THESIS FINAL REPORT

UNIVERSITY RIDGE
AT EAST STROUDSBURG UNIVERSITY
EAST STROUDSBURG, PA

PREPARED FOR:
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BY:
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MECHANICAL OPTION
APRIL 12, 2007

University Ridge at East Stroudsburg University

East Stroudsburg, PA

Project Team:

Owner: University Housing, Inc.
GC: Capstone Building Corp.
Architect: Design Collective, Inc.
Structural Engineer: Greenman-Pedersen Inc.
MEP Engineer: Greenman-Pedersen Inc.
Civil Engineer: Greenman-Pedersen Inc.

Mechanical System:

- Split system air handlers ranging from 2.5 to 3.5 tons per unit
- Operable windows provide natural ventilation

Electrical System:

- 208/120V 3 phase, 4 wire service provided by Met-Ed with a transformer for each building
- Incandecent Luminaires used for apartment lighting
- 125 KW, 208/120V 3 phase, 4 wire emergency fuel fired generator

Structural System:

- Reinforced concrete footing and foundation wall system
- Conventional wood construction is used in the framed walls
- Pre-engineered roof trusses compose the roofing system

Project Information:

Size: 140,000 ft^2, 544 Beds
Cost: $27,425,000 (Overall Project Cost)
Delivery Method: Design-Build
Stories and Buildings: 10 buildings at 3 Stories above grade
Function: Student Residence Complex with Amenity Space in a Central Community Building
Occupancy: Student Apartments, Four Bedrooms per Apartment, Community Buildging with Lounges, Offices, and Conference Room

Architecture:

- Rocky site features dramatic topography
- Site is split into an an upper and a lower quad
- Hilltop location leads to commanding vistas toward the Delaware Water Gap
- Utilization of stone foundation walls, clap board siding, board and batten siding, large brackets and deep roof overhangs incorporates traditional design elements of Pocono Lodges and railroad depots found in the area

Matthew Carr
Mechanical Option

http://www.arche.psu.edu/thesis/eportfolio/2007/portfolios/MWC138/

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Executive Summary

The following report contains a proposed redesign to the mechanical system for University Ridge at East Stroudsburg University from a conventional duct furnace system to a more environmentally friendly cogeneration system. University Ridge is a 140,000 ft^2 apartment complex which consists of ten buildings for student housing.

The following thesis will illustrate the effects of reducing the complex's dependency on the electrical grid. A combined heating, cooling, and power system is implemented in order to take care of the buildings thermal loads and reduce the amount of power purchased. This system is able to do this by harnessing otherwise waste exhaust heat from the production of electricity. Absorption cooling also harvests the waste heat which it uses as a "free" source of energy. Also, a chilled water storage tank is used in order to balance the buildings ever changing load thus resulting in a more efficient chiller operation. Additional equipment which will accompany the system are pumps, cooling towers, and piping which will be sized.

The new turbines will be located outside of the pump house where the absorption chiller will be located. The use of these efficient turbines will reduce the amount of pollutants released to the atmosphere as a result of using a clean burning fuel and the flattening of the loads on the prime mover. The additional first cost of this cogeneration system will be analyzed and a payback period will be identified and the systems feasibility will be justified from this.

Existing Mechanical Systems

The following is a list of major system components based on design data from University Ridge at East Stroudsburg. These buildings are each 4 stories and have an overall size of 140,000 ft^2. The primary use of the facility is apartments for student housing. There is also a commons area with lounges, offices and conference rooms. The following is a basic summary of the mechanical systems for these buildings.

University Ridge contains 153 apartment units with a dedicated duct furnace air handling unit for each of the units. These units are purely re-circulatory. Heating capacity is supplied by hot water coils with hot water supplied from the domestic water heaters. Cooling comes from individual condensing units for greater control. The duct furnace air handlers for the commons area are individually gas fired and are cooled in the same was as the apartments.

The water heaters that supply domestic hot water and hot water for the duct furnaces fired by natural gas and are sized according to the National Plumbing Code with adjustments for the HVAC demand. All other water heaters are electrically heated for spaces such as public bathrooms and mechanical rooms.

There are individual exhaust fans for each bathroom in which they are controlled intermittently.

Introduction to Redesign

Alternatives Considered

There are a few alternatives that would be available as viable mechanical systems. A few of the following were considered during design but due to financial restraints were not used. Due to these financial restraints, University Ridge offers many different options for a redesign alternative.

An initial redesign possibility would be the use of 4-pipe chiller and boiler system in each building to supply the heating and cooling. A replacement of the airside system would also be required and would be done so with the use of stacked vertical fan coils. The intent of this would be to increase the efficiency and lower the operating cost. However, this type of system ultimately has a higher initial cost than the original system and would be justified by a payback period. A variation of this type of system would be to use centralized boilers and chillers in an existing service building and run hot and chilled water to the buildings and using the same airside system. Furthermore, this system is not the most overall efficient system for a project like this.

A second option would be the utilization of a geothermal grounds source heat pump (GSHP) system. However, the site sits on a ridge where the ground is extremely rocky. Therefore, the drilling of wells for heat exchanging loops would be inefficient and very costly. This option was considered in the original design and because of the previous problem was not used and for the purposes of the redesign will not be used because of its ineffectiveness.

A third option would be the use of a combined heat and power cogeneration system. The use of this type of system has a couple of options available to produce heating, cooling, and electricity. Analysis of turbines, reciprocating engines, and various new fuel cells will be done to determine which of the previous would be the best solution and which one is more efficient to accomplish the required tasks. The potential benefits of the payback period and increased efficiency will also be determined.

Scope, Goals, and Justification

The main purpose of the mechanical system redesign for University Ridge at East Stroudsburg University is to see if the complex and university will benefit from creating its own power. The apartment complex would have had an easy integration as there is already a pump house and service trenches which could have been expanded to accommodate a cogeneration system.

With an increasing awareness of energy use and pollution, the overall goal of the redesign for University Ridge is to centralize the mechanical systems while reducing operating costs and increasing overall energy efficiency. Therefore, a combined heat and power, CHP, system was a natural choice to accomplish the above goals.

The CHP system will produce electricity while providing heating, cooling, and domestic hot water through the utilization of a prime movers waste heat such as exhaust gases. Natural gas will be used to fire the prime mover since natural gas is used to fire the domestic hot water heaters. The prime mover will produce enough electricity for the complex and any excess will be sold back to the power grid or used else where on the ESU campus. It will also produce enough thermal energy to provide enough heat to maintain thermal comfort in the buildings.

The CHP system will also have to be designed to either the peak thermal energy load or the peak electrical load. After determining the method as to which the prime mover will be sized, prime movers will be analyzed as to how well they will perform. Deciding criteria for selecting a prime mover will be characteristics such as how well they follow the load, efficiency of the unit and other defining characteristics. A variety of natural gas reciprocating engines and natural gas turbines will be analyzed for the CHP redesign.

The waste heat from the generation of electricity will be used for space heating through the use of heat exchangers. This waste heat will be used for both heating and for cooling where cooling uses absorption chillers. The absorption cooling process uses the waste heat as free energy to regenerate brine during the heat exchange cycle. Moreover, chilled water storage will be used to even out the load on the chiller. This will result in an overall increase in efficiency because the chillers will be running at an optimal rate.

In conclusion, in optimizing the mechanical system, the goal is to increase the way energy is used to produce heat and electric power for the buildings. This increase in efficiency is due to the production of heat and electricity from an onsite source, thus reducing transmission inefficiencies and possible generation inefficiencies from off site sources. Also, chilled water production will be optimized using the waste heat from power generation and the balancing of the cooling load using chilled water storage. This proposed redesign is assuming that the system can be integrated with the existing duct furnaces and the addition of the proposed equipment. The redesign will also reduce the need for the buildings to be dependent on the power grid.

Mechanical Design Conditions

In order to gain accurate data on the buildings loads and profiles, simulations must be used to calculate these loads and profiles. This data must be obtained for critical analyses of the buildings cooling, heating, and power consumption needs. The mechanical loads used in this report were generated by the use of Trane's Trace 700 Load calculation program. These loads calculated from the use of Trace include the peak design criteria for heating, cooling and power needed to size equipment. Also, the load profiles generated hourly over the course of a year give an estimate as to how energy will be needed over the course of a day. These profiles are calculated for design days, weekdays, weekends, and holidays. Monthly total usage is also determined from these calculations. These loads can be found in Appendix A.

Using the capabilities of Trace's Load calculation program, each spaces load was determined and can be added up to determine the overall capacities required for the centralization of the CHP system. Since the building has already been constructed, accurate wall type U-values and window U-values and shading coefficients were known. Also, miscellaneous internal loads were assumed using conventional power densities and miscellaneous appliance loads such as computers and refrigerators. Applying these values to the space with the known occupancy densities and weather data, accurate internal and thermal loads were obtained. However, the occupancy schedule was a variable since it is a collegiate residency and an occupancy schedule is difficult to determine. Outdoor air design conditions were based on ASHRAE weather data provided by TRACE for Allentown, PA.

Electricity use was also determined using Trace. Values for hourly demand and monthly use were obtained with the assumptions of power densities from lighting and appliances. Moreover, real data from an electric utility bill was used to make sure the values obtained in the program were close to the actual billing data. Using the obtained electrical data from Trace and looking at actual building electric profile data, a daily electric profile was assumed.

These results obtained from Trace and known data will be used to size the CHP system in the following sections. Profiles will be shown and utilized for analyses in later sections.

Combined, Heat, and Power Concepts

The basic concept of a cogeneration is fairly simple. Power is produced on-site to negate the inefficiencies caused in the transmission of electricity. With the production of electricity using a fuel, in this case natural gas, exhaust is produced which contains useful energy in the form of heat. This “waste” heat can then be harnessed for heating and cooling purposes. The following diagrams are basic schematics as to how gas turbines and reciprocating engines operate to achieve combined heat and power.

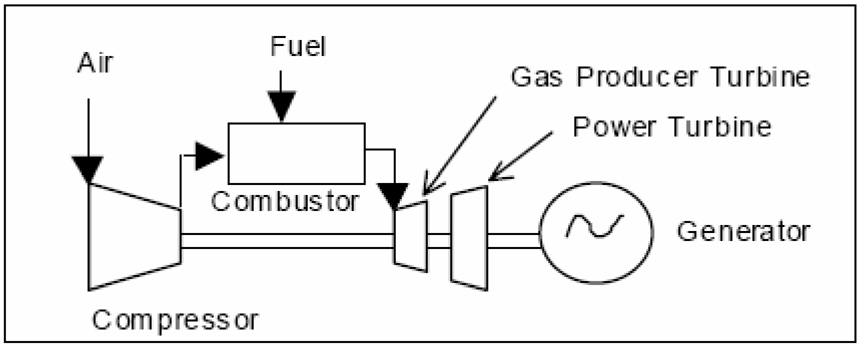


Figure 1: Gas turbine operation

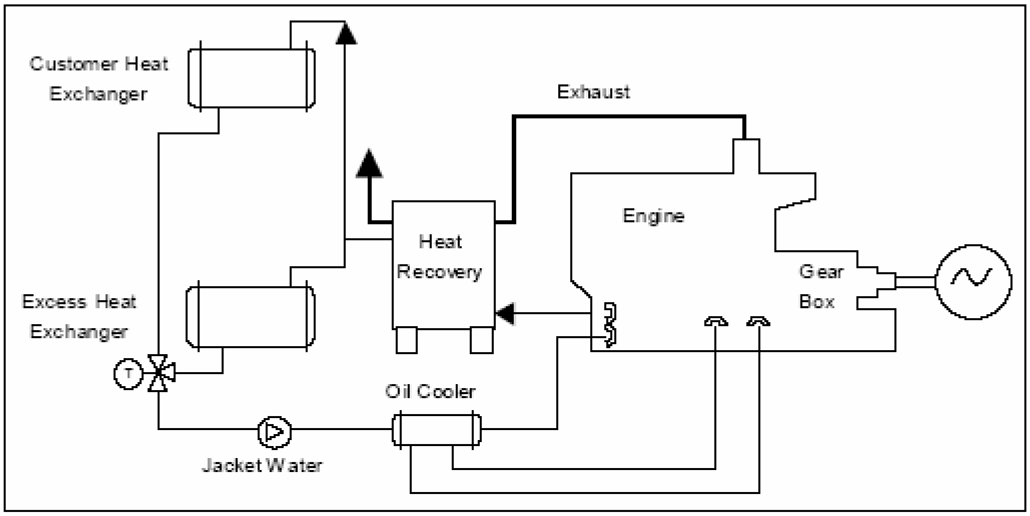


Figure 2: Reciprocating engine operation

The heat exchangers use the waste heat to heat spaces directly or for the use of regenerating heat for absorption cooling.

Mechanical System Redesign

Spark Gap Analysis

The calculation of a spark gap for the electric and natural gas costs is one of the first steps in determining the best solution for a CHP system. The spark gap is a ratio of the cost of electricity versus natural gas at the building location. This number can vary greatly depending on location due to how electricity is generated and how natural gas has to be transported.

In calculating the spark gap, utility costs were determined from an existing utility bill from Met-Ed and gas prices from DOE's website, which is located in Appendix B. The electric energy unit is then converted to $/BTU and both are then multiplied by 1,000,000 BTU to get to dollars per MMBTU. The difference between the both energy sources is determined to be the spark gap. The calculation is worked out below.

Natural Gas:

$1.33/therm

$$\frac{\$1.33}{therm} \cdot \frac{therm}{100{,}000 BTU} \cdot 1{,}000{,}000 BTU = \frac{\$13.30}{MMBTU}$$

Electricity:

$0.0919/kWh

$$\frac{\$0.0919}{kWh} \cdot \frac{kWh}{3{,}412 BTU} \cdot 1{,}000{,}000 BTU = \frac{\$26.94}{MMBTU}$$

$26.94 - $13.30 = **$13.64**

For CHP to be considered a feasible application, the spark gap should be no less then $12.00/MMBTU. As shown above, the spark gap is fairly close to $12.00 so the payback period and economic feasibility may not be at highly desirable levels.

Prime Mover Analysis

Fuel Cells

Fuel cells represent one of the cleanest and quietest methods of converting fuel into usable energy. This is done by converting the fuel, usually natural gas, from chemical energy into DC power and heat. A fuel cell is similar to a battery as it has an anode, electrolyte solution, and a cathode. Although fuel cells have a high efficiency and are capable of load following fairly well, they will not generate enough waste heat in order to meat the heating capacities needed. Also, fuel cells have a very high initial first cost relative to other prime movers and are unproven in long term use due to the technology being relatively new.

Reciprocating Engines

Reciprocating engines come in various forms of operating capabilities. The characteristics of these engines range from self ignited to diesel engines. They come in four-stroke and two stroke cycles and are capable of operating on a variety of different fuels such as gasoline, natural gas, diesel or multiple fuel operations. Reciprocating engines work on an open cycle, called the Otto cycle, that is to say that the cycle does not return to its original state point after a cycle is complete. Therefore, the ideal efficiencies are never realized due to this open cycle and is a function of the compression ratio.

These engines are available in a wide range of sizes and are efficient at small sizes. However, system maintenance is intensive due to the many moving internal parts. Also, reciprocating engines typically produce more pollutants compared to other prime movers. Another draw back is the amount of noise and vibration produced from the movement of the cylinders in the engine.

Gas Turbine Generator

Natural gas micro-turbines are a clean reliable way of generating electricity and heat for use in space conditioning. Gas turbines are typically applied to base loaded or peaking applications and are very reliable due to the few moving parts contained within them which intern leads to low maintenance costs. The fewer amount of moving parts also results in reduce vibration and noise levels. These turbines are also small relative to other prime movers, are capable of high temperature heat recovery. However, gas turbines are not very good at load following and lose efficiency at part load.

