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.
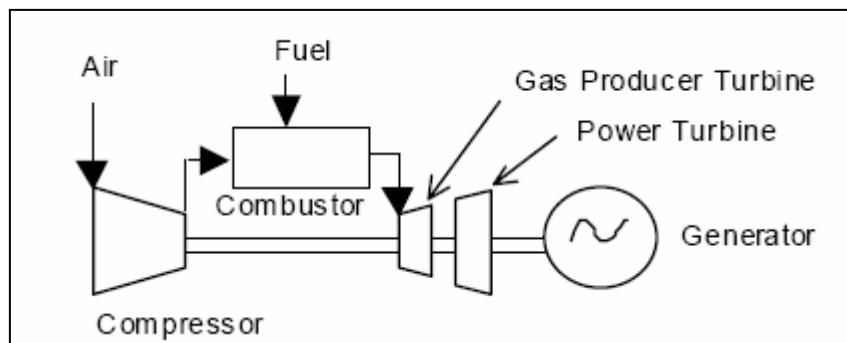
Figure 1: Gas turbine operation
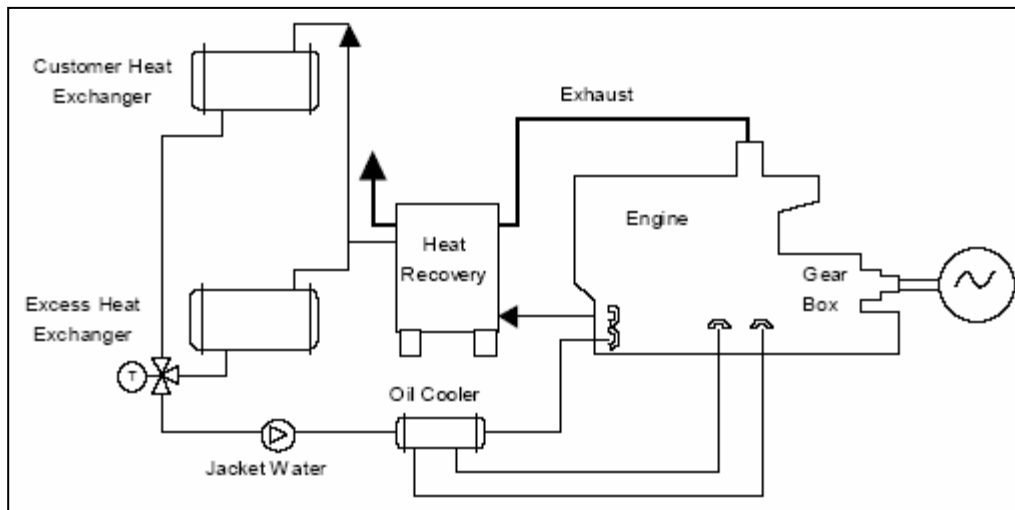
Figure 2: Reciprocating engine operation

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

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

Electricity:

$0.0919/kWh

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

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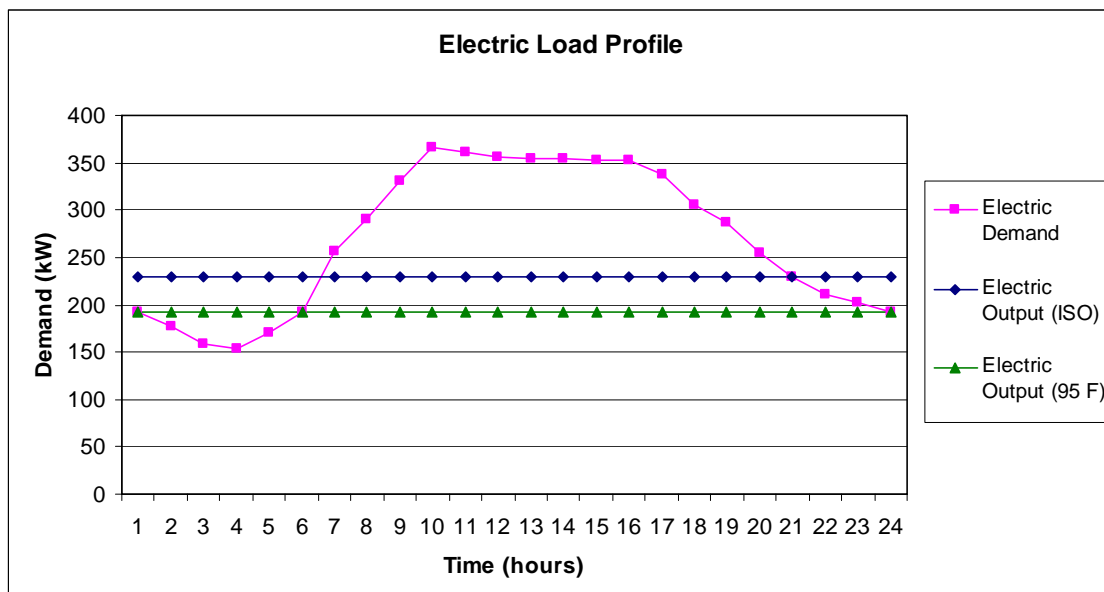
At the above output levels, adequate capacity for heating and cooling are produced for space conditioning. A gross efficiency ranges from 69% for power and heating at 32° F to 85% at ISO conditions of 59°F. Electrical efficiency is at about 27%. All values indicated are at a Low Heating Value (LHV).

