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5.0 Mechanical Depth

Purpose

The purpose of the Mechanical Depth is to perform a chiller plant optimization study. As described in Section 4.0 of this report, the HBCCH is currently designed to utilize both district chilled water and district steam. While studying these systems during the fall semester in order to complete Technical Reports 1, 2, and 3, numerous questions arose. Was the district approach really the most cost-effective? Would on site chilling (either electric or absorption) be a better design alternative? What about absorption cooling with combined heat and power? These questions brought to light the value of creating an in-depth chiller plant optimization study.

The primary goal of this study is to evaluate numerous design alternatives for the HBCCH in order to quantitatively prove which alternative is the most cost-effective. First and operating costs for each system will be calculated so that they may be used in the final life-cycle cost analysis. The most cost-effective system will be the design alternative with the lowest life-cycle cost. The original district system serves as the base case scenario.

Justification

Improved economics and helping the environment by using less energy are the primary areas of justification for the chiller plant optimization study. By optimizing the chiller plant, the owner of the HBCCH will pay less while still receiving quality results. Money will be saved by designing a chiller plant which uses less energy, which in turn also helps the environment. An emissions study is not in the scope of this report. In order to accurately justify lowering emissions, data from ComfortLink and Trigen would be needed. Neither of these district system providers was willing to share any emissions data.

Design Alternatives Considered

Option 1: District System with Backpressure Steam Turbine

Steam enters the HBCCH at a pressure of 150 psi, but steam at that pressure is not utilized throughout the building. Its pressure must first be reduced. The base case scenario design uses a pressure reducing valve (PRV) to lower the pressure of the steam. During this process, energy from the steam is lost which could be utilized in other processes.

A backpressure steam turbine can reduce the pressure of the steam while converting the steam energy that would be wasted into electrical energy. In a backpressure steam turbine, shaft power is produced when high-pressure steam is directed against the blades of the turbine's rotor. The rotor is attached to a shaft that is then coupled to an electrical generator. The electricity created in the generator can then be used to offset some of the yearly electric utility cost.

A diagram of a typical backpressure steam turbine can be seen in Figure-6 below, and an overall schematic of this design alternative can be seen in Figure-7 below. The base case scenario district chilled water system is not altered in this design alternative and is identical to the system shown in Figure-2 of Section 4.0 of this report.