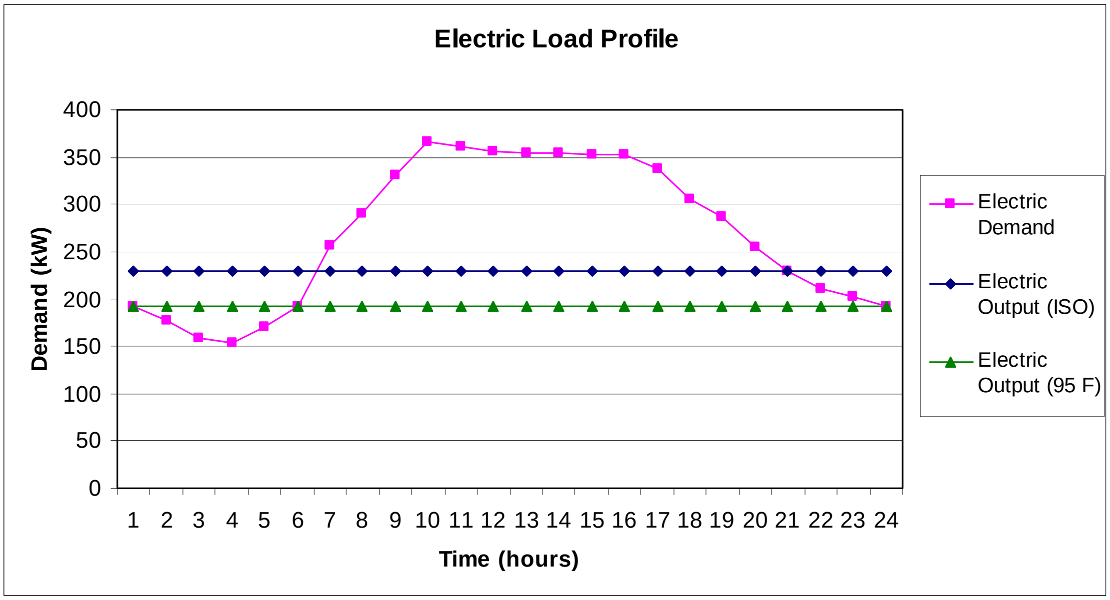
It is these factors of simplicity, cost effectiveness and efficiency at base loading that have driven my decision for choosing gas micro turbines for this system redesign.

Prime Mover Selection

After considerable analysis of prime movers and their associated technology, it was determined that a natural gas turbine would be the best option. Keeping efficiency, reliability, and ease of integration and maintenance in mind, use of the UTC Power Pure Comfort Solution integrated micro-turbine chiller/heater power system will power and condition the University Ridge complex. The micro-turbines come in sets of four, five or six 60 kW micro-turbines which allows for more efficient part load conditions. These part load conditions are achieved by simply turning off successive turbines to achieve a desired output.

Efficiency and reliability of the systems gas turbines are reliant on the fact that there are fewer moving parts compared to reciprocating engines. However, regular maintenance is required about every 40,000 hours of operation.

The Pure Comfort system is very versatile as it can be run connected to the grid, as stand alone and in a dual mode. In this case, Pure Comfort Model 240M will be run connected in parallel to the grid in order to run at a base output of 230 kilowatts. Since there is not an overly large difference in the spark gap, the remaining electricity will be supplied from the grid. As mentioned before, if there is less of a demand for electricity, the system can be turned down in order to operate more efficiently. The following load profile was obtained using TRACE 700 and by looking at actual profiles to get a variance in demand and the maximum demand was calculated at 366 kilowatts.



At the above output levels, adequate capacity for heating and cooling are produced for space conditioning. A gross efficiency ranges from 69% for power and heating at 32° F to 85% at ISO conditions of 59°F. Electrical efficiency is at about 27%. All values indicated are at a Low Heating Value (LHV).

Another benefit of this system is that it can be placed outside thus skipping a whole set of other problems such as noise, vibration, space, maintenance, and safety issues with units placed inside. The units come standard with weather proof casing which enables them to be placed outside as can be seen in a previous installation below. Also, emissions are lower than most conventional power plants due to the use of natural gas and its high fuel efficiency. However, this natural gas must be boosted to a higher pressure in order for the unit to work properly.

Figure 4: Outdoor installation of Pure Comfort Model 240 M

Equipment data for the Pure Comfort 240M can be found in Appendix C.

Absorption Cooling

For the cooling side of the load, a standard equipped model 16DNP Carrier indirectly fired double-effect absorption chiller will generate chilled water instead of a standard electrically driven chiller. The waste heat from the exhaust gases of the micro-turbines is a “free” source of energy used to regenerate a lithium bromide (LiBr) solution and water absorption refrigerant to produce either chilled or hot water. The total capacity of the chiller specified in this instance is 124 tons. The design day load however is 178 tons so a chilled water storage tank must be utilized in order to balance the load and will intern increase the efficiency of the unit since it will be running constantly. A diagram of the operation of flow of solution is pictured below in Figure 5.

The output of the absorption chiller can be changed according to needs of operation. The efficiency of the unit, coefficient of performance (COP), in this instance for a 95°F day is 1.20. For this situation, continuous operation down to 25% can be obtained. This enables the chillers to follow the cooling load and integrate into the chilled water storage more easily if needed.

Different types of chillers can be used to process chilled water. Direct fired absorption chillers use an outside source of fuel to gain the heating capacity needed instead of the hot water which will be used in this instance. Also, there are single-effect absorption chillers which have a much simpler operation of cooling the chilled water but are less efficient than double-effect cooling. For this redesign the double-effect absorption chiller operates as follows:

- LiBr solution absorbs water vapor.
- The weak LiBr solution is pumped to the generators to be re-concentrated in two stages.
- The weak solution is then pumped to the high temperature generator to be heated and regenerated to a medium solution.
- The medium solution is pumped to the low temperature generator to become a strong solution.
- Condensed water vapor on the tube side is cooled and returned to a liquid state to be used again.
- Refrigerant water returns to the evaporator to start the cycle over.

This process is illustrated in the diagram below. A conventional electrically powered condenser is replaced by the LiBr strong solution and the refrigerant liquid thus saving electrical energy. A benefit of using an absorption chiller is the elimination of Chlorofluorocarbons (CFC's), which are often blamed for the depletion of the ozone layer.

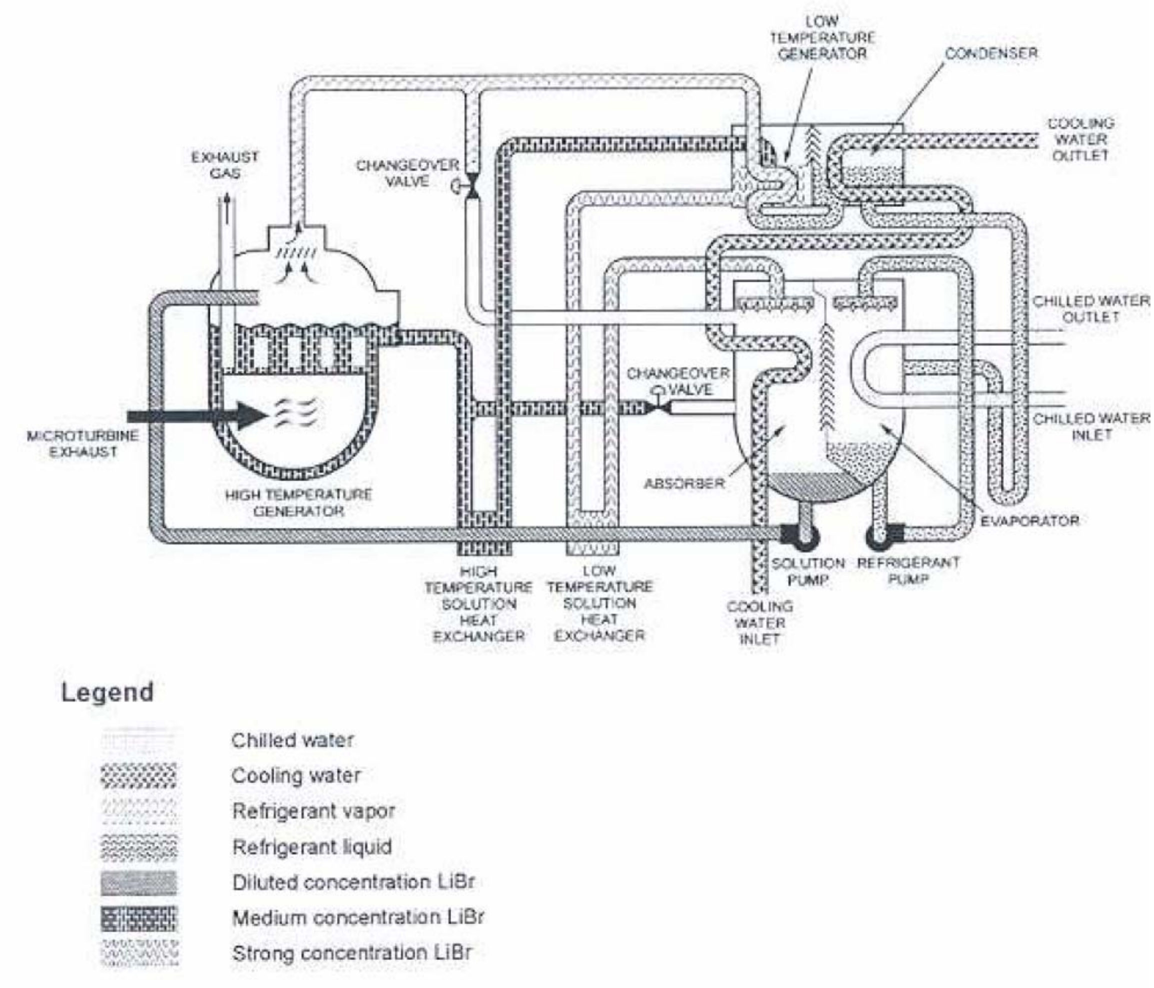


Figure 5: Absorption Cooling Cycle

Heating Cycle

The heating cycle for the selected equipment is handled under the use of the flow through the absorption chiller. The flow through the chiller takes a different path through the absorption chiller. This flow does not use the condenser section of the chiller as it is not needed. This process uses the high temperature generator, evaporator and absorber sections to evaporate and then condense the refrigerant liquid over the hot water section. This cycle produces hot water at 140°F for use in the heating of the building. The existing duct furnaces are set up for this 140°F water and can be used with this system. The following diagram illustrates this heating cycle.

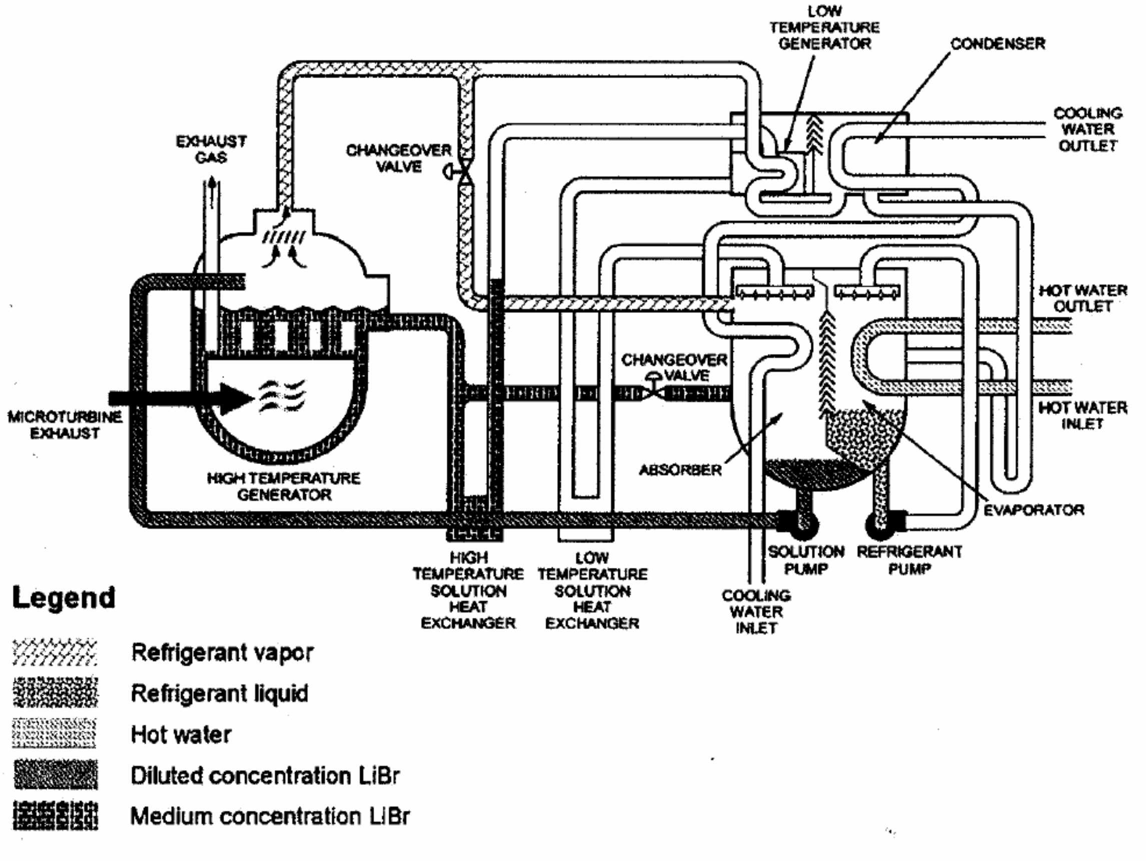


Figure 6: Heating Cycle

Cooling Tower

With the operation of an absorption chiller, the use of a cooling tower is needed for the process of using cooling water to cool the refrigerant and the LiBr solution in the section that acts as the condenser. This cooling water is sprayed over fill located in the cooling tower, which usually has a large surface area to increase heat transfer. As this liquid evaporates and absorbs heat from the fill, the warm cooling water from the absorption chiller is cooled down for recirculation through the chiller. However, since this is an open cycle, special care is needed in dealing with the cooling tower water. It must be treated so that it does not become contaminated. This water also must be replenished as a result of evaporation to the atmosphere.

The selection of the tower is dependent on the flow of the cooling water, the ambient temperature, and the temperature differential required by the chiller. The cooling tower selected is a Marley NC8302DL1 with one cell. This cooling tower was selected on the following criteria; 494 gpm, 95°F entering water temperature, 85°F leaving water temperature, and a 78°F wet-bulb temperature. The equipment data can be found in Appendix D. Also, for redundancy purposes, N+1 cooling towers should be installed for this application.

Chilled Water Storage

Absorption chillers operate at their peak efficiency when they are running at 100%. Therefore, in order to level the variant load in the building and keep the chiller running at constant speed, chilled water storage will be use to level the load and to also shift it. The shifting and leveling of the load also reduces the size of the chiller needed when operating on a load leveling partial storage scheme and hereby reducing the operating cost. The following graph is a representation of a design cooling day taken from TRACE and how the chiller and storage will handle the load. The areas below the blue line are when the system is charging during off peak hours and above the blue line is when the system is discharging during peak hours.

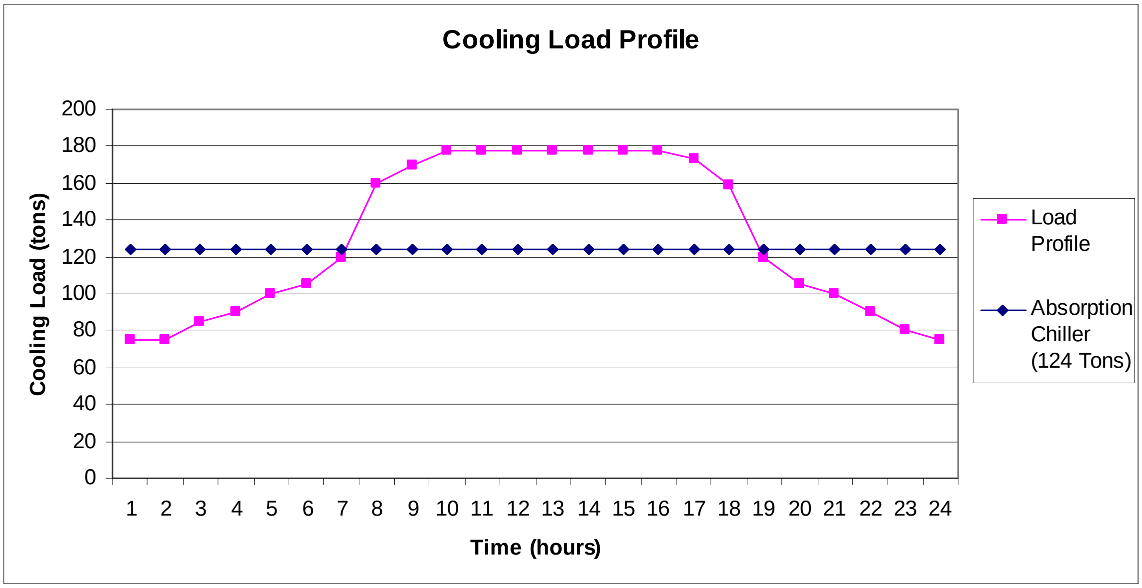


Figure 7: Cooling Load Profile

There are two kinds of thermal storage which can be implemented, sensible storage or latent storage. Latent storage uses the thermal capacity of water during phase change from a liquid state to a solid state or ice and also uses the sensible capacity. Sensible storage uses just the sensible of capacity of water with a change in water temperature. These two types of storage operate off of the same principle of loading and unloading as mentioned above.