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.
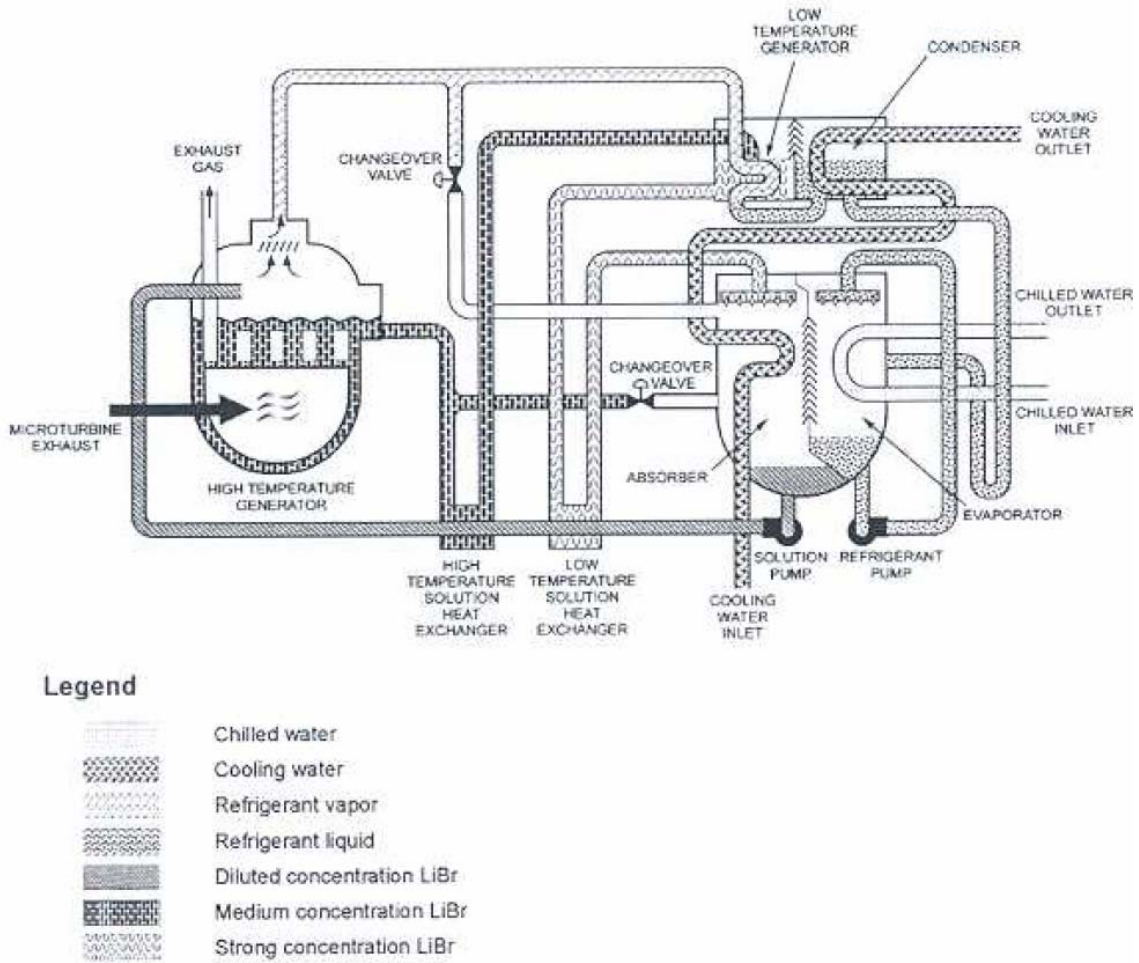
Absorption Cooling