Figure-6: Typical Backpressure Steam Turbine Diagram

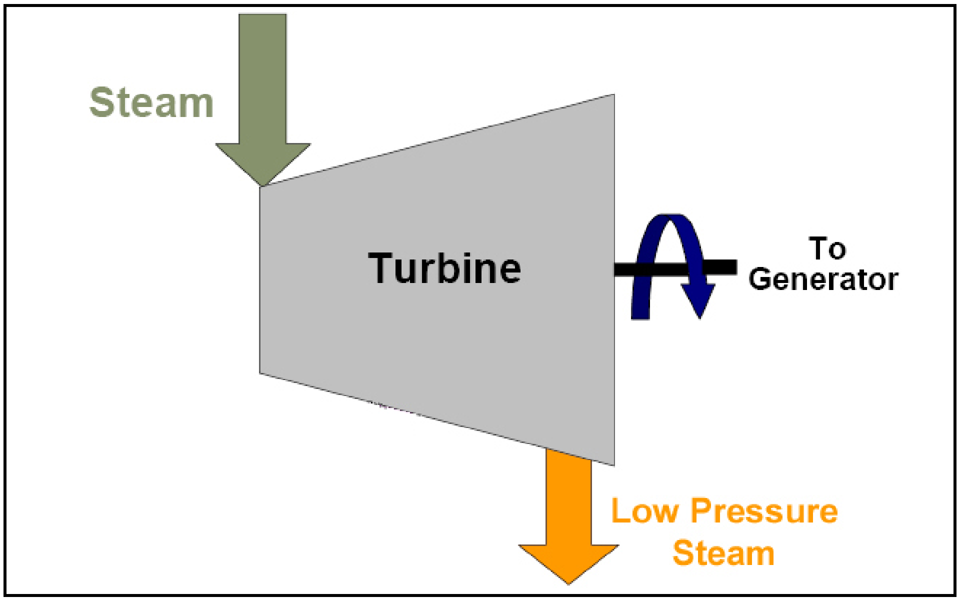
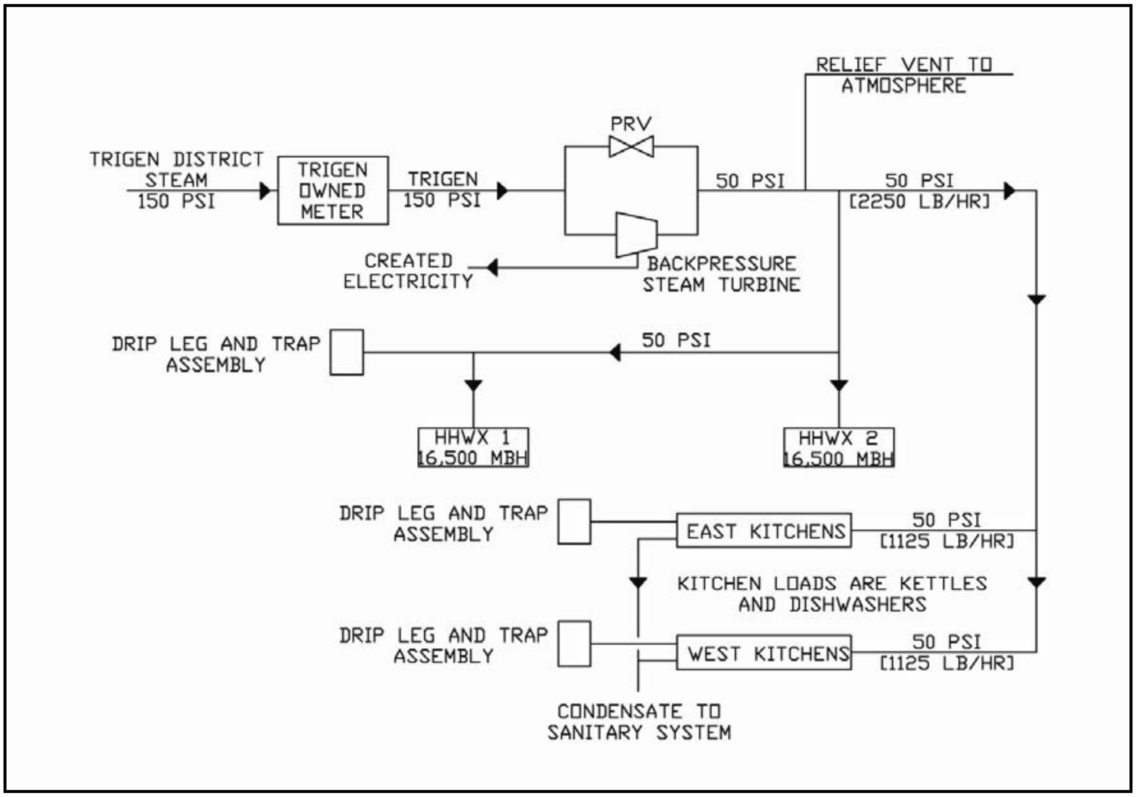