For this case, a sensible storage system will be used. A vertical chilled water storage tank using naturally stratified water will store the thermal energy. The warmer stratified water at the top of the tank is where the water will be supplied to the chiller or come from the cooling load at 59°F. Lower in the tank underneath the thermocline which is the boundary layer separating the high and low temperatures is the cold part of the tank. This section is at a temperature of 44°F which is the chilled water supply temperature from the chiller and to the load.

Sizing the tank depends on how much thermal energy needs to be stored in order to offset the load and maintain a constant chiller output. To determine the size of the tank, a general equation was used to achieve a tank size. The tank must discharge 11 hours of cooling at a total of 1905.8 tons. This intern gives a tank discharge of 173 ton-hr as a value for S in the following equation. The figure of merit FoM is a representation of the heat gain in the stored water and is usually a value of 0.9. As mentioned earlier, a delta T of 15° is used for the temperature differential in the stratification. The calculation is as follows.

$$Volume(gal) = \frac{1440 \times S[ton - hr]}{FoM \times \Delta T[F]}$$

$$Volume(gal) = \frac{1440 \times 1905.8[ton - hr]}{0.9 \times 15[F]}$$

$$Volume(gal) = 18{,}480\,gal$$

However, I also used an alternative method of sizing the tank using a program called HVAC Solution. This tank size is based on a typical value of 100gal/ton. A tank size of 22,250 gal was calculated assuming a tank usability factor of 80%. Using this program directly links the storage tank to the chiller and the load. The schematic and sizes can be seen in Figure 8 below.

Use of the tank will be determined by controls based on the demand of the cooling system. An ample amount of chilled water will be stored to offset the peak load of the system. Whenever the system is not in peak load, the chiller can directly handle the load if needed or store enough chilled water to offset the peak load. Operating as such reduces the required size of the chiller needed.

Pumps and Piping

Due to the addition of the equipment, pumps will have to be sized to supply the chilled, hot and cooling water for the system. Also, piping has to be run to the buildings from the pump house where the CHP and other units will be located. Pumps must be sized in order to distribute the hot and chilled water throughout the site. The following diagram is a calculation produced by HVAC Solutions. The length of pipe, flows and loads were put in from previously gathered data. From this data, the pumps can be sized using Bell & Gossett's website.

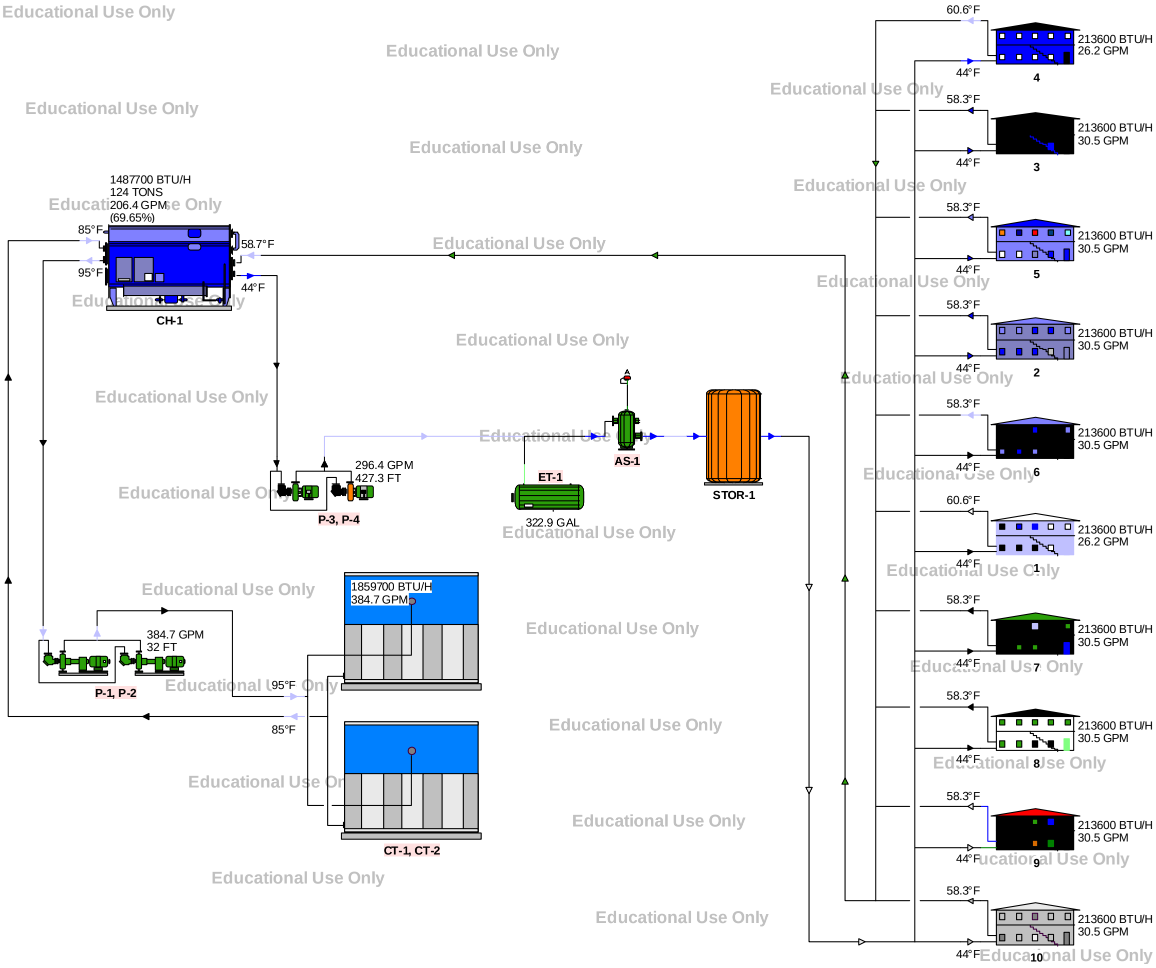


Figure 8: Cooling Schematic

The pumps for the chilled water and hot water system are both sized at the same size since they have the same flow rate and head loss due to the pipe sizes being the same. Four pumps Bell & Gossett 1510 1-1/2BCs will be needed to pump each system, three in parallel and one for redundancy. Specific data and pump curves can be found in Appendix E. Cooling tower pumps to run the cooling water from the chiller will be sized at 385 gpm and 34 feet of head. One pump will run with another redundant pump.

Redesign Analysis

Cost Analysis

The previously selected equipment in the redesign will have a higher primary cost then the existing system due to its complexity. The first cost was calculated using R.S. Means Cost Data and must be calculated to compare to the first cost of the existing equipment. The initial cost of the existing HVAC system was determined to be $2.1 after construction. The following table is the total overall cost of the additional equipment needed to achieve the cost. The equipment was determined from the above analysis and from the measuring of the site plan to price the piping. All costs are as installed.

Equipment	Size	Installed Cost	Quantity	Total
Prime Mover	240 kW	$2,500	240	$600,000
Cooling Tower	205 (tons)	$95.50 (per ton)	2	$39,155
Absorption Chiller	142 (tons)	$1197 (per ton)	1	$170,000
Storage Tank	-	$17,000	-	$17,000
Expansion tank	2 - 266 (gal)	$3,325	2	$6,650
4" Service pad	2835 s.f.	$180 (per c.y.)	35 (c.y.)	$6,300
Chilled Water Pumps	1 1/2" 100gpm	$3,875	8	$31,000
Cooling Water Pumps	3" 385 gpm	$6,175	2	$12,350
				$882,455

Table 1: Redesign Equipment

Pipe Size w/ Insulation	Length (ft)	Cost per l.f.	Cost & 10% for Fittings	Quantity	Total
1 1/4"	100	$13.50	$1,485.00	4	$5,940.00
1 1/2"	100	$14.72	$1,619.20	4	$6,476.80
2"	946	$17.92	$18,647.55	4	$74,590.21
2 1/2"	41	$23.97	$1,081.05	4	$4,324.19
3"	97	$28.41	$3,031.35	4	$12,125.39
4"	556	$37.65	$23,026.74	4	$92,106.96
5"	273	$57.25	$17,192.18	4	$68,768.70
					$264,332.24

Table 2: Pipe Cost

As seen in Tables 1 and 2 above, the installed cost is relatively low for a CHP system. The prime mover cost is based on average costs of similar sizes as described by RETscreen as the manufacturer was unable to quote a price for this use. This total installed cost of the system would also include the initial cost of the original system as this application is just an addition added on to reduce operating costs. A payback period will be determined in the following energy analysis.

Energy Analysis

The following energy analysis was performed by a RETscreen International excel spreadsheet designed specifically for the calculation of energy use of CHP systems. RETscreen is a program run by the Canadian government which encourages clean energy use and provides a number of programs which help designers make decisions in clean design. This CHP program was used to calculate the yearly load profiles given the peak cooling, heating and power loads. These loads were calculated earlier with the use of Trace 700.

The loads were entered into the program along with energy costs and a load characteristic chart was generated. Also, the power gross average loads were entered to simulate the electricity use of the system. After all loads and energy costs were entered, a base case electricity cost was calculated while the proposed case energy cost will be produced later.

Inputs for the type of prime movers, chillers and heaters are input after the load data is entered. The prime mover and absorption chiller equipment data which were selected are contained in a database and the data is directly inserted into the program. However, the chiller was not at the correct size which is specified with the selected equipment and had to be adjusted accordingly. Also, to trick the program into thermal storage, free cooling was selected as to serve the extra peak load. For the gas turbine, the gas price per mmBTU and the redesigned equipment were input. The heat rate and heat recovery efficiency was calculated using the tool menu of the program. Also, the operating strategy was selected as heating load following as this is how the system will operate.

For the cost analysis section of the program, the costs as calculated from above were input into the spreadsheet. This cost data will produce a payback period in the financial summary.

Greenhouse Gas emissions can also be calculated with the use of this tool. The program utilizes the capacity of the system, the efficiencies and the fuel use to calculate the amount of tons of CO_2 produced from the system. The proposed case is then compared to the base case and a difference is calculated. The national grid average for the tons of CO_2 produced per MWh of electricity was used for all sources of fuel for the base case. In this case, the proposed system acts as if 48 cars and light trucks are taken off the road per year.

Finally the financial summary calculates the payback of the proposed system. Due to the high efficiency of the unit selected and the relatively low price of the equipment, the simple payback period of the system is estimated at about 14.8 years with an inflation rate of 3.0% and fuel inflation rate of 2%. As a result of this time period for a payback and given the small spark gap for the site, a university which is energy and environmentally conscientious will most likely implements this system as it is economically feasible.

All of the output data for RETscreen for this CHP system comparison can be viewed in Appendix F.

Emission Analysis

The energy used in a CHP system should always be less than a conventional system. This reduction is a result of producing two forms of energy simultaneously therefore resulting in reduced emissions as well.

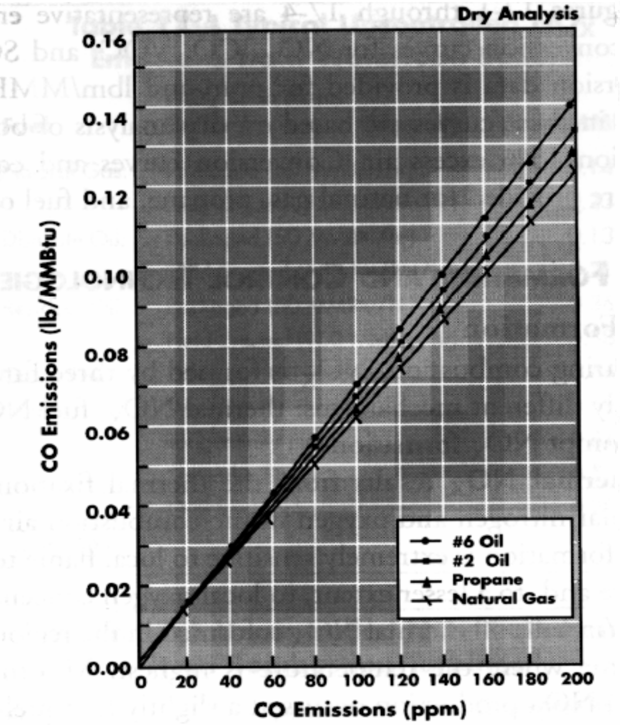
As mentioned before the amount of carbon dioxide produced for the base case is estimated on yearly basis and beats the production of the national grid. Also, emissions data is provided for the Pure Comfort CHP system. Emission of nitrogen oxide (NO_x), hydrocarbons, and carbon monoxide are provided by the manufacturer for this prime mover. These emissions are produced at an amount of 9ppmv, 9ppmv, and 15ppmv respectively at a rate of 15% excess O_2. Translating this data using the charts below and converting to lbm/kWh, the following values for the prime mover can be seen in Table 3. Also, these values are compared to the national grid average in a Table 4 with thanks from James Freihaut for use.

lbm Pollutant /kWh Prime Mover				
Fuel	**Particulates**	**SO2/kWh**	**NOx/kWh**	**CO/kWh**
Nat. Gas.	2.37E-04	n/a	2.15E-04	8.60E-05

Table 3: Prime Mover Emissions

		lbm Pollutant$_j$ /kWh U.S.			
Fuel	**% Mix U.S.**	**Particulates**	**SO_2/kWh**	**NO_x/kWh**	**CO_2/kWh**
Coal	55.7	6.13E-04	7.12E-03	4.13E-03	1.20E+00
Oil	2.8	3.03E-05	4.24E-04	7.78E-05	5.81E-02
Nat. Gas	9.3	0.00E+00	1.26E-06	2.36E-04	1.25E-01
Nuclear	22.8	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydro/Wind	9.4	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Totals	100.0	6.43E-04	7.54E-03	4.44E-03	1.38E+00

Table 4: National Emissions



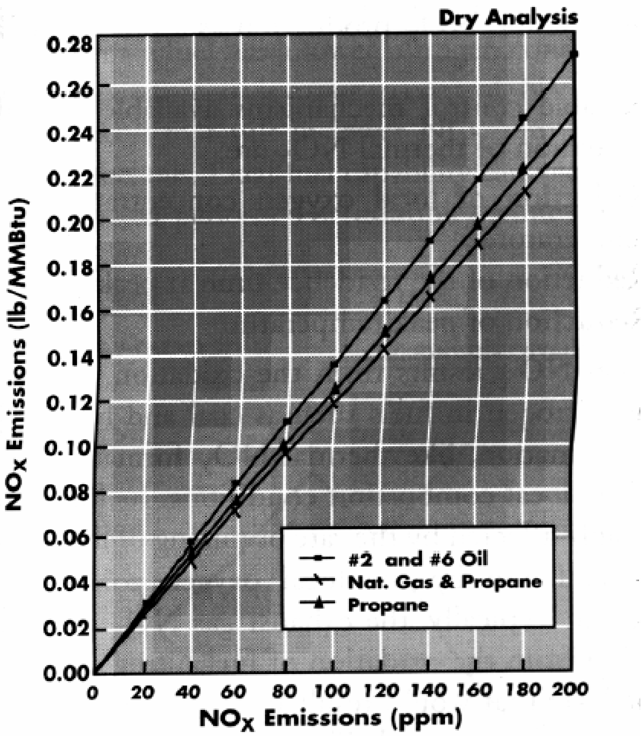
Conversion Equations

#2 Oil:
ppm = (lb/MMBtu) *1290
lb/MMBtu = (ppm)/1290

Natural Gas:
ppm= (lb/MMBtu) *1370
lb/MMBtu = (ppm)/1370

#6 Oil:
ppm = (lb/MMBtu) *1260
lb/MMBtu = (ppm)/1260

Propane:
ppm = (lb/MMBtu) *1340
lb/MMBtu = (ppm)/1340

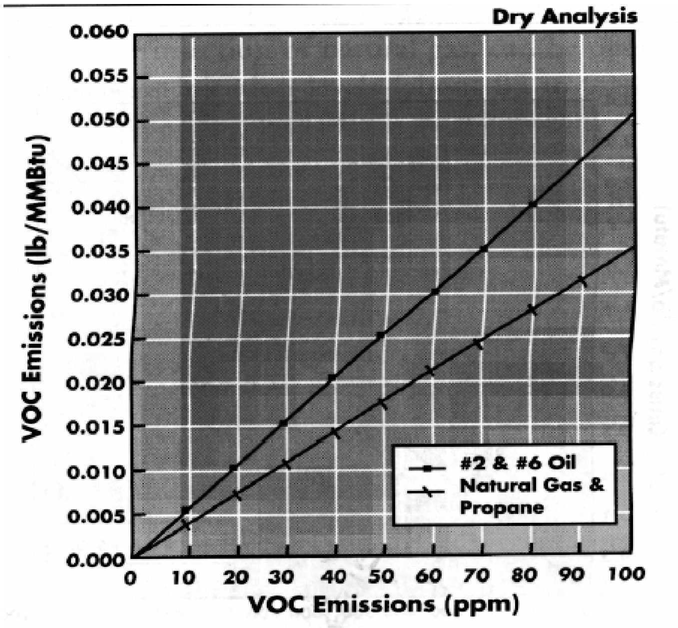


Conversion Equations

#2 & #6 Oil:
ppm = (lb/MMBtu)*750
lb/MMBtu = (ppm)/750

Natural Gas:
ppm= (lb/MMBtu) *850
lb/MMBtu = (ppm)/850

Propane:
ppm = (lb/MMBtu) *810
lb/MMBtu = (ppm)/810



Conversion Equations

#2 & #6 Oil:
ppm = (lb/MMBtu) *2000
lb/MMBtu = (ppm)/2000

Natural Gas & Propane:
ppm= (lb/MMBtu) *2500
lb/MMBtu = (ppm)/2500

It is as expected that the proposed CHP system will beat the national average due to the overall fuel efficiency of the system and the use of natural gas to drive the prime mover.