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.
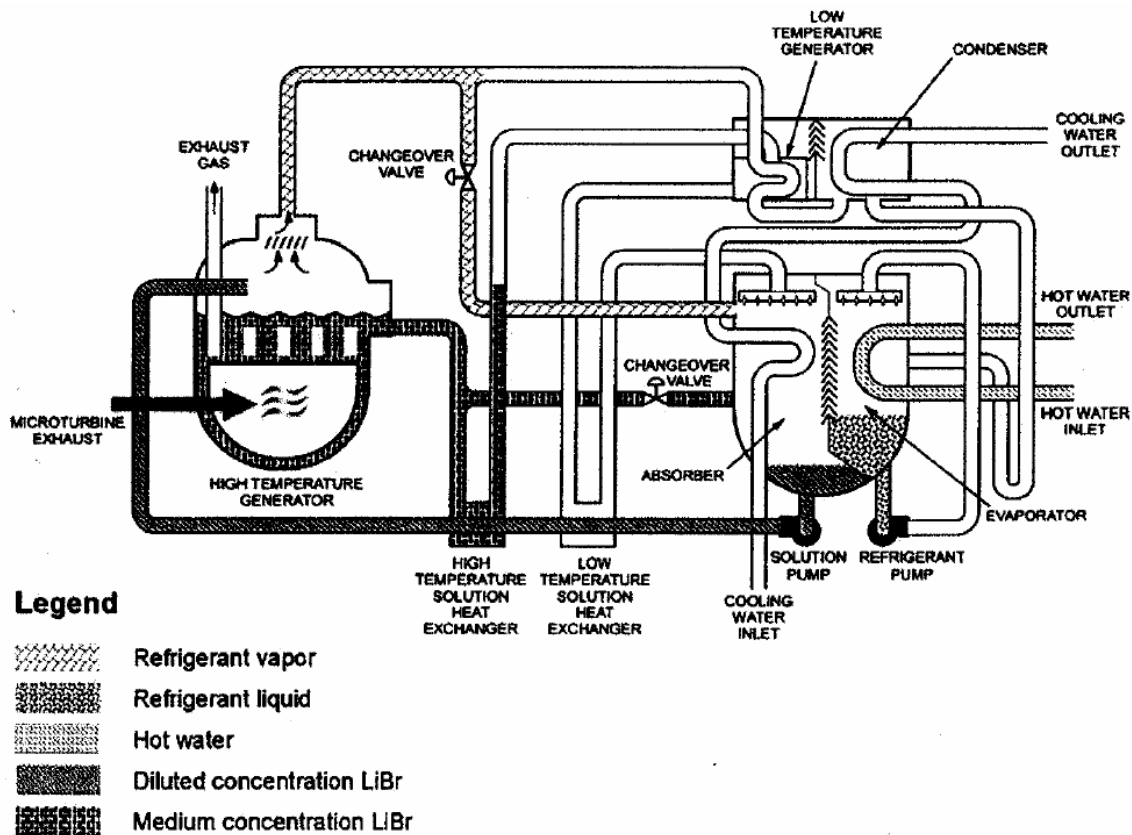

Figure 6: Heating Cycle

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.
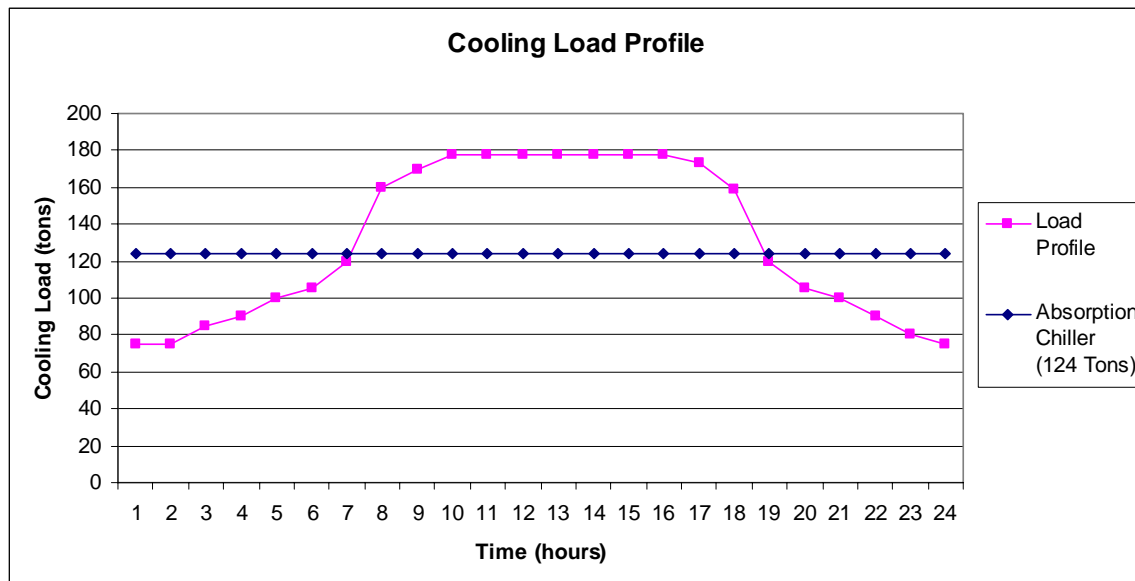
Figure 7: Cooling Load Profile