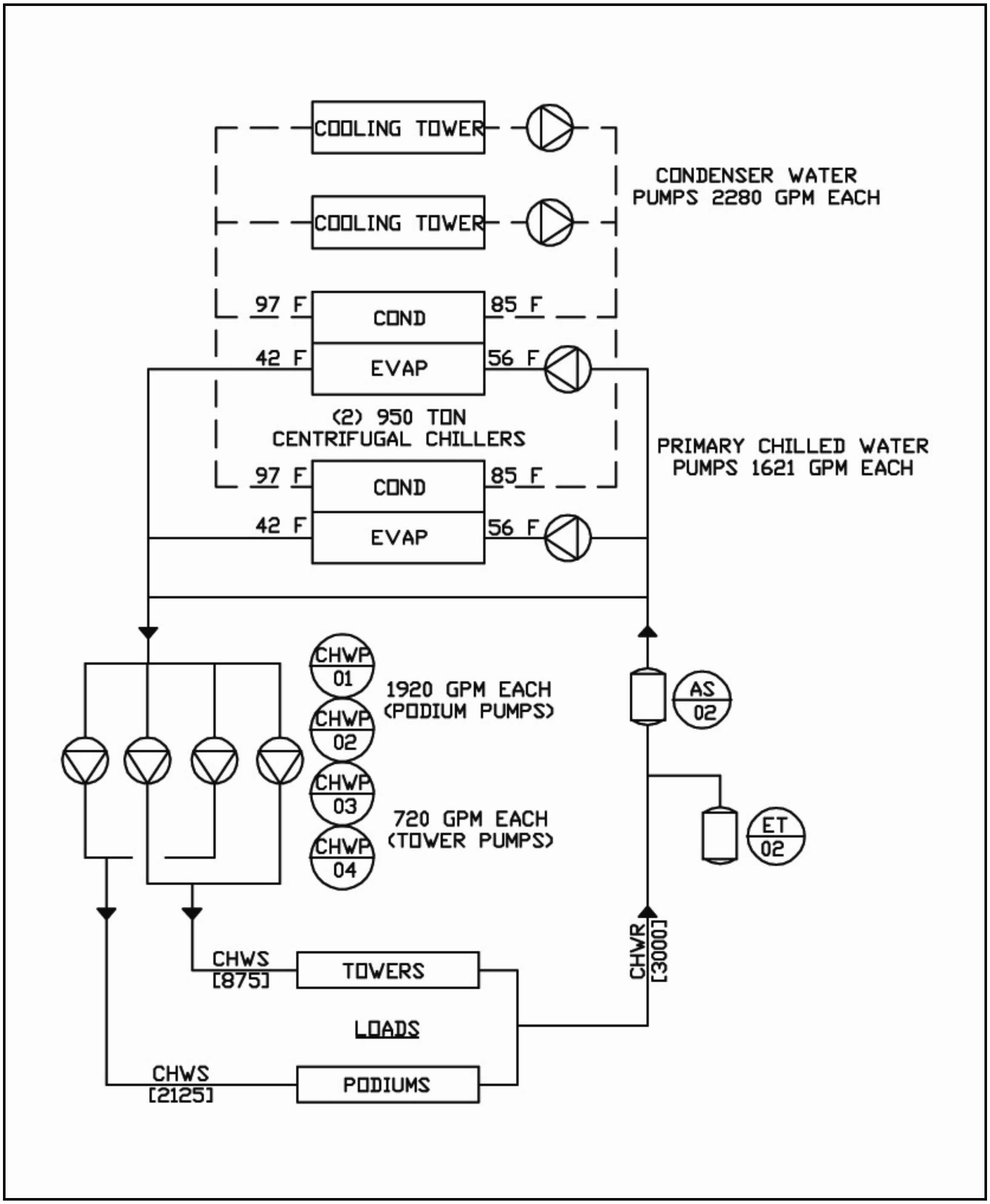
Figure-7: District System with BST Schematic



Option 2: On Site Centrifugal Chilling

For this design alternative, the district chilled water system is completely replaced with on site electric chilling. The building's cooling load is now handled by two 950 ton centrifugal chillers. Due to the fact that none previously existed with the district chilled water system, primary water pumps are also included in this alternative. Two pumps were selected, each of which can handle the full capacity of one of the chillers. No secondary pumps are needed since they are already included in the base case design. A two-celled cooling tower along with two condenser water pumps is also a necessity. Cut sheets of these equipment selections can be seen in Appendix-A of this report. A schematic of this design alternative can be seen in Figure-8 below. The base case scenario district steam system is not altered in this design alternative and is identical to the system shown in Figure-4 of Section 4.0 of this report.

Figure-8: On Site Centrifugal Chillers Schematic



Option 3: On Site Absorption Chilling

For this design alternative, the district chilled water system is completely replaced with on site absorption chilling. The building's cooling load is now handled by two 950 ton double-effect absorption chillers. These chillers use steam at 100 psi from the district steam system to power the generator in their "thermal compressors." Due to the fact that none previously existed with the district chilled water system, primary water pumps are also included in this alternative. Two pumps were selected, each of which can handle the full capacity of one of the chillers. No secondary pumps are needed since they are already included in the base case design. A two-celled cooling tower along with two condenser water pumps is also a necessity. A different cooling tower than the one used in Option 2 is required since the condenser water flow rates are not the same. Cut sheets of these equipment selections can be seen in Appendix-A of this report. Schematics of this design alternative can be seen in Figure-9 and Figure-10 below.