Electrical Integration

Electrical integration can be done with relative ease as each building is equipped with its own transformer which is connected directly to the gird. A main distribution panel will need to be located at the prime mover and will be interconnected to the electric grid. The selected prime mover comes with the capacity to automatically handle the electrical load and will supply the needed grid power when required.

Photovoltaic Breadth

Photovoltaic Introduction

Photovoltaic (PV) cells capture the suns energy using chemical means to convert the energy into usable electricity. This analysis focuses on the use of thin films of material for the conversion of energy. There are four main types of thin film technology which are cadmium telluride, copper indium diselenide, amorphous silicon, and thin film silicon. This converted solar energy is converted directly into direct current electricity which needs to be converted to alternating current through the use of an inverter. Currently photovoltaic and solar energy in general has a very high initial cost and is very inefficient. Solar technology obviously works best in areas where sun light is abundant which is primarily in places closer to the equator. However, with the recent energy crisis, more northern countries are promoting the use of solar technology.

Photovoltaic Design

The use of PV cells in this case is based on the fact that the highest electrical peaks occur in the summer months due to the cooling process of buildings. Even though the location of the buildings is at a fairly high latitude, the use of PV cells will help offset the peak electrical load during the summer. Also, with the implementation of thin film amorphous silicon (a-Si) PV cells that are in the form of roof shingles, the buildings with their south facing gabled roofs make for a good implementation of this technology. The PV cell units act the same as shingles while producing DC electricity.

These photovoltaic roof shingles will also be analyzed in a RETscreen spreadsheet program. The cells were analyzed to determine how much power output will come from the units.

The initial step was to get a basic idea of what type of unit would work for this PV shingle integration. The units decided on are Uni-Solar’s SHR-17 Solar Shingle. These units have a 20 year warranty, are designed for up to a 60 mph wind, and have a capacity of 17 Watts. This is the model which was used in the RETscreen model.

The effectiveness of the PV cells was tested to determine the economic feasibility and how much power can be produced given the 18° slope of the roofs. Also, the orientation of the buildings are 18° west of south, where south is the solar azimuth. In the analysis, the project location is the first criteria selected for weather and solar data. Next, the PV array is selected which includes the module type, manufacturer, efficiency and losses. The manufacturer's data for the Uni-Solar model SHR-17 is given in the data base and the previously mentioned efficiencies and losses are given. From this information, the renewable energy delivered to the load is 49.073 MWh annually. The solar resource and system load gives the weather data and the monthly average daily radiation for a horizontal surface for the location.

A cost analysis is then performed for the particular PV cell. It was found that each shingle costs $170.28. With this cost information entered, it is now possible to get a payback period for the information entered. It was found that there is a simple payback period of 12.4 years and 8.9 years to a positive cash flow. The PV shingle manufacturers data and RETscreen calculation can be found in Appendix G.

Structural Breadth

Structural Breadth Introduction

Upon investigation of the structural system of my building, the use of metal studs for the structure will be compared as an economic and environmentally friendlier alternative to wood studs. The basis of this analysis will be the based on the fact that harvesting of trees reduces the amount of carbon dioxide which can be absorbed from the atmosphere. This sequestration of carbon dioxide by forests helps remove the amount of green house gas in the atmosphere. By using cold rolled metal studs which are at least 25% recycled on average will result reduced deforestation. Moreover, when metal framed structures are demolished, the structural framing can be recycled where as a wood structure will be disposed of in landfills.

The transportation of these two materials also has an effect on emissions. Depending on location, lumber products may have to be shipped from a much further distance than metal studs. In this instance for the location of my site, metal studs are shipped from producers in Pittsburg. Wood studs on the other hand come from as far away as parts of Canada. The following table shows average emissions for heavy trucks on a freeway.

		Local Road Emission Factors (grams/mile)				
	Year	**VOC**	**CO**	**NOx**	**PM-10**	**PM-10 (Exhaust only)**
Single-Unit Gasoline Truck	2002	7.06	144.07	5.94	0.13	0.11
	2010	1.87	34.32	4.09	0.09	0.07
	2020	0.63	21.71	1.58	0.05	0.03
Single-Unit Diesel Truck	2002	1.18	6.86	14.95	0.42	0.38
	2010	0.74	3.39	7.27	0.17	0.13
	2020	0.52	0.71	1.27	0.07	0.03
Combination Diesel Truck	2002	1.22	7.64	16.07	0.41	0.37
	2010	0.78	3.52	7.45	0.17	0.13
	2020	0.56	0.78	1.29	0.07	0.03

Table 5: Truck Emissions

Moreover, since metal studs are lighter per unit than wood studs, the amount of metal studs which can be transported at one time is much higher thus reducing the amount of pollutants put into the air by the transporter. The fact that the metal studs are also in the shape of a C means that more can be stacked together to conserve space.

Metal studs have the same structural capacity as their wood counterparts. This works towards an advantage of also bringing the weight of the structure down due to the fact that they are hollow. However, metal studs have some disadvantages such as buckling under high temperatures, oxidation and thermal short circuiting when not installed properly. Lastly, metal studs are competitive in cost with wood studs so they are not a financial issue. Therefore, metal studs would be a good alternative to wood framing as it can reduce green house gas emissions from its transportation and will reduce deforestation from the harvesting of lumber.

Conclusion and Recommendations

After reviewing the findings in the above analysis, the addition of a cogeneration system, which will produce heating, cooling, and power for the University Ridge complex, would offer many advantages as well as a few disadvantages over the current configuration. The biggest advantages are the reduction of emissions as compared to the national grid, reduced energy costs, and a payback period within a reasonable time frame. However, all of these pros come at a drawback in that the cogeneration system has a higher first cost and requires more maintenance to maintain reliable operation.

In the end, the benefits greatly outweigh the negatives and is an environmentally conscious decision as well as a fiscally sound solution.

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I would also like to acknowledge my peers and friends for all the help and support through the past couple of years.

Finally, I would not be where I am today without the support of my parents and family.

Appendix A

Mechanical Load Calculations

SYSTEM SUMMARY

DESIGN CAPACITY QUANTITIES

By ae

System Description	System Type	COOLING Main System Capacity ton	Auxiliary System Capacity ton	Optional Vent Capacity ton	Cooling Totals ton	HEATING Main System Capacity Btu/h	Auxiliary System Capacity Btu/h	Preheat Capacity Btu/h	Reheat Capacity Btu/h	Humidification Capacity Btu/h	Optional Vent Capacity Btu/h	Heating Totals Btu/h
Terminal A/C	Packaged Terminal Air Conditior	171	0	0	171	-650,017	0	0	0	0	0	-650,017
Heating only	Unit Heaters	0	0	0	0	-64,400	0	0	0	0	0	-64,400
Commons	Packaged Terminal Air Conditior	6	0	0	6	-60,288	0	-21,338	0	0	0	-60,288
Totals		177	0	0	177	-774,705	0	-21,338	0	0	0	-774,705

*** The building peaked at hour 14 month 7 with a capacity of 178 tons.**

ELECTRICAL PEAK CHECKSUMS

By ae

Alternative: 1 ESU Housing Study
Yearly Time of Peak: 18(Hr) 7(Month)

Equipment Description		Electrical Demand (kw)	Percent of Total (%)
Cooling Equipment			
Air-cooled chiller - 001		178.08	48.87
	Sub total	178.08	48.87
Miscellaneous			
Lights		64.27	17.64
Base Utilities		0.00	0.00
Misc Equipment		122.01	33.49
	Sub total	186.28	51.13
	Total	364.36	100

MONTHLY ENERGY CONSUMPTION

By ae

Alternative: 1 ESU Housing Study

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Electric													
On-Pk Cons. (kWh)	60,410	54,211	70,899	67,713	81,040	86,734	82,868	92,878	76,320	75,615	68,107	59,105	875,900
Off-Pk Cons. (kWh)	80,775	72,829	76,191	79,060	83,676	83,036	101,112	85,908	85,469	80,150	76,712	83,613	988,529
On-Pk Demand (kW)	287	289	329	318	327	341	364	358	337	311	327	326	364
Off-Pk Demand (kW)	314	312	362	347	338	345	354	345	339	349	348	329	362
Gas													
On-Pk Cons. (therms)	95	82	39	12	0	0	0	0	0	13	29	55	325
Off-Pk Cons. (therms)	94	88	48	20	0	0	0	0	0	20	32	76	378
On-Pk Demand (therms/hr)	5	1	1	0	0	0	0	0	0	0	1	1	5
Off-Pk Demand (therms/hr)	7	1	1	1	0	0	0	0	0	1	1	1	7

------- Monthly Energy Consumption -------

Building Energy Consumption =	50,049	Btu/(ft2-year)
Source Energy Consumption =	149,096	Btu/(ft2-year)
Floor Area =	128,547	ft2

Appendix B

Electric Utility Bill

Charges from Met-Ed this billing period

☎ When contacting an Electric Generation Supplier, please provide the customer numbers below.

Call Met-Ed at 1-800-545-7741 with questions on these charges.

Met-Ed Basic Charges

Customer Number: 0804331178 0006411045 - General Secondary 3 Phase Service - ME_GS3_01F

Customer Charge						**16.74**
Generation Charges	34,080	KWH	x	0.048070		**1,638.23**
Transmission Charges	32,080	KWH	x	0.000000	0.00	
	2,000	KWH	x	0.002830	5.66	
	102.5	KW	x	0.780000	79.95	
	5.0	KW	x	0.000000	0.00	
Total Transmission Charges					**85.61**	**85.61**
Distribution Charges	12,580	KWH	x	0.006600	83.03	
	19,500	KWH	x	0.007200	140.40	
	2,000	KWH	x	0.035000	70.00	
	102.5	KW	x	4.570000	468.43	
	5.0	KW	x	0.000000	0.00	
Total Distribution Charges					**761.86**	**761.86**
Transition Charges	2,000	KWH	x	0.002010	4.02	
	19,500	KWH	x	0.000860	16.77	
	12,580	KWH	x	-0.005810	-73.09	
	5.0	KW	x	0.000000	0.00	
	102.5	KW	x	4.610000	472.53	
[illegible]l Transition Charges					**420.23**	**420.23**
State Tax Surcharge						**32.44**
State Sales Tax						**177.31**
Total Met-Ed Charges						**$ 3,132.42**

Detail Payment and Adjustment Information

Date	Reference	Amount	
Payments:			
08/22/06		-3,280.64	
Total Payments			**-3,280.64**
Total Payments and Adjustments			**-$3,280.64**

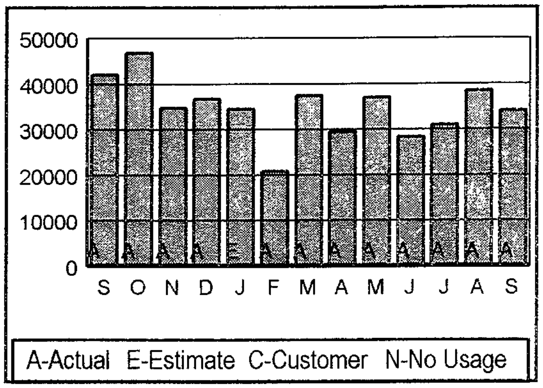
Meter Reading Information

General Secondary 3 Phase Service

Meter Number	G28337850
Present KWH Reading (Actual)	2,821
Previous KWH Reading (Actual)	2,608
Difference	213
Multiplier	160
Kilowatt Hours Used	34,080
Metered Load in KW	0.672
Billed Load in KW/KVA	107.5

Usage Information

Usage Comparison



	Sep 05	Sep 06
Average Daily Use (KWH)	1275	1136
Average Daily Temperature	72	69
Days in Billing Period	33	30
Last 12 Months Use (KWH)		409,280
Average Monthly Use (KWH)		34,107

A Message About Pricing

Generation prices and charges are set by the electric generation supplier you have chosen.
The Public Utility Commission regulates distribution prices and services.
The Federal Energy Regulatory Commission regulates transmission prices and services.

Appendix C

Pure Comfort 240M Equipment Data

PERFORMANCE - 59 ° (Standard ISO) DAY[1], continued

	MODEL 240M		MODEL 300M		MODEL 360M	
	ENGLISH	SI	ENGLISH	SI	ENGLISH	SI
ISO – Power/Cooling (Microturbines + Chilled Water)						
Gross Power Output 90 psig (620 kPa) Natural Gas Supply to Microturbine	240 kW	240 kW	300 kW	300 kW	360 kW	360 kW
Gross Electrical Efficiency (LHV) ± 2%	28	28	28	28	27	27
Net Power Output [2] 10 psig (69 kPa) Natural Gas Supply to Fuel Gas Booster	227 kW	227 kW	284 kW	284 kW	341 kW	341 kW
Net Electrical Efficiency (LHV) [2] ± 2%	26	26	26	26	26	26
Gross System Efficiency ± 5%	85	85	83	83	80	80
Net System Efficiency (LHV) [2] ± 5%	84	84	81	81	79	79
Nominal Cooling Capacity [3] ± 5%	142 RT	500 kW	171 RT	602 kW	198 RT	696 kW
Chiller Coefficient of Performance (COP)	1.30	1.30	1.29	1.29	1.26	1.26
Chilled Water Flow Rate Pressure Drop	297 gpm 26 ft	19 l/s 77 kPa	358 gpm 38 ft	23 l/s 114 kPa	415 gpm 50 ft	26 l/s 149 kPa
Cooling Water Flow Rate Pressure Drop	494 gpm 24 ft	31 l/s 71 kPa	597 gpm 34 ft	38 l/s 102 kPa	691 gpm 45 ft	44 l/s 134 kPa
Fuel Consumption (LHV)	3,000 MBh	3,100,000 kJ/hr	3,700 MBh	3,900,000 kJ/hr	4,500 MBh	4,700,000 kJ/hr
Microturbine Exhaust Gas Temperature	604° F	318° C	606° F	319° C	609° F	321° C
Chiller Exhaust Gas Temperature	236° F	113° C	249° F	121° C	262° F	128° C
Microturbines Sound Level [4,5]	76 dBA @ 33 ft	76 dBA @ 10 m	77 dBA @ 33 ft	77 dBA @ 10 m	78 dBA @ 33 ft	78 dBA @ 10 m
Chiller/Heater Sound Level[5]	65 dBA @ 33 ft	65 dBA @ 10 m	65 dBA @ 33 ft	65 dBA @ 10 m	65 dBA @ 33 ft	65 dBA @ 10 m
System Sound Level [4,5]	76 dBA @ 33 ft	76 dBA @ 10 m	77 dBA @ 33 ft	77 dBA @ 10 m	78 dBA @ 33 ft	78 dBA @ 10 m

1. Rating based on 59° F (15° C) ambient temperature at sea level, 60% RH, at ≤ 7 iwc microturbine backpressure.
2. Inclusive of parasitic power for fuel gas booster and chiller; fuel gas booster inlet pressure = 10 psig.
3. Rating based on ARI 560, latest edition, 44° F out (2.4 gpm/ton) chilled water; 67° F (4.0 gpm/ton) cooling water; fouling factor 0.00025 ft^2 hr F/Btu for absorber and condenser, 0.0001 ft^2 hr F/Btu for evaporator.
   Rating based on ARI 560, latest edition, 6.7° C out (0.043 L/s per kW)) chilled water; 29.4° C (0.072 L/s per kW)) cooling water; fouling factor 0.000044 m^2 • °C/W for absorber and condenser, 0.0000176 m^2 • °C/W for evaporator.
4. Subtract 7 ± 2 dB if using optional silencers.
5. No PureComfort™ system model will exceed the 85 decibel, 8 hour time weighted average, OSHA hearing protection threshold under normal operation.
6. Rating based on ARI 560, latest edition, 140° F hot water out; 0.0001 ft^2 hr F/Btu evaporator fouling factor.
   Rating based on ARI 560, latest edition, 54.4° C in, 60° C hot water out; 0.0000176 m^2 • °C/W for evaporator.