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.
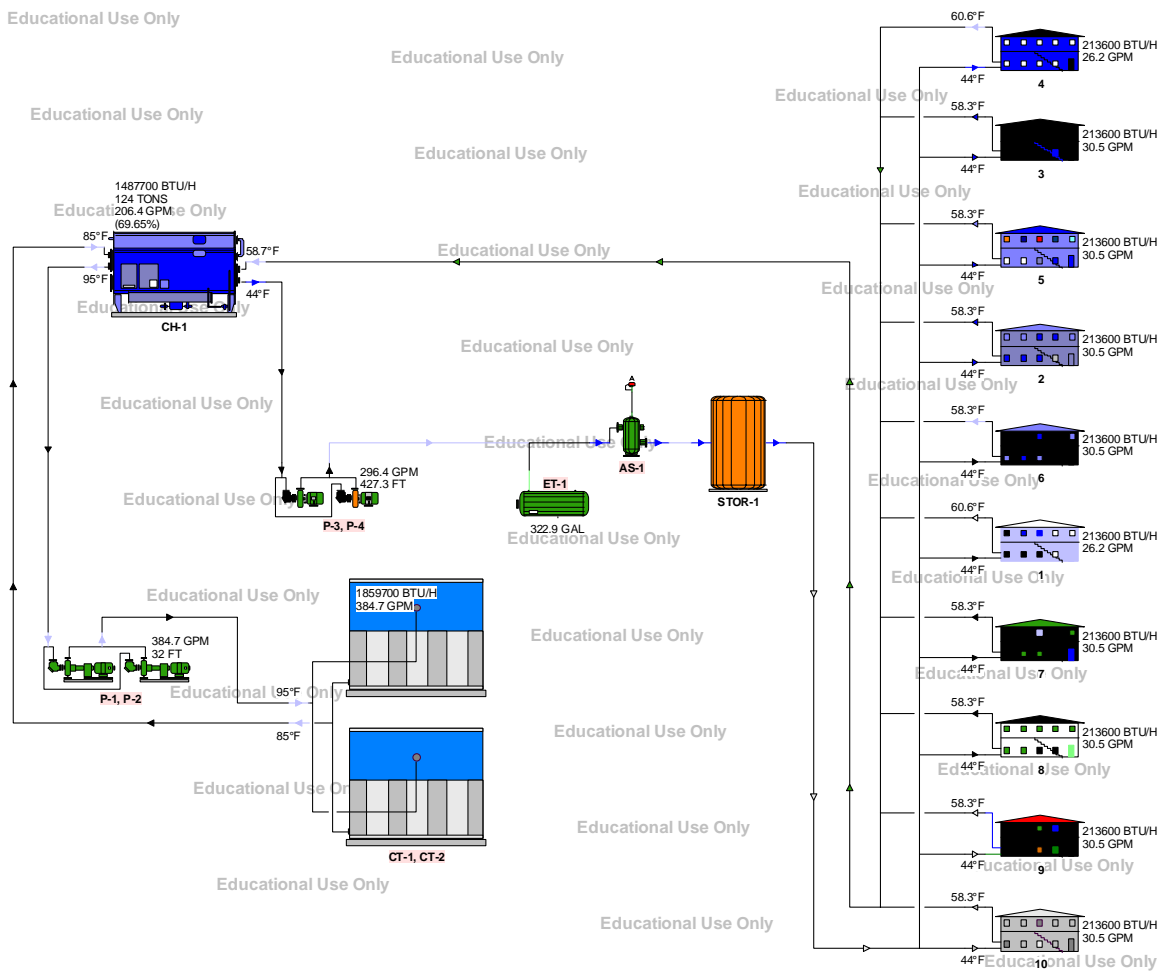
Figure 8: Cooling Schematic

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

Dry Analysis

CO Emissions (lb/MMBtu) vs CO Emissions (ppm)