Figure-9: On Site Absorption Chillers Schematic

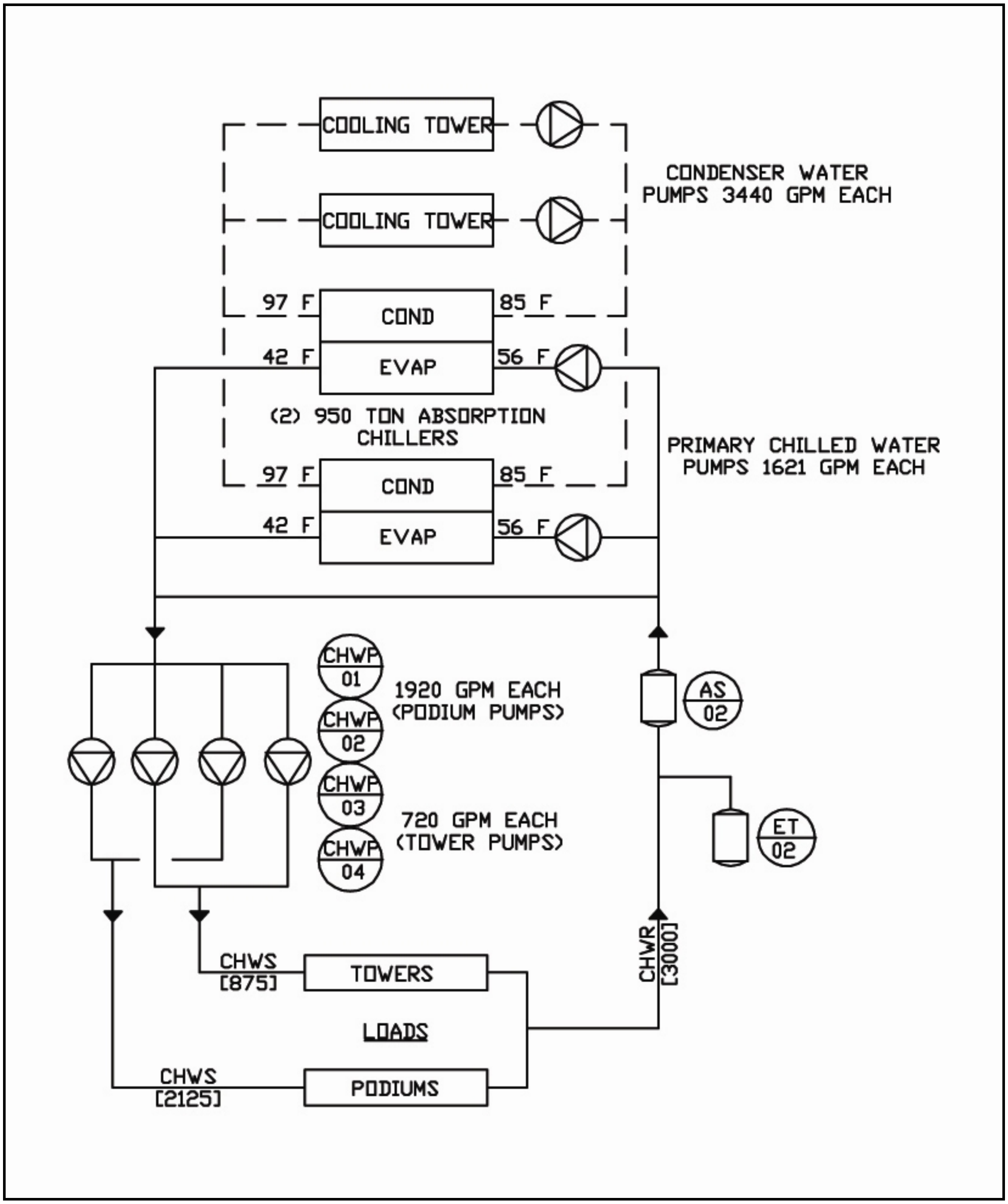
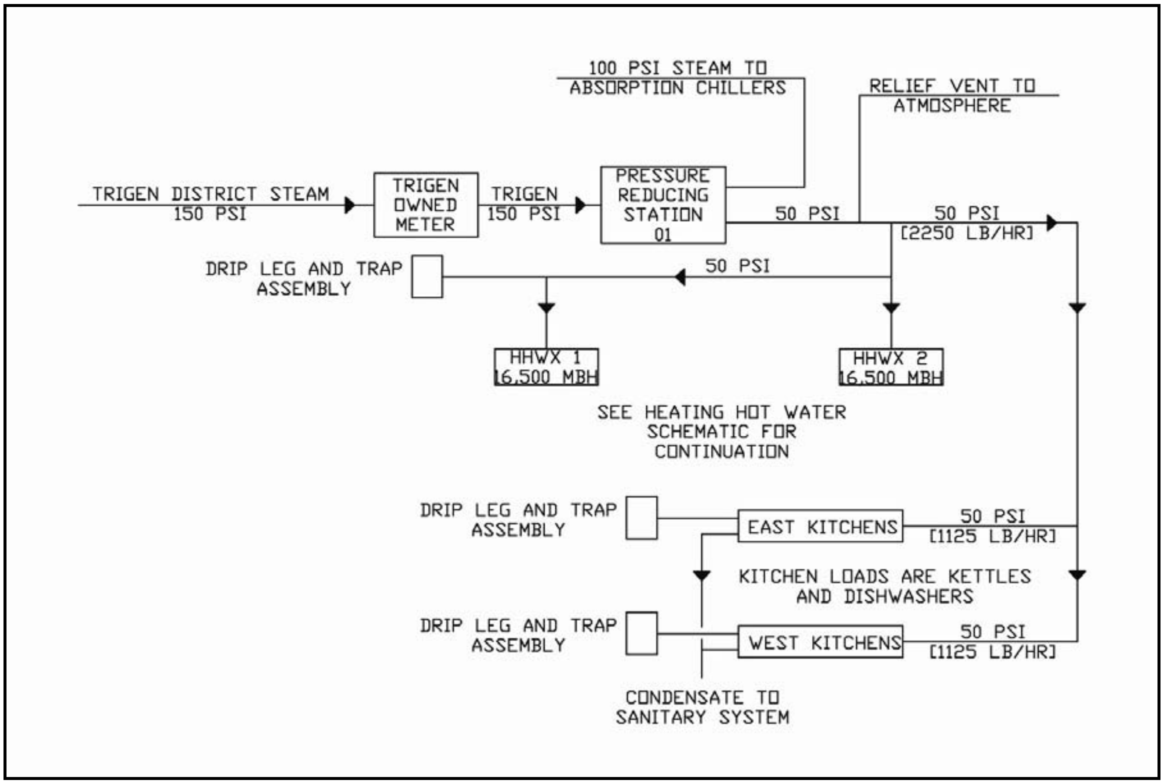