PERFORMANCE - 59° (Standard ISO) DAY[1], continued

	MODEL 240M		MODEL 300M		MODEL 360M	
	ENGLISH	SI	ENGLISH	SI	ENGLISH	SI
ISO – Power/140° F Heating (Microturbines + Heated Water)						
Gross Power Output 90 psig (620 kPa) Natural Gas Supply to Microturbine	240 kW	240 kW	300 kW	300 kW	360 kW	360 kW
Gross Electrical Efficiency (LHV) ± 2%	28	28	28	28	27	27
Net Power Output [2] 10 psig (69 kPa) Natural Gas Supply to Fuel Gas Booster	230 kW	230 kW	287 kW	287 kW	344 kW	344 kW
Net Electrical Efficiency (LHV) [2] ± 2%	27	27	26	26	26	26
Gross System Efficiency ± 5%	71	71	71	71	70	70
Net System Efficiency (LHV) [2] ± 5%	70	70	70	70	69	69
Nominal Heating Capacity [6] ± 5%	1,282 MBh	376 kW	1,601 MBh	469 kW	1,928 MBh	565 kW
Hot Water Flow Rate Pressure Drop	297 gpm 26 ft	19 l/s 77 kPa	358 gpm 38 ft	23 l/s 114 kPa	415 gpm 50 ft	26 l/s 149 kPa
Fuel Consumption (LHV)	3,000 MBh	3,100,000 kJ/hr	3,700 MBh	3,900,000 kJ/hr	4,500 MBh	4,700,000 kJ/hr
Microturbine Exhaust Gas Temperature	604° F	318° C	606°F	319°C	609° F	321° C
Chiller Exhaust Gas Temperature	245° F	118° C	248°F	120°C	253° F	123° C
Microturbines Sound Level [4,5]	76 dBA @ 33 ft	76 dBA @ 10 m	77 dBA @ 33 ft	77 dBA @ 10 m	78 dBA @ 33 ft	78 dBA @ 10 m
Chiller/Heater Sound Level[5]	65 dBA @ 33 ft	65 dBA @ 10 m	65 dBA @ 33 ft	65 dBA @ 10 m	65 dBA @ 33 ft	65 dBA @ 10 m
System Sound Level [4,5]	76 dBA @ 33 ft	76 dBA @ 10 m	77 dBA @ 33 ft	77 dBA @ 10 m	78 dBA @ 33 ft	78 dBA @ 10 m

1. Rating based on 59° F (15° C) ambient temperature at sea level, 60% RH, at ≤ 7 iwc microturbine backpressure.
2. Inclusive of parasitic power for fuel gas booster and chiller; fuel gas booster inlet pressure = 10 psig.
3. Rating based on ARI 560, latest edition, 44° F out (2.4 gpm/ton) chilled water; 67° F (4.0 gpm/ton) cooling water; fouling factor 0.00025 ft^2 hr F/Btu for absorber and condenser, 0.0001 ft^2 hr F/Btu for evaporator.
   Rating based on ARI 560, latest edition, 6.7° C out (0.043 L/s per kW)) chilled water; 29.4° C (0.072 L/s per kW)) cooling water; fouling factor 0.000044 m^2 • °C/W for absorber and condenser, 0.0000176 m^2 • °C/W for evaporator.
4. Subtract 7 ± 2 dB if using optional silencers.
5. No PureComfort™ system model will exceed the 85 decibel, 8 hour time weighted average, OSHA hearing protection threshold under normal operation.
6. Rating based on ARI 560, latest edition, 140° F hot water out; 0.0001 ft^2 hr F/Btu evaporator fouling factor.
   Rating based on ARI 560, latest edition, 54.4° C in, 60° C hot water out; 0.0000176 m^2 • °C/W for evaporator.

PERFORMANCE – 95° DAY[1] - continued

	MODEL 240M		MODEL 300M		MODEL 360M	
	ENGLISH	SI	ENGLISH	SI	ENGLISH	SI
ARI – Power/Cooling (Microtubines + Chilled Water)						
Gross Power Output 90 psig (620 kPa) Natural Gas Supply to Microturbine	206 kW	206 kW	256 kW	256 kW	304 kW	304 kW
Gross Electrical Efficiency (LHV) ± 2%	25	25	25	25	25	25
Net Power Output [7] 10 psig (69 kPa) Natural Gas Supply to Fuel Gas Booster	193 kW	193 kW	239 kW	239 kW	285 kW	285 kW
Net Electrical Efficiency (LHV) [7] ± 2%	23	23	23	23	23	23
Gross System Efficiency ± 5%	77	77	76	76	74	74
Net System Efficiency (LHV) [7] ± 5%	76	76	74	74	72	72
Nominal Cooling Capacity [8] ± 5%	124 RT	436 kW	149 RT	524 kW	173 RT	608 kW
Chiller Coefficient of Performance (COP)	1.20	1.20	1.19	1.19	1.18	1.18
Chilled Water Flow Rate Pressure Drop	297 gpm 26 ft	19 l/s 77 kPa	358 gpm 38 ft	23 l/s 114 kPa	415 gpm 50 ft	26 l/s 149 kPa
Cooling Water Flow Rate Pressure Drop	494 gpm 24 ft	31 l/s 71 kPa	597 gpm 34 ft	38 l/s 102 kPa	691 gpm 45 ft	44 l/s 134 kPa
Fuel Consumption (LHV)	2,800 MBh	3,000,000 kJ/hr	3,500 MBh	3,700,000 kJ/hr	4,200 MBh	4,500,000 kJ/hr
Microturbine Exhaust Gas Temperature	630° F	332° C	630° F	332° C	632° F	334° C
Chiller Exhaust Gas Temperature	287° F	141° C	298° F	148° C	309° F	154° C
Microturbines Sound Level [5,6]	76 dBA @ 33 ft	76 dBA @ 10 m	77 dBA @ 33 ft	77 dBA @ 10 m	78 dBA @ 33 ft	78 dBA @ 10 m
Chiller/Heater Sound Level[6]	65 dBA @ 33 ft	65 dBA @ 10 m	65 dBA @ 33 ft	65 dBA @ 10 m	65 dBA @ 33 ft	65 dBA @ 10 m
System Sound Level [5,6]	76 dBA @ 33 ft	76 dBA @ 10 m	77 dBA @ 33 ft	77 dBA @ 10 m	78 dBA @ 33 ft	78 dBA @ 10 m

1. Rating based on 95° F (35° C) ambient temperature at sea level, 46% RH, at ≤ 7 iwc microturbine backpressure.
2. Inclusive of parasitic power for fuel gas booster and air seal blower; fuel gas booster inlet pressure = 10 psig.
3. Grid connect only.
4. Meets California Air Resources Board (CARB) 2003 requirements.
5. Subtract 7 ± 2 dB if using optional silencers.
6. No PureComfort™ system model will exceed the 85 decibel, 8 hour time weighted average, OSHA hearing protection threshold under normal operation.
7. Inclusive of parasitic power for fuel gas booster and chiller.
8. Rating based on ARI 560, latest edition, 44 °F out (2.4 gpm/ton) chilled water; 85° F (4.0 gpm/ton) cooling water; fouling factor 0.00025 ft^2 hr F/Btu for absorber and condenser, 0.0001 ft^2 hr F/Btu for evaporator.
   Rating based on ARI 560, latest edition, 6.7° C out (0.043 L/s per kW) chilled water; 29.4° C (0.072 L/s per kW) cooling water; fouling factor 0.000044 m^2 • °C/W for absorber and condenser, 0.0000176 m^2 • °C/W for evaporator.

PERFORMANCE – 32° DAY[1] - continued

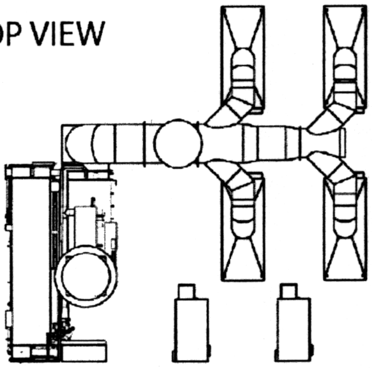
	MODEL 240M		MODEL 300M		MODEL 360M	
	ENGLISH	**SI**	**ENGLISH**	**SI**	**ENGLISH**	**SI**
32° F Day – Power/140° F Heating (Microturbines + Heated Water)						
Gross Power Output 90 psig (620 kPa) Natural Gas Supply to Microturbine	240 kW	240 kW	300 kW	300 kW	360 kW	360 kW
Gross Electrical Efficiency (LHV) ± 2%	29	29	29	29	29	29
Net Power Output[7] 10 psig (69 kPa) Natural Gas Supply to Fuel Gas Booster	231 kW	231 kW	288 kW	288 kW	346 kW	346 kW
Net Electrical Efficiency (LHV) [7] ± 2%	28	28	28	28	28	28
Gross System Efficiency ± 5%	69	69	69	69	68	68
Net System Efficiency (LHV)[7] ± 5%	68	68	67	67	67	67
Nominal Heating Capacity [8] ± 5%	1,100 MBh	324 kW	1,381 MBh	405 kW	1,660 MBh	487 kW
Hot Water Flow Rate Pressure Drop	297 gpm 26 ft	19 L/s 77 kPa	358 gpm 38 ft	23 L/s 114 kPa	415 gpm 50 ft	26 L/s 149 kPa
Fuel Consumption (LHV)	2,800 MBh	2,900,000 kJ/hr	3,500 MBh	3,700,00 kJ/hr	4,200 MBh	4,500,000 kJ/hr
Microturbine Exhaust Gas Temperature	573° F	301° C	575° F	301° C	577° F	303° C
Chiller Exhaust Gas Temperature	238° F	115° C	242° F	117° C	245° F	119° C
Microturbines Sound Level [5,6]	76 dBA @ 33 ft	76 dBA @ 10 m	77 dBA @ 33 ft	77 dBA @ 10 m	78 dBA @ 33 ft	78 dBA @ 10 m
Chiller/Heater Sound Level[6]	65 dBA @ 33 ft	65 dBA @ 10 m	65 dBA @ 33 ft	65 dBA @ 10 m	65 dBA @ 33 ft	65 dBA @ 10 m
System Sound Level [5,6]	76 dBA @ 33 ft	76 dBA @ 10 m	77 dBA @ 33 ft	77 dBA @ 10 m	78 dBA @ 33 ft	78 dBA @ 10 m

1. Rating based on 32° F (0° C) ambient temperature at sea level, 60% RH, at ≤ 7 iwc microturbine backpressure.
2. Inclusive of parasitic power for fuel gas booster and air seal blower; fuel gas booster inlet pressure = 10 psig.
3. Grid connect only.
4. Meets California Air Resources Board (CARB) 2003 requirements.
5. Subtract 7 ± 2 dB if using optional silencers.
6. No PureComfort™ system model will exceed the 85 decibel, 8 hour weighted average, OSHA hearing protection threshold under normal operation.
7. Inclusive of parasitic power for fuel gas booster and chiller, fuel gas booster inlet pressure = 10 psig.
8. Rating based on ARI 560, latest edition, 140° F hot water out; 0.0001 ft^2 hr F/Btu evaporator fouling factor. Rating based on ARI 560, latest edition, 54.4° C in, 60° C hot water out; 0.0000176 m^2 • °C/W for evaporator.

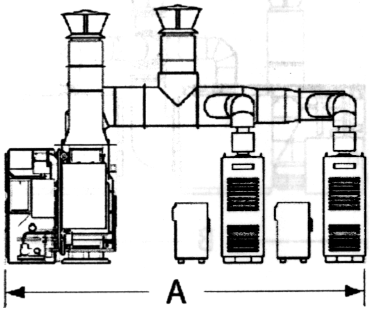
15.0 DIMENSIONS

PureComfort™ *Model 240M System*

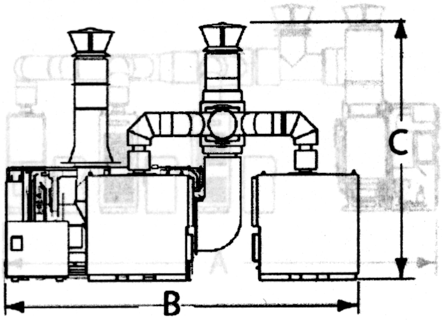
TOP VIEW



SIDE VIEW



END VIEW



MODEL	ENGLISH		SI
Overall Length A	21'-6"	258"	6553 mm
Overall Width B	22'-6"	270"	6858 mm
Overall Height C	15'-6"	186"	4724 mm

Appendix D

Cooling Tower Equipment Data

Marley UPDATE™ Version 4.8.1
Product Data: 3/16/2007 (Current)

4/11/2007 8:20:04 AM

Job Information

University Ridge

Selected By

SPX Cooling Technologies Contact

Marley Cooling Technologies, Inc.
7401 W. 129 Street
Overland Park, KS 66213
info@marleyct.spx.com
Tel 1-800-462-7539

Cooling Tower Definition

Manufacturer	Marley	Fan Motor Speed	1200 rpm
Product	NC Class	Fan Motor Capacity per cell	7.500 BHp
Model	NC8302DL1	Fan Motor Output per cell	7.500 BHp
Cells	1	Fan Motor Output total	7.500 BHp
CTI Certified	Yes	Air Flow per cell	62330 cfm
Fan	7.000 ft, 8 Blades	Air Flow total	62330 cfm
Fan Speed	313 rpm, 6883.2 fpm	ASHRAE 90.1 Performance	90.7 gpm/Hp
Fans per cell	1		
Model Group	Low Noise Fan (L)		

Conditions

Tower Water Flow	494.0 gpm	Air Density In	0.07094 lb/ft³
Hot Water Temperature	95.00 °F	Air Density Out	0.07142 lb/ft³
Range	10.00 °F	Humidity Ratio In	0.01712
Cold Water Temperature	85.00 °F	Humidity Ratio Out	0.02789
Approach	7.00 °F	Wet-Bulb Temp. Out	86.62 °F
Wet-Bulb Temperature	78.00 °F	Estimated Evaporation	5.6 gpm
Relative Humidity	50 %	Total Heat Rejection	2461300 Btu/h

- This selection satisfies your design conditions.

Weights & Dimensions

	Per Cell	Total
Shipping Weight	5380 lb	5380 lb
Max Operating Weight	11640 lb	11640 lb
Width	15.500 ft	15.500 ft
Length	7.896 ft	7.896 ft
Height	10.198 ft	
Static Lift	9.411 ft	

Minimum Enclosure Clearance

Clearance required on air inlet sides of tower without altering performance. Assumes no air from below tower.