- #6 Oil
- #2 Oil
- Propane
- Natural Gas
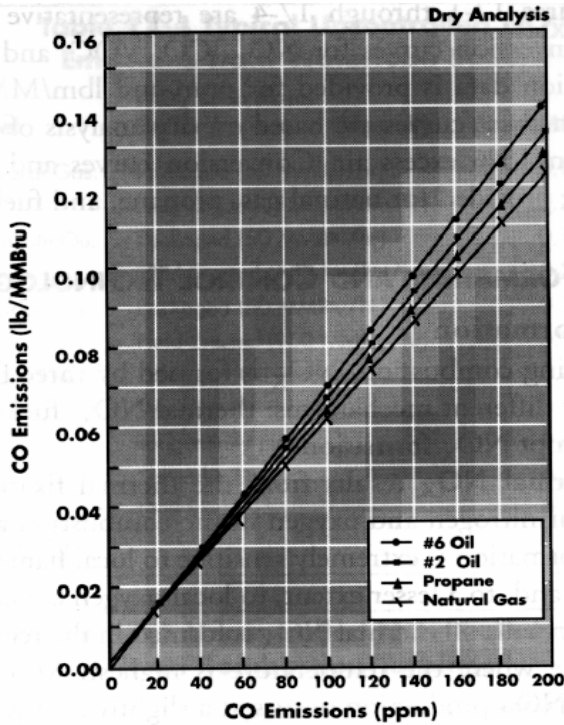
Conversion Equations

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

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

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

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

Dry Analysis

NO_X Emissions (lb/MMBtu) vs NO_X Emissions (ppm)

- #2 and #6 Oil
- Nat. Gas & Propane
- Propane
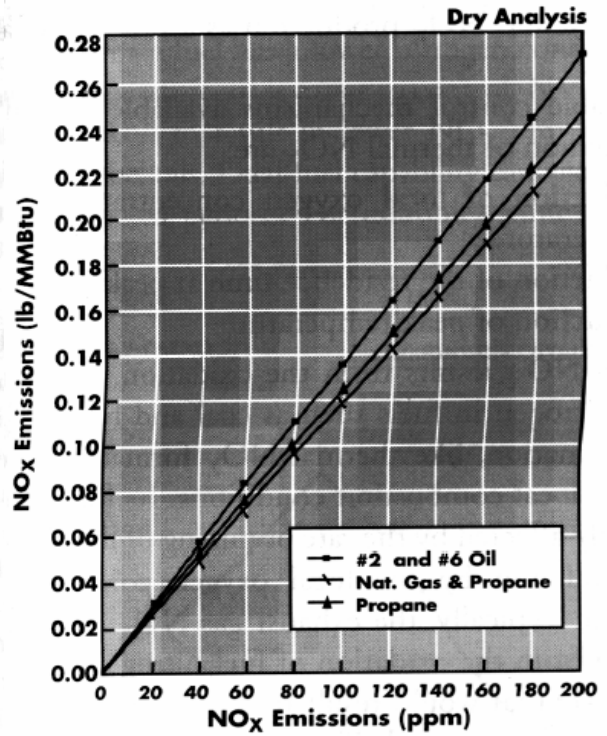
Conversion Equations

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

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

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

Dry Analysis

VOC Emissions (lb/MMBtu) vs VOC Emissions (ppm)
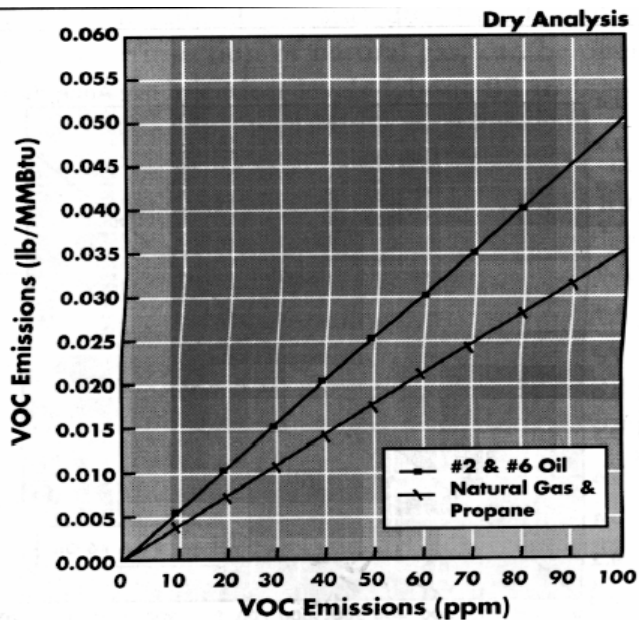
- #2 & #6 Oil
- Natural Gas & Propane

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.