Figure-10: Absorption Chilling Steam Schematic



Option 4: On Site Absorption Chilling with Backpressure Steam Turbine

Once again, the district chilled water system is completely replaced with on site absorption chilling. The same chillers, cooling towers, and pumps are used as in Option 3. The only difference is that now a backpressure steam turbine (similar to the one added in Option 1) is added to the district steam system. Due to the fact that the absorption chillers require 100 psi steam while the rest of the HBCCH requires 50 psi steam, a slightly different type of backpressure steam turbine is needed. Called an extraction backpressure steam turbine, the turbine utilized in this design alternative can produce two different outlet steam pressures. The extraction turbine will lower the pressure of the district steam to 100 psi for the absorption chillers and to 50 psi for the remainder of the HBCCH. A diagram of a typical extraction backpressure steam turbine can be seen in Figure-11 below, and an overall schematic of this design alternative can be seen in Figure-12 below. The cooling schematic for this alternative matches that seen in Figure-9 above.

Figure-11: Typical Extraction Backpressure Steam Turbine Diagram

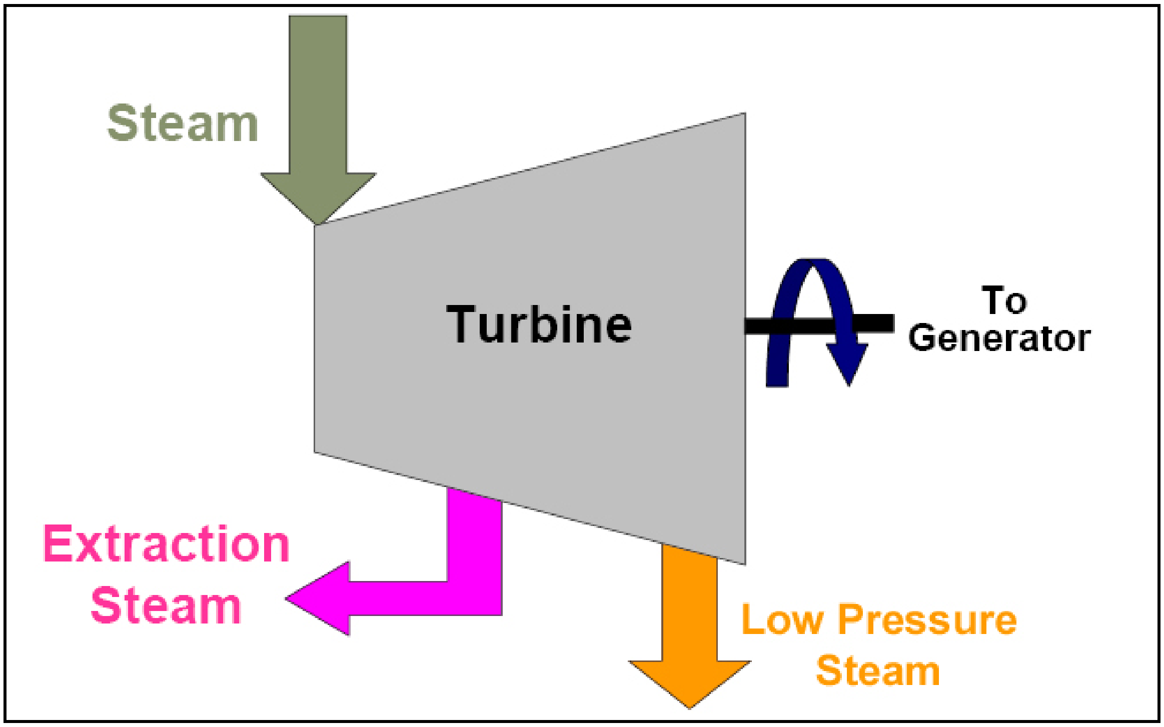
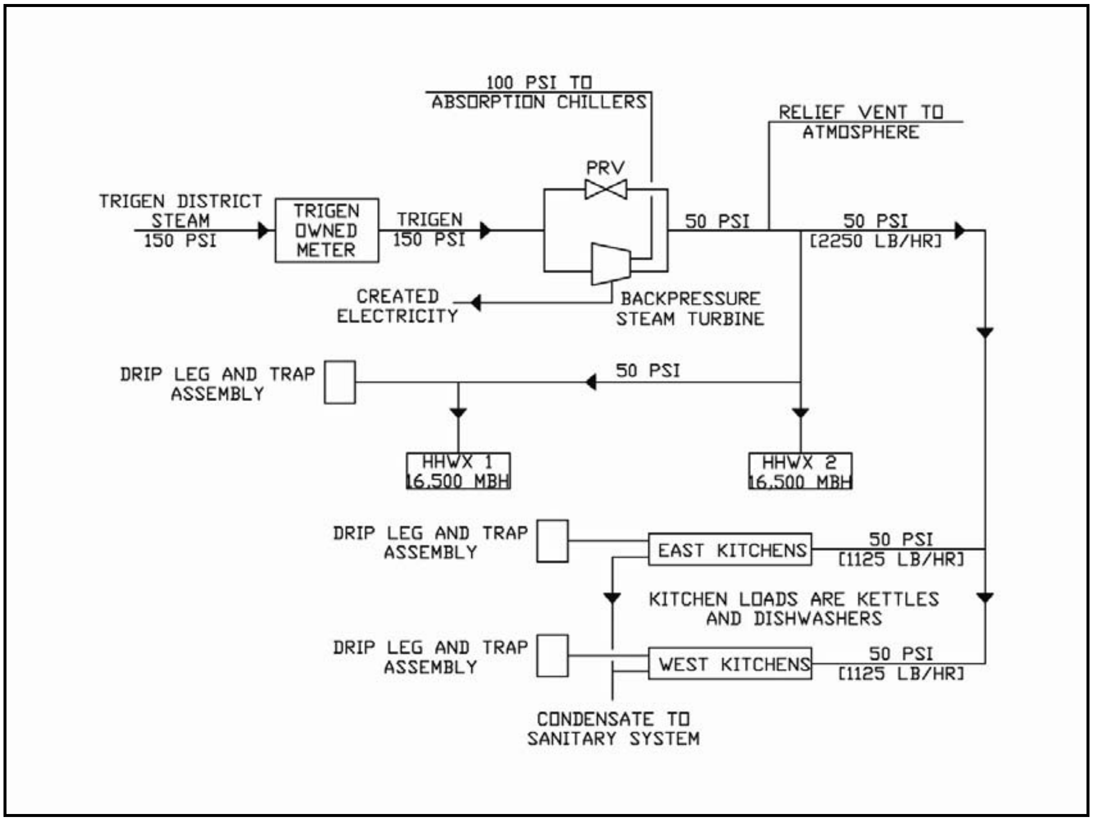