Solid Wall	4.216 ft
50 % Open Wall	3.000 ft

Weights and dimensions do not include options; refer to sales drawings. For CAD layouts refer to file NC8302.dxf

Cold Weather Operation

Heater Sizing (to prevent freezing in the collection basin during periods of shutdown)

Heater kW/Cell	12.0	9.0	7.5	6.0	4.5	3.0
Ambient Temperature °F	-21.75	-5.25	3.00	11.25	19.50	27.75

Appendix E

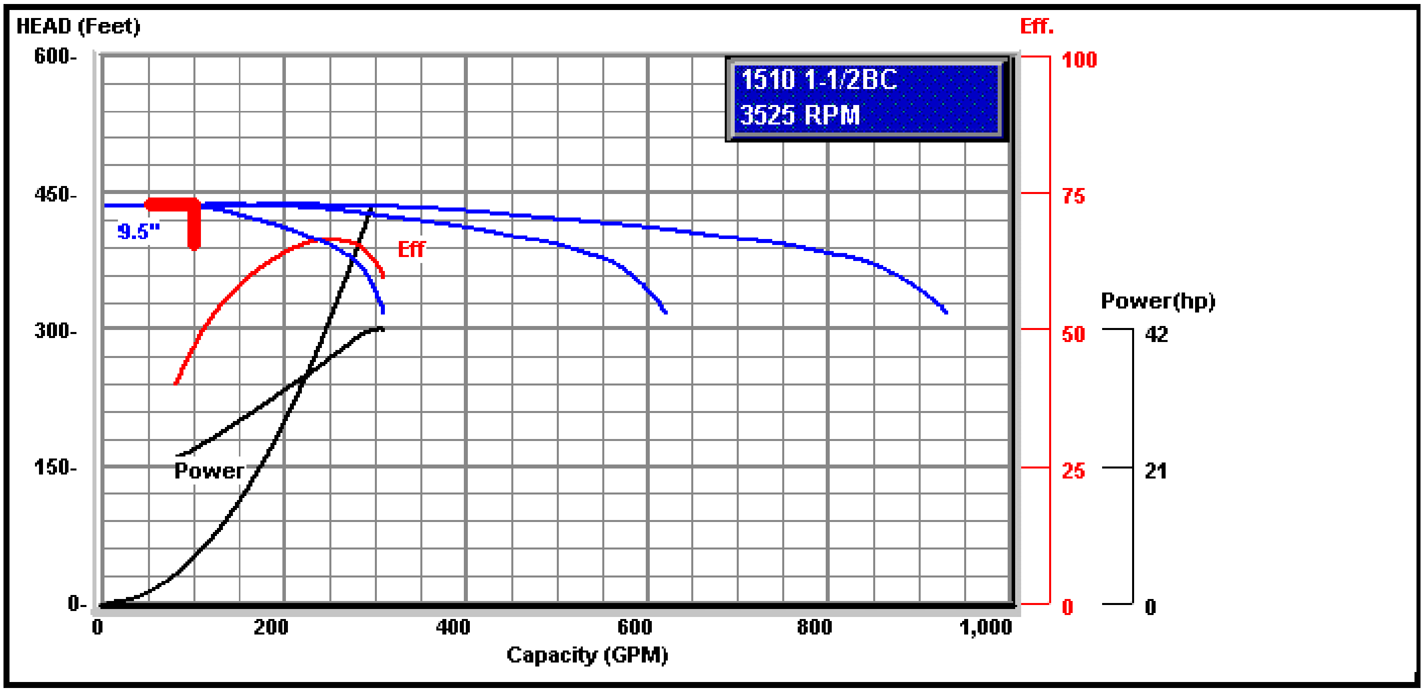
Pump Selections

Bell & Gossett®

Log Out My Schedule

DETAIL SUMMARY

Pump Series:	1510	Pump Size:	1-1/2BC
Flow Rate: (USGPM)	99	Total Head: (ft.)	438
Pump Speed (RPM)	3525	NPSH req (ft)	22.3
Weight: (lbs)	590	Cost Index:	100
Suction Size: (in)	2	Suction Velocity (fps)	9.5
Discharge Size: (in)	1.5	Discharge Velocity: (fps)	15.6
Impeller Diameter: (in)	9.5	Efficiency: (%)	46.45
Max Impeller Dia (in)	9.5		
Max Flow (USGPM)	310	Duty Flow/Max Flow (%)	0.32
Flow @ BEP (USGPM)	251	Min. Rec. Flow: (USGPM)	40
Motor Power, HP:	40	Frame Size:	324T
Pump Power (BHP)	23.31		
Max Power (BHP)	41.74	Aprox Wt (lbs)	

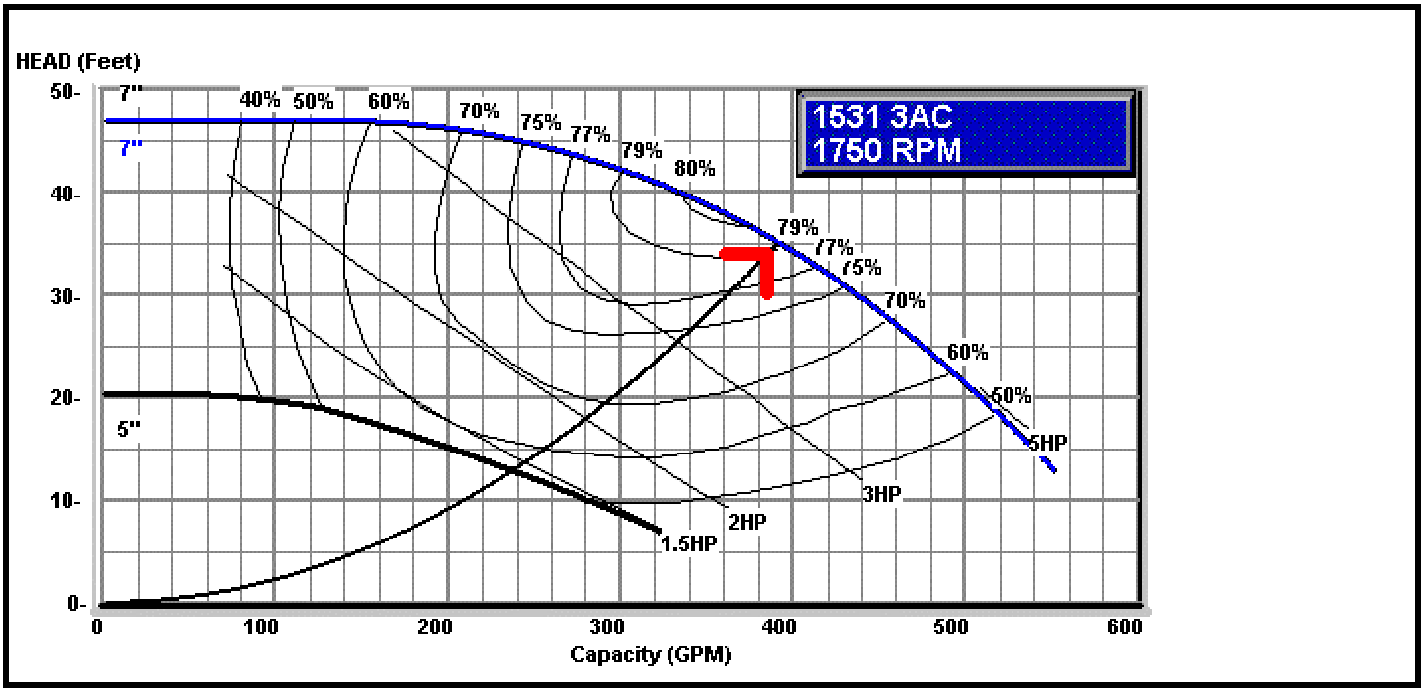


Another Selection Generate Submittal Download CAD Back To Pumps

Bell & Gossett®

Log Out My Schedule

DETAIL SUMMARY			
Pump Series:	1531	Pump Size:	3AC
Flow Rate: (USGPM)	385	Total Head: (ft.)	34
Pump Speed (RPM)	1750	NPSH req (ft)	4.8
Weight: (lbs)	180	Cost Index:	100
Suction Size: (in)	4	Suction Velocity (fps)	9.7
Discharge Size: (in)	3	Discharge Velocity: (fps)	16.7
Impeller Diameter: (in)	7.	Efficiency: (%)	78.66
Max Impeller Dia (in)	7.		
Max Flow (USGPM)	551	Duty Flow/Max Flow (%)	0.7
Flow @ BEP (USGPM)	300	Min. Rec. Flow: (USGPM)	80
Motor Power, HP:	5	Frame Size:	184JM
Pump Power (BHP)	4.30		
Max Power (BHP)	4.84	Aprox Wt (lbs)	



Another Selection | Generate Submittal | Download CAD | Back To Pumps

Appendix F

Mechanical Energy Analysis Data

RETScreen Energy Model - Combined cooling, heating & power project

See Online Manual

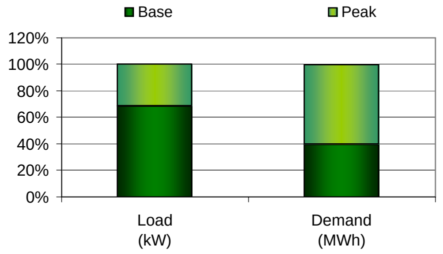
Settings

Language - Langue	English - Anglais	Online manual - English
Currency	$	○ Metric units
		● Imperial units
Project name	**Univeristy Ridge**	
Project location	**East Stroudsburg, PA**	○ Higher heating value (HHV)
Proposed project	Combined cooling, heating & power	● Lower heating value (LHV)

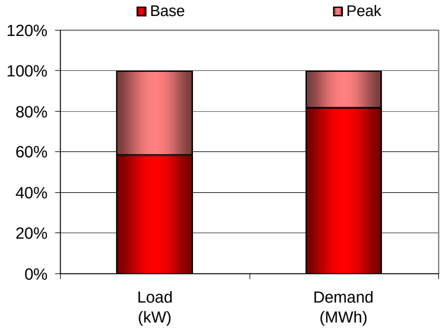
Complete Load & Network sheet

Proposed case system characteristics	Unit	Estimate	%
Power			
Base load power system			
Type		Gas turbine	
Operating strategy		Heating load following	
Capacity	kW	240	68.3%
Electricity delivered to load	MWh	1,030	39.4%
Electricity exported to grid	MWh	1	
Peak load power system			
Type		Grid electricity	
Suggested capacity	kW	111	
Capacity	kW	112	31.9%
Electricity delivered to load	MWh	1,581	60.6%
Back-up power system (optional)			
Type			
Capacity	kW	0	

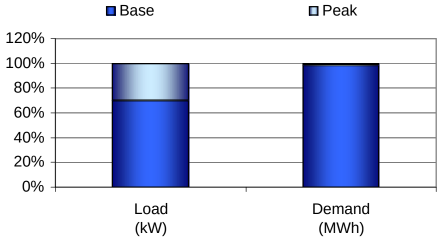
System design graph



Proposed case system characteristics	Unit	Estimate	%
Heating			
Base load heating system			
Type		Gas turbine	
Capacity	million Btu/h	1.4	58.1%
Heating delivered	million Btu	5,955	81.5%
Intermediate load heating system			
Type		Not required	
Peak load heating system			
Type		Boiler	
Fuel type		Natural gas - mmBtu	
Fuel rate	$/mmBtu	0.350	
Suggested capacity	million Btu/h	1.0	
Capacity	kW	292.8	41.9%
Heating delivered	million Btu	1,350	18.5%
Manufacturer			*See PDB*
Model			
Seasonal efficiency	%	65%	
Back-up heating system (optional)			
Type			
Capacity	kW	0.0	



Proposed case system characteristics	Unit	Estimate	%
Cooling			
Base load cooling system			
Type		Absorption	
Fuel source		Heating system	
Capacity	RT	124.0	70.1%
Cooling delivered	RTh	439,558	98.3%
Peak load cooling system			
Type		Free cooling	
Fuel source		Free cooling	
Capacity	RT	53.0	29.9%
Cooling delivered	RTh	7,579	1.7%
Back-up cooling system (optional)			
Type			
Capacity	kW	0	



Proposed case system summary	Fuel type	Fuel consumption - unit	Fuel consumption	Capacity (kW)	Energy delivered (MWh)	Clean Energy production credit?
Power						
Base load	Natural gas	mmBtu	13,442	240	1,030	☐
Peak load	Electricity	MWh	1,581	112	1,581	☐
Electricity exported to grid					1	☐
			Total	**352**	**2,611**	
Heating						
Base load	Recovered heat			406	1,745	☐
Peak load	Natural gas	mmBtu	2,077	293	396	☐
			Total	**699**	**2,141**	
Cooling						
Base load	Heating system			436	1,546	☐
Peak load	Free cooling			186	27	☐
			Total	**622**	**1,573**	

Complete Cost Analysis sheet

RETScreen Load & Network Design - Combined cooling, heating & power project

Heating project	**Unit**			
Site conditions		**Estimate**		**Notes/Range**
Nearest location for weather data	Allentown			*See Weather Database*
Heating design temperature	°C	-11.6	11.1 °F	-40 to 15 °C
Annual heating degree-days below 18°C	°C-d	3,045	5,480 °F-d	*Complete Monthly inputs*
Domestic hot water heating base demand	%	0%		0% to 25%
Equivalent degree-days for DHW heating	°C-d/d	0.0		0 to 10 °C-d/d
Equivalent full load hours	h	1,972		

Monthly inputs

Month	°C-d <18°C	°F-d <65°F	Month	°C-d <18°C	°F-d <65°F	Month	°C-d <18°C	°F-d <65°F	
January	648	1,167	May	67	120	September	0	0	*See Weather Database*
February	545	981	June	0	0	October	193	348	
March	434	782	July	0	0	November	354	638	
April	244	440	August	0	0	December	559	1,006	

Base case heating system	Single building - space heating	
Heated floor area for building	ft²	128,547
Fuel type		Natural gas - mmBtu
Seasonal efficiency	%	85%
Heating load calculation		
Heating load for building	Btu/ft²	5.7
Total heating demand	million Btu	**1,445**
Total peak heating load	million Btu/h	**0.7**
Fuel consumption - annual	mmBtu	1,700
Fuel rate	$/mmBtu	13.330
Fuel cost		$ 22,657
Proposed case energy efficiency measures		
End-use energy efficiency measures	%	0%
Net peak heating load	million Btu/h	0.7
Net heating demand	million Btu	1,445

RETScreen Load & Network Design - Combined cooling, heating & power project

Cooling project	Unit			
Site conditions		**Estimate**		**Notes/Range**
Nearest location for weather data		Allentown		*See Weather Database*
Cooling design temperature	°C	31.1	88.0 °F	10 to 47 °C
Annual cooling degree-days above 10°C	°C-d	1,589	2,860 °F-d	*Complete Monthly inputs*
Equivalent full load hours	h	2,526		

Monthly inputs

Month	°C-d >10°C	°F-d >50°F	Month	°C-d >10°C	°F-d >50°F	Month	°C-d >10°C	°F-d >50°F	
January	0	0	May	181	326	September	241	433	*See Weather Database*
February	0	0	June	325	584	October	55	98	
March	0	0	July	412	742	November	0	0	
April	0	0	August	376	677	December	0	0	

Base case cooling system	Single building - process cooling		
Cooled floor area for building	ft²	128,547	
Fuel type		Electricity	
Seasonal efficiency	%	500%	
Cooling load calculation			
Peak process cooling load	RTh	177.0	
Process cooling load characteristics		Detailed	
Equivalent full load hours - process cooling	h	2,526	*Complete monthly process load*
Total cooling demand	RTh	**447,137**	
Total peak cooling load	RT	**177.0**	
Fuel consumption - annual	MWh	315	
Fuel rate	$/kWh	0.092	
Fuel cost		$ 28,903	
Proposed case energy efficiency measures			
End-use energy efficiency measures	%	0%	
Net peak cooling load	RT	177.0	
Net cooling demand	RTh	447,137	

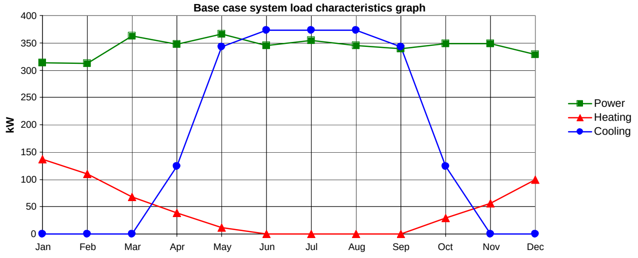
RETScreen Load & Network Design - Combined cooling, heating & power project

Power project	Unit	
Base case power system		
Grid type		Central-grid

Base case load characteristics

Month	Power gross average load kW	Power net average load kW	Cooling % time process operating	Cooling average load kW	Heating average load kW
January	314	314	0%	0	137
February	312	312	0%	0	110
March	362	362	0%	0	68
April	347	322	20%	124	39
May	366	298	55%	342	12
June	345	270	60%	373	0
July	354	279	60%	373	0
August	345	270	60%	373	0
September	339	271	55%	342	0
October	349	324	20%	124	29
November	348	348	0%	0	57
December	329	329	0%	0	99
System peak electricity load over max monthly average	0.0%		*Return*		
Peak load - annual	366	362	100%	622	215

	Unit		
Electricity demand	MWh	3,006	2,691
Electricity rate - base case	$/kWh	0.092	0.092
Total electricity cost		$ 276,216	$ 247,313

