30,098.60 | $4,401.99 | -$3,903.98 | -$29,600.58 | -$20,867.24 | -$220,962.17 | $11,661.41 | -$18,437.18 | $184,370.00 | | 0.7050 |
| 7 | -$30,098.60 | $4,534.05 | -$3,943.02 | -$29,507.56 | -$19,624.22 | -$240,586.39 | $10,601.27 | -$19,497.32 | $164,872.68 | | 0.6651 |
| 8 | -$30,098.60 | $4,670.07 | -$3,982.45 | -$29,410.97 | -$18,452.81 | -$259,039.20 | $9,480.18 | -$20,618.42 | $144,254.26 | | 0.6274 |
| 9 | -$30,098.60 | $4,810.17 | -$4,022.27 | -$29,310.70 | -$17,348.96 | -$276,388.15 | $8,294.62 | -$21,803.98 | $122,450.28 | | 0.5919 |
| 10 | -$30,098.60 | $4,954.48 | -$4,062.49 | -$29,206.61 | -$16,308.82 | -$292,696.97 | $7,040.89 | -$23,057.71 | $99,392.57 | | 0.5584 |
| 11 | -$30,098.60 | $5,103.11 | -$4,103.12 | -$29,098.60 | -$15,328.78 | -$308,025.75 | $5,715.07 | -$24,383.52 | $75,009.05 | | 0.5268 |
| 12 | -$30,098.60 | $5,256.21 | -$4,144.15 | -$28,986.54 | -$14,405.42 | -$322,431.18 | $4,313.02 | -$25,785.58 | $49,223.47 | | 0.4970 |
| 13 | -$30,098.60 | $5,413.89 | -$4,185.59 | -$28,870.30 | -$13,535.52 | -$335,966.70 | $2,830.35 | -$27,268.25 | $21,955.23 | | 0.4688 |
| 14 | -$30,098.60 | $5,576.31 | -$4,227.45 | -$28,749.74 | -$12,716.04 | -$348,682.73 | $1,262.43 | -$28,836.17 | -$6,880.94 | | 0.4423 |
| 15 | -$30,098.60 | $5,743.60 | -$4,269.72 | -$28,624.72 | -$11,944.10 | -$360,626.83 | -$395.65 | -$30,494.25 | -$37,375.19 | | 0.4173 |
| 15 | | | | **Totals:** | $2,002.87 | -$358,623.96 | -$2,149.0737 | | | | |

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