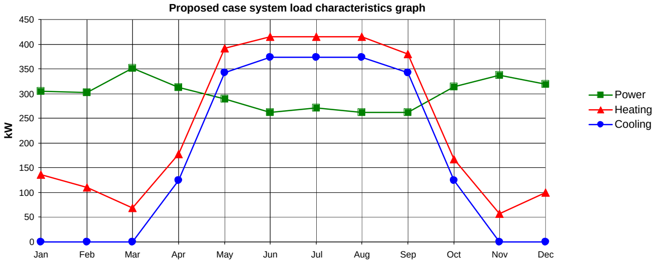


Proposed case energy efficiency measures

	Unit	
End-use energy efficiency measures	%	3%
Net peak electricity load	kW	351
Net electricity demand	MWh	2,610

Proposed case load characteristics

Month	Power net average load kW	Power for cooling kW	Power system load kW	Cooling system load kW	Heating net average load kW	Heat for cooling kW	Heating system load kW
January	305	0	305	0	137	0	137
February	303	0	303	0	110	0	110
March	351	0	351	0	68	0	68
April	312	0	312	124	39	138	177
May	289	0	289	342	12	380	392
June	262	0	262	373	0	415	415
July	271	0	271	373	0	415	415
August	262	0	262	373	0	415	415
September	262	0	262	342	0	380	380
October	314	0	314	124	29	138	167
November	338	0	338	0	57	0	57
December	319	0	319	0	99	0	99
Peak load - annual	351	0	**351**	**622**	215	485	**699**



Proposed case load and demand		Power		Heating		Cooling
System peak load	kW	351	million Btu/h	2.4	RT	177.0
System energy demand	MWh	2,610	million Btu	7,306	RTh	447,137

Complete Equipment Selection sheet

Complete Equipment Selection sheet

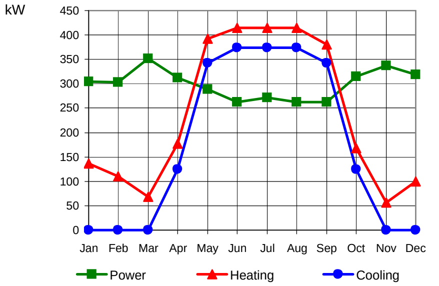
RETScreen Equipment Selection - Combined cooling, heating & power project

☐ Show alternative units

Proposed case cooling system

Base load cooling system				
Type		Absorption		
Fuel source		Heating system		
Capacity	RT	124.0	70.1%	*See product database*
Seasonal efficiency	%	90%		
Manufacturer		Carrier		
Model		16JB-200		1 unit(s)
Cooling delivered	RTh	439,558	98.3%	
Peak load cooling system				
Type		Free cooling		
Fuel source		Free cooling		
Suggested capacity	RT	53.0		
Capacity	RT	53.0	29.9%	
Manufacturer		Chilled Water Storage		
Model				
Cooling delivered	RTh	7,579	1.7%	

Proposed case system load characteristics graph



Proposed case power system

System selection		Base load system		
Base load power system				
Type		Gas turbine		
Availability	%		100.0%	8,760 h
Fuel selection method		Single fuel		
Fuel type		Natural gas - mmBtu		
Fuel rate	$/mmBtu	1.330		
Gas turbine				
Power capacity	kW	240	68.3%	*See product database*
Minimum capacity	%	40%		
Electricity delivered to load	MWh	1,030	39.4%	
Electricity exported to grid	MWh	1		
Manufacturer		UTC Power		
Model		PureThermal		4 unit(s)
Heat rate	kJ/kWh	13,762		
Heat recovery efficiency	%	60%		
Fuel required	million Btu/h	3.1		
Heating capacity	million Btu/h	1.4	58.1%	

Operating strategy - base load power system

Fuel rate - base case heating system	$/MWh	15.68
Electricity rate - base case	$/MWh	91.90
Fuel rate - proposed case power system	$/MWh	4.54
Electricity export rate	$/MWh	70.00
Electricity rate - proposed case	$/MWh	120.00

Operating strategy	Electricity delivered to load MWh	Electricity exported to grid MWh	Remaining electricity required MWh	Heat recovered million Btu	Remaining heat required million Btu	Power system fuel million Btu	Operating profit (loss) $	Efficiency %
Full power capacity output	2,102	1	509	7,100	206	27,423	175,052	52.0%
Power load following	2,102	0	509	7,095	211	27,413	174,987	52.0%
Heating load following	**1,030**	**1**	**1,581**	**5,955**	**1,350**	**13,442**	**59,762**	**70.5%**

Select operating strategy: Heating load following

Return to Energy Model sheet

RETScreen Cost Analysis - Combined cooling, heating & power project

Settings - Univeristy Ridge - East Stroudsburg, PA

● Pre-feasibility analysis
○ Feasibility analysis

● Cost reference
○ Second currency

Cost reference: None

Initial costs (credits)	**Unit**	**Quantity**	**Unit cost**	**Amount**	**Relative costs**
Feasibility study					
	cost	1	$ -	$ -	
Sub-total:				**$ -**	0.0%
Development					
	cost	1	$ -	$ -	
Sub-total:				**$ -**	0.0%
Engineering					
	cost	1	$ -	$ -	
Sub-total:				**$ -**	0.0%
Power system					
Base load - Gas turbine	kW	240	$ 2,500	$ 600,000	
Peak load - Grid electricity	kW	112		$ -	
Road construction	km			$ -	
Transmission line	km			$ -	
Substation	project			$ -	
Energy efficiency measures	project	1	$ 5,000	$ 5,000	
Custom	cost	1	$ 6,000	$ 6,000	
				$ -	
Sub-total:				**$ 611,000**	45.6%
Heating system					
Base load - Gas turbine	kW	406.5	$ 40	$ 16,259	
Peak load - Boiler	kW	292.8		$ -	
Energy efficiency measures	project	1	$ 7,000	$ 7,000	
Custom	cost	1	$ 2,000	$ 2,000	
				$ -	
Sub-total:				**$ 25,259**	1.9%
Cooling system					
Base load - Absorption	RT	124.0	$ 1,371	$ 170,004	
Peak load - Free cooling	RT	53.0		$ -	
Energy efficiency measures	project	1	$ 7,000	$ 7,000	
Custom	cost	1	$ 5,000	$ 5,000	
				$ -	
Sub-total:				**$ 182,004**	13.6%
Balance of system & miscellaneous					
	cost	1	$ 376,787	$ 376,787	
Contingencies	%	10.0%	$ 1,195,050	$ 119,505	
Interest during construction	8.00%	6 month(s)	$ 1,314,555	$ 26,291	
Sub-total:				**$ 522,583**	39.0%
Total initial costs				**$ 1,340,846**	100.0%

Annual costs (credits)	**Unit**	**Quantity**	**Unit cost**	**Amount**	**Relative costs**
O&M					
Parts & labour	project	0	$ 3,000	$ -	
O&M	cost	0	$ 1,000	$ -	
Contingencies	%	0.0%	$ -	$ -	
Sub-total:				**$ -**	0.0%
Fuel					
Natural gas	mmBtu	15,519	$ 1.199	$ 18,605	
Electricity	MWh	1,581	$ 120.000	$ 189,682	
Sub-total:				**$ 208,286**	100.0%
Total annual costs				**$ 208,286**	100.0%

Periodic costs (credits)	**Unit**	**Year**	**Unit cost**	**Amount**
Overhaul	cost	5	$ 6,000	**$ 6,000**
				$ -
				$ -
End of project life				**$ -**

Go to GHG Analysis sheet

RETScreen Greenhouse Gas (GHG) Emission Reduction Analysis - Combined cooling, heating & power project

Settings - Univeristy Ridge - East Stroudsburg, PA

☑ GHG Analysis
☐ Potential CDM project

● Simplified analysis
○ Standard analysis
○ Custom analysis

Base case electricity system (Baseline)

Country - region	Fuel type	GHG emission factor (excl. T&D) tCO2/MWh	T&D losses %	GHG emission factor tCO2/MWh
United States of America (USA)	All types	0.690	5.0%	0.726

☐ Baseline changes during project life

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Natural gas	14.2%	498	0.197	98
Electricity	85.8%	3,006	0.726	2,184
Total	100.0%	3,505	0.651	2,282

Proposed case system GHG summary (Combined cooling, heating & power project)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Natural gas	74.2%	4,548	0.197	898
Electricity	25.8%	1,581	0.726	1,148
Total	100.0%	6,129	0.334	2,046

Electricity exported to grid	MWh	1	T&D losses	1.0%	0	0.726	0
						Total	2,046

GHG emission reduction summary

Combined cooling, heating & power project	Base case GHG emission tCO2	Proposed case GHG emission tCO2	Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
	2,282	2,046	236	0%	**236**

Net annual GHG emission reduction	236	tCO2	is equivalent to	48.0	Cars & light trucks not used

Complete Financial Summary sheet

RETScreen Financial Summary - Combined cooling, heating & power project

Annual fuel cost summary - Univeristy Ridge - East Stroudsburg, PA

Base case system	Peak load kW	Energy demand MWh	End-use energy rate $/MWh	Fuel cost $
Power	366	2,691	91.90	247,313
Heating	215	423	53.51	22,657
Cooling	622	1,573	18.38	28,903
Fuel cost - base case				**298,872**

Proposed case system	Capacity kW	Energy delivered MWh	End-use energy rate $/MWh	Fuel cost $
Power	352	2,611	79.49	207,559
Heating	699	2,141	0.34	727
Cooling	622	1,573	0.00	0
Fuel cost - proposed case				**208,286**

Yearly cash flows

Year #	Pre-tax $	After-tax $	Cumulative $
0	(402,254)	(402,254)	(402,254)
1	(41,178)	(41,178)	(443,432)
2	(39,329)	(39,329)	(482,761)
3	(37,443)	(37,443)	(520,204)
4	(35,519)	(35,519)	(555,724)
5	(40,513)	(40,513)	(596,236)
6	(31,555)	(31,555)	(627,792)
7	(29,514)	(29,514)	(657,306)
8	(27,431)	(27,431)	(684,737)
9	(25,307)	(25,307)	(710,044)
10	(31,204)	(31,204)	(741,249)
11	112,704	112,704	(628,545)
12	114,958	114,958	(513,587)
13	117,257	117,257	(396,331)
14	119,602	119,602	(276,729)
15	112,646	112,646	(164,083)
16	124,434	124,434	(39,649)
17	126,922	126,922	87,274
18	129,461	129,461	216,734
19	132,050	132,050	348,785
20	123,854	123,854	472,639
21	137,385	137,385	610,024
22	140,133	140,133	750,157
23	142,935	142,935	893,092
24	145,794	145,794	1,038,886
25	136,147	136,147	1,175,033

Financial parameters

General		
Fuel cost escalation rate	%	2.0%
Inflation rate	%	3.0%
Discount rate	%	10.0%
Project life	yr	25
Finance		
Incentives and grants	$	
Debt ratio	%	70.0%
Debt	$	938,592
Equity	$	402,254
Debt interest rate	%	7.00%
Debt term	yr	10
Debt payments	$/yr	**133,634**
Income tax analysis		☐

Project costs and savings/income summary

Initial costs			
Feasibility study	0.0%	$	-
Development	0.0%	$	-
Engineering	0.0%	$	-
Power system	45.6%	$	611,000
Heating system	1.9%	$	25,259
Cooling system	13.6%	$	182,004
Balance of system & misc.	39.0%	$	522,583
Total initial costs	100.0%	**$**	**1,340,846**
Annual costs and debt payments			
O&M		$	-
Fuel cost - proposed case		$	208,286
Debt payments - 10 yrs		$	133,634
Total annual costs		**$**	**341,921**
Periodic costs (credits)			
Overhaul - 5 yrs		$	6,000
Annual savings and income			
Fuel cost - base case		$	298,872
Electricity export income		$	57
Total annual savings and income		**$**	**298,930**

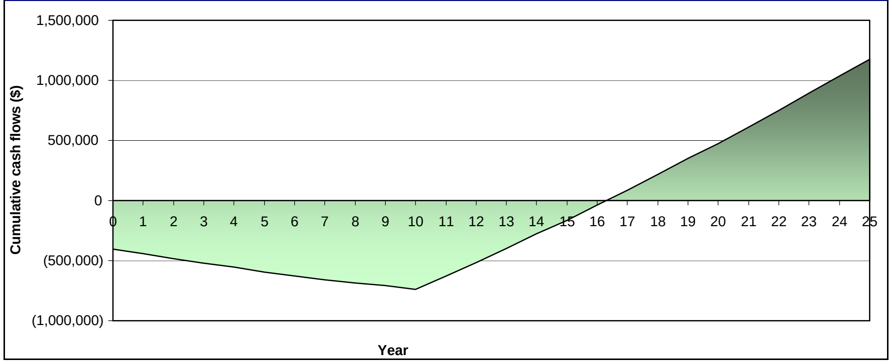
Annual income

Customer premium income (rebate)		☐
Electricity export income		
Electricity exported to grid	MWh	1
Electricity export rate	$/MWh	70.00
Electricity export income	$	**57**
Electricity export escalation rate	%	2.0%
Clean Energy (CE) production income		☐
GHG reduction income		☐
Net GHG reduction	tCO2/yr	236
Net GHG reduction - 25 yrs	tCO2	5,894

Financial viability

Pre-tax IRR - equity	%	6.2%
Pre-tax IRR - assets	%	0.8%
After-tax IRR - equity	%	6.2%
After-tax IRR - assets	%	0.8%
Simple payback	yr	14.8
Equity payback	yr	16.3
Net Present Value (NPV)	$	(255,112)
Annual life cycle savings	$/yr	(28,105)
Benefit-Cost (B-C) ratio	-	0.37
Debt service coverage	-	0.69
GHG reduction cost	$/tCO2	119

Cumulative cash flows graph



Appendix G

Photovoltaic Analysis and Equipment

UNI-SOLAR®

Sell Sheet

SOLAR SHINGLES
SHR-17

- **Power Rating 17W**
- **Lightweight & Flexible**
- **No Support Structures Needed**
- **Virtually Unbreakable (No Glass)**
- **Shadow & High Heat Tolerant**
- **Delivers Up To 20% More Real Energy**

Photo Courtesy of Oakland University

UNI-SOLAR® shingles are unique and have been honored with the prestigious Popular Science Grand Award, “Best of What’s New (Environmental Technology),” and Discover Magazine’s “Technological Innovation Award” for best innovation (Environment). The PV shingle permits the roof of commercial buildings or residential homes to evolve from mere protection from the weather to a source of electrical power. The flexible, thin film solar cell shingle blends into a roofing pattern or traditional asphalt shingles.

Why Do *UNI-SOLAR* Products Outperform Others?

All solar panels are rated in terms of peak power output (watts). Outdoors, under normally higher operating temperatures, solar panel performance changes, depending on temperature, solar spectrum (light color) and related effects. *UNI-SOLAR* products are less affected by temperature than monocrystalline or polycrystalline solar technology products. The result is up to 20% more delivered energy.**

** Source Solfest, “Module Shoot Out”

Applications

- Residential Grid Connected Systems
- Commercial Grid Connected Systems
- Schools & Institutions
- Apartment Complexes
- Condominiums
- Renovation Or New Construction

MORE kW HRS

LIGHTWEIGHT

NO-GLASS

DURABLE

SHADOW TOLERANT

HIGH TEMP PERFORMANCE

UNI-SOLAR®

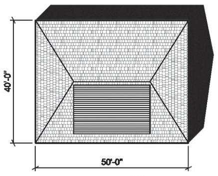
SOLAR SHINGLES SHR-17

UNI-SOLAR®

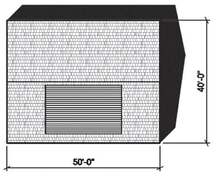
Specifications

Model	SHR-17
Rated Power (Watts)	17
Max Power Point VMPP (V)	9
Max Power Point IMPP (A)	1.9
Open-Circuit Voltage (Volts)	13
Short-Circuit Current (Amps)	2.4
Shingle Length (in./mm)	86.4 in./2195 mm
Shingle Width (in./mm)	12 in. (5 in. exposed area)/305 mm
Shingle Thickness (in./mm)	0.1 in./4 mm
Weight (lb./kg)	4.8 lb./2.2 kg
Customer-Supplied Substrate	Wood Deck and Fire retardant underlayment
Minimum Slope	3:12 (15˚)
Maximum Slope	21:12 (60˚)
Warranty on Power Output	20 Year

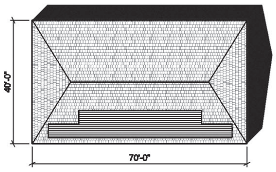
During the first 8-10 weeks of operation, electrical output exceeds specific ratings. Power output may be higher by 15%, operating voltage may be higher by 11% and operating current may be higher by 4%. Electrical specifications (±10%) are based on measurements performed at standard test conditions of 1000 W/m^2 irradiance, Air Mass 1.5, and Cell Temperature of 25°C after long-term stabilization. Actual performance may vary up to 10% from rated power due to low temperature operation, spectral and other related effects. Maximum system open-circuit voltage not to exceed 600 VDC. Specifications subject to change without notice.



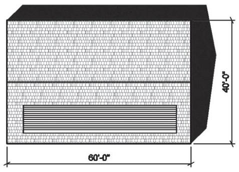
HIPPED ROOF
108 SH-17 SOLAR SHINGLES
324 SQUARE FEET
3.2 ROOF SQUARES



GABLED ROOF
108 SH-17 SOLAR SHINGLES
324 SQUARE FEET
3.2 ROOF SQUARES



HIPPED ROOF
108 SH-17 SOLAR SHINGLES
324 SQUARE FEET
3.2 ROOF SQUARES



GABLED ROOF
108 SH-17 SOLAR SHINGLES
324 SQUARE FEET
3.2 ROOF SQUARES

Quality Assurance, Proven Reliability

UNI-SOLAR shingles comply with the following qualification tests:

- UL Listed Up To 600 VDC as A Prepared Roofing Cover Ⓤ
- Capable Of Withstanding 80 mph Wind Speeds
- Meets IEC 61646 Requirements
- Thermal Cycling
- Humidity-Freeze Test
- Damp Heat Test
- UV-Test
- Wet Insulation Test
- Mechanical Load Test
- Hail Impact Test
- Robustness of Terminations Test

Product Description

Each SHR (solar home roofing) shingle utilizes the proprietary Triple Junction solar cells manufactured by *UNI-SOLAR.* These cells are made in a roll-to-roll deposition process on a continuous roll of stainless steel. The result is a unique, flexible, lightweight solar cell. The *UNI-SOLAR* PV Shingles are encapsulated in UV stabilized polymers making them exceptionally durable. Bypass diodes are connected across each cell, allowing the modules to produce power even when partially shaded.

The Solar Shingle will replace the conventional shingle. The shingles are UL Listed both as an electricity generator and as a prepared roofing cover. Each shingle has a pair of wires coming off the back of the shingle that will be fed through the roof deck for wiring inside the attic. The solar shingle wires can be "shorted" during installation. The wires from adjacent shingles are connected together using moisture resistant butt splices. The shingles are mounted over 30 lb. felt or a fire resistant underlayment (e.g. Elk® Versa Shield.)

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Auburn Hills, MI 48326 USA
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Toll Free: 800.843.3892
Fax: 248.364.0510
Email: info@uni-solar.com
www.uni-solar.com

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Email: westerninfo@uni-solar.com

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Email: europeinfo@uni-solar.com

Your *UNI-SOLAR* Distributor:

UNI-SOLAR®
ovonics@work

RETScreen® Financial Summary - Photovoltaic Project

Annual Energy Balance

Project name		University Ridge			
Project location		East Stroudsburg, PA	Nominal PV array power	kWp	37.74
Renewable energy delivered	MWh	49.073			
Firm RE capacity	kW	-			
Application type		On-grid			

Financial Parameters

Avoided cost of energy	$/kWh	0.919	Debt ratio	%	60.0%
RE production credit	$/kWh	0.015	Debt interest rate	%	8.5%
RE production credit duration	yr	25	Debt term	yr	25
RE credit escalation rate	%	2.0%			
			Income tax analysis?	yes/no	No
Energy cost escalation rate	%	5.0%			
Inflation	%	2.5%			
Discount rate	%	9.0%			
Project life	yr	25			

Project Costs and Savings

Initial Costs				**Annual Costs and Debt**		
Feasibility study	0.0%	$	-	O&M	$	880
Development	0.0%	$	-	Fuel	$	-
Engineering	0.0%	$	-	Debt payments - 25 yrs	$	32,683
Energy equipment	67.8%	$	378,060	**Annual Costs and Debt - Total**	**$**	**33,563**
Balance of equipment	27.4%	$	152,479			
Miscellaneous	4.8%	$	26,936	**Annual Savings or Income**		
Initial Costs - Total	100.0%	**$**	**557,476**	Energy savings/income	$	45,098
Incentives/Grants		$	-	RE production credit income - 25 y	$	736
				Annual Savings - Total	**$**	**45,835**
Periodic Costs (Credits)						
Inverter Repair/Replacement		$	50,000	Schedule yr # 12,24		
		$	-			
		$	-			
End of project life -		$	-			

Financial Feasibility

			Calculate energy production cost?	yes/no	No
Pre-tax IRR and ROI	%	13.6%			
After-tax IRR and ROI	%	13.6%			
Simple Payback	yr	12.4			
Year-to-positive cash flow	yr	8.9	Project equity	$	222,990
Net Present Value - NPV	$	137,362	Project debt	$	334,485
Annual Life Cycle Savings	$	13,984	Debt payments	$/yr	32,683
Benefit-Cost (B-C) ratio	-	1.62	Debt service coverage	-	1.44

Yearly Cash Flows

Year #	Pre-tax $	After-tax $	Cumulative $
0	(222,990)	(222,990)	(222,990)
1	14,519	14,519	(208,471)
2	16,879	16,879	(191,592)
3	19,357	19,357	(172,235)
4	21,960	21,960	(150,275)
5	24,692	24,692	(125,583)
6	27,562	27,562	(98,021)
7	30,574	30,574	(67,447)
8	33,738	33,738	(33,709)
9	37,060	37,060	3,351
10	40,548	40,548	43,900
11	44,211	44,211	88,111
12	(19,187)	(19,187)	68,924
13	52,096	52,096	121,019
14	56,337	56,337	177,356
15	60,789	60,789	238,145
16	65,465	65,465	303,611
17	70,375	70,375	373,986
18	75,530	75,530	449,516
19	80,944	80,944	530,460
20	86,628	86,628	617,088
21	92,597	92,597	709,685
22	98,865	98,865	808,550
23	105,446	105,446	913,996
24	21,920	21,920	935,915
25	119,612	119,612	1,055,528

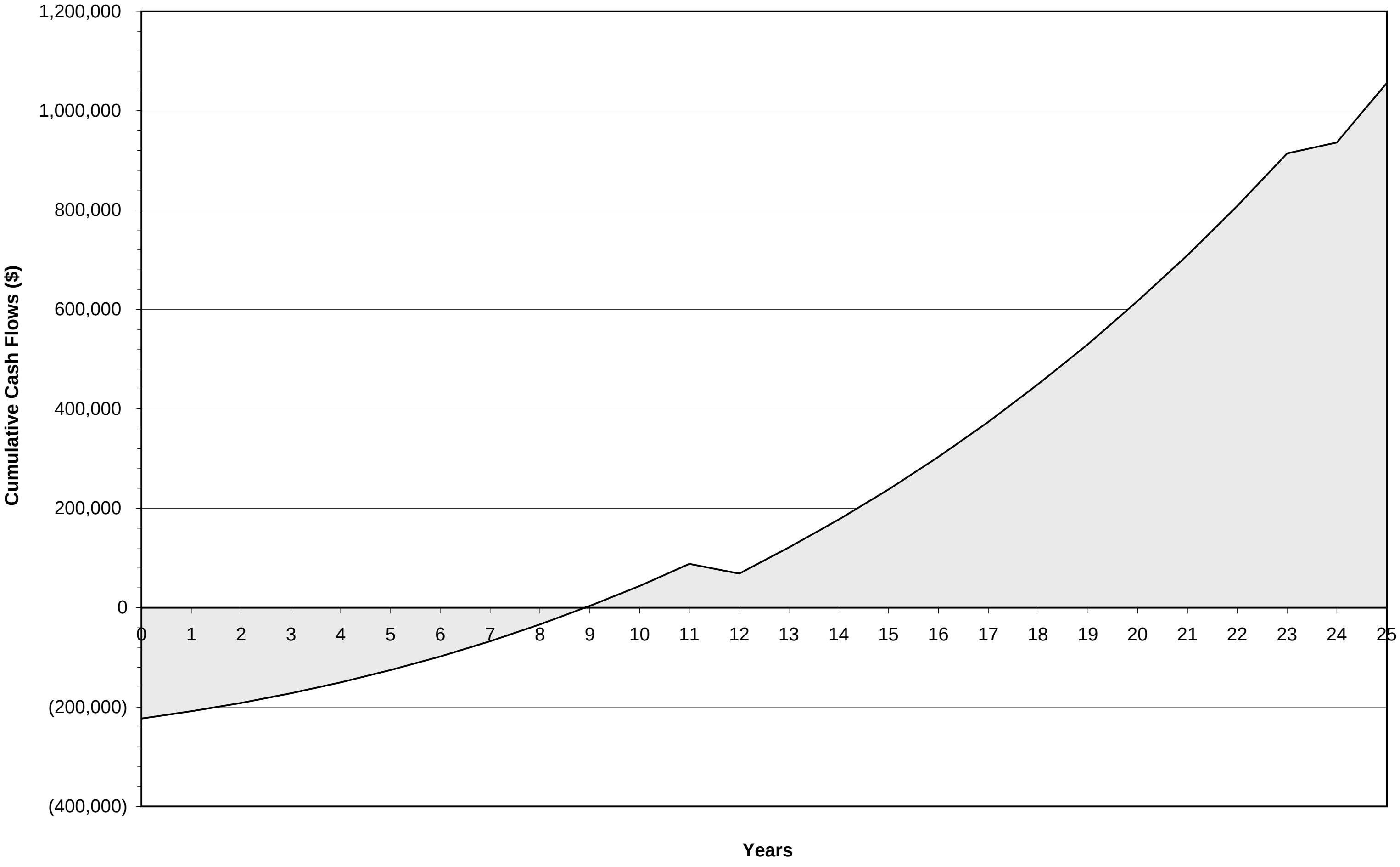
RETScreen® Financial Summary - Photovoltaic Project

Cumulative Cash Flows Graph

Photovoltaic Project Cumulative Cash Flows
University Ridge, East Stroudsburg, PA

Renewable energy delivered (MWh/yr): 49.073

Total Initial Costs: $ 557,476



IRR and ROI: 13.6%

Year-to-positive cash flow: 8.9 yr

Net Present Value: $ 137,362

RETScreen® Energy Model - Photovoltaic Project

Training & Support

Site Conditions		Estimate	Notes/Range
Project name		**University Ridge**	*See Online Manual*
Project location		**East Stroudsburg, PA**	
Nearest location for weather data	-	Allentown, PA	➡ *Complete SR&SL sheet*
Latitude of project location	°N	40.7	-90.0 to 90.0
Annual solar radiation (tilted surface)	MWh/m²	1.54	
Annual average temperature	°C	10.6	-20.0 to 30.0

System Characteristics		Estimate	Notes/Range
Application type	-	**On-grid**	
Grid type	-	Central-grid	
PV energy absorption rate	%	100.0%	
PV Array			
PV module type	-	a-Si	
PV module manufacturer / model #		Uni-Solar/ SHR-17	*See Product Database*
Nominal PV module efficiency	%	6.1%	4.0% to 15.0%
NOCT	°C	50	40 to 55
PV temperature coefficient	% / °C	0.11%	0.10% to 0.50%
Miscellaneous PV array losses	%	5.0%	0.0% to 20.0%
Nominal PV array power	kWp	**37.74**	
PV array area	m²	618.7	
Power Conditioning			
Average inverter efficiency	%	90%	80% to 95%
Suggested inverter (DC to AC) capacity	kW (AC)	34.0	
Inverter capacity	kW (AC)	34.0	
Miscellaneous power conditioning losses	%	0%	0% to 10%

Annual Energy Production (12.00 months analysed)		Estimate	Notes/Range
Specific yield	kWh/m²	79.3	
Overall PV system efficiency	%	5.2%	
PV system capacity factor	%	14.8%	
Renewable energy collected	MWh	54.526	
Renewable energy delivered	MWh	**49.073**	
	kWh	49,073	
Excess RE available	MWh	**0.000**	
			Complete Cost Analysis sheet

Version 3.2

NRCan/CETC - Varennes

RETScreen® Solar Resource and System Load Calculation - Photovoltaic Project

Site Latitude and PV Array Orientation		Estimate	Notes/Range
Nearest location for weather data		Allentown, PA	*See Weather Database*
Latitude of project location	°N	40.7	-90.0 to 90.0
PV array tracking mode	-	Fixed	
Slope of PV array	°	18.5	0.0 to 90.0
Azimuth of PV array	°	18.0	0.0 to 180.0

Monthly Inputs

Month	Fraction of month used (0 - 1)	Monthly average daily radiation on horizontal surface (kWh/m²/d)	Monthly average temperature (°C)	Monthly average daily radiation in plane of PV array (kWh/m²/d)	Monthly solar fraction (%)
January	1.00	1.89	-2.9	2.57	-
February	1.00	2.70	-1.5	3.35	-
March	1.00	3.69	4.0	4.16	-
April	1.00	4.71	9.9	4.96	-
May	1.00	5.44	15.9	5.46	-
June	1.00	5.96	20.8	5.86	-
July	1.00	5.87	23.3	5.83	-
August	1.00	5.22	22.1	5.39	-
September	1.00	4.19	18.0	4.60	-
October	1.00	3.06	11.8	3.64	-
November	1.00	1.95	6.2	2.54	-
December	1.00	1.57	0.0	2.15	-

		Annual	Season of use
Solar radiation (horizontal)	MWh/m²	1.41	1.41
Solar radiation (tilted surface)	MWh/m²	1.54	1.54
Average temperature	°C	10.6	10.6

Load Characteristics		Estimate
Application type	-	On-grid

Return to Energy Model sheet

Version 3.2

NRCan/CETC - Varennes

RETScreen® Cost Analysis - Photovoltaic Project

Type of analysis: Pre-feasibility   Currency: $ Cost references: None

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
Feasibility Study							
Other - Feasibility study	Cost	1	$ -	$ -		-	-
Sub-total :				**$ -**	0.0%		
Development							
Other - Development	Cost	1	$ -	$ -		-	-
Sub-total :				**$ -**	0.0%		
Engineering							
Other - Engineering	Cost	1	$ -	$ -		-	-
Sub-total :				**$ -**	0.0%		
Energy Equipment							
PV module(s)	kWp	37.74	$ 10,018	$ 378,060		-	-
Transportation	project	0	$ -	$ -		-	-
Other - Energy equipment	Cost	0	$ -	$ -		-	-
Credit - Energy equipment	Credit	0	$ -	$ -		-	-
Sub-total :				**$ 378,060**	67.8%		
Balance of Equipment							
Module support structure	m^2	618.7	$ 100	$ 61,869		-	-
Inverter	kW AC	34.0	$ 1,000	$ 34,000		-	-
Other electrical equipment	kWp	37.74	$ -	$ -		-	-
System installation	kWp	37.74	$ 1,500	$ 56,610		-	-
Transportation	project	0	$ -	$ -		-	-
Other - Balance of equipment	Cost	0	$ -	$ -		-	-
Credit - Balance of equipment	Credit	0	$ -	$ -		-	-
Sub-total :				**$ 152,479**	27.4%		
Miscellaneous							
Training	p-h	6	$ 65	$ 390		-	-
Contingencies	%	5%	$ 530,929	$ 26,546		-	-
Sub-total :				**$ 26,936**	4.8%		
Initial Costs - Total				**$ 557,476**	100.0%		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
O&M							
Property taxes/Insurance	project	0	$ -	$ -		-	-
O&M labour	p-h	16	$ 55	$ 880		-	-
Other - O&M	Cost	0	$ -	$ -		-	-
Credit - O&M	Credit	0	$ -	$ -		-	-
Contingencies	%	0%	$ 880	$ -		-	-
Sub-total :				**$ 880**	100.0%		
Annual Costs - Total				$ 880	100.0%		

Periodic Costs (Credits)		Period	Unit Cost	Amount		Interval Range	Unit Cost Range
Inverter Repair/Replacement	Cost	12 yr	$ 50,000	**$ 50,000**		-	-
			$ -	**$ -**		-	-
			$ -	**$ -**		-	-
End of project life		-	$ -	**$ -**			*Go to GHG Analysis sheet*

Version 3.2 NRCan/CETC - Varennes