Figure-12: Absorption Chilling Steam Schematic with BST



Method of Analysis

In order to accurately compare all of the design alternatives described above, both first and operating costs for the systems need to be determined.

First Costs

First costs include any monetary expenses paid up front by the owner during the completion of a project. For the design alternatives considered in this report, first costs include equipment such as chillers, pumps, cooling towers, and a backpressure steam turbine. All first costs listed in Table-2 below were found using CostWorks 2005. The original base case scenario has zero first costs because the only on site equipment, two chilled water heat exchangers, is owned by the district chilled water supplier.

Table-2: Mechanical System First Cost

Mechanical System First Costs					
	District System, no CHP	**District System w/ CHP**	**Centrifugal Chilling**	**Absorption Chilling, no CHP**	**Absorption Chilling w/ CHP**
Chillers	$0	$0	$707,000	$879,000	$879,000
Cooling Towers	$0	$0	$174,000	$174,000	$174,000
Primary Pumps + Piping	$0	$0	$142,500	$249,375	$249,375
Condenser Water Pumps + Piping	$0	$0	$142,500	$249,375	$249,375
Backpressure Steam Turbine	$0	$21,000	$0	$0	$30,000
Total System First Cost	**$0**	**$21,000**	**$1,166,000**	**$1,551,750**	**$1,581,750**
Overall Rank	**1**	**2**	**3**	**4**	**5**

Operating Costs

Operating costs rely on two main factors: the amount of energy being used by the building and the rate being paid for that energy. In order for the design alternatives to be modeled accurately, actual utility rates for the HBCCH were required. Utility rates used in this report were obtained from ComfortLink, Trigen Baltimore, and Baltimore Gas & Electric.

Table-3: District Chilled Water Utility Rate

Charge	Monthly Rate
Capacity Charge	$210/ton of capacity
Usage Charge	$0.15/tonhr

Table-4: District Steam Utility Rate

Charge	Monthly Rate
Capacity Charge	$15,000
Usage Charge	$0.43/Therm

Table-5: Electrical Utility Cost

Charge	Rate	
	Summer	Non-Summer
Minimum Customer Charge	$110	$110
Delivery Service Charge (cents/kWh)	1.239	1.239
Demand Charges (per kW)		
Generation Charge	-	-
Transmission Charge	$1.05	$1.05
Delivery Service	$2.67	$2.67
Energy Charges (cents/kWh)		
Peak	9.319	5.534
Intermediate	8.802	5.406
Off-Peak	8.464	5.118
Hours		
Peak	10am-8pm	7am-11am 5pm-9pm
Intermediate	7am-10am 8pm-11pm	11am-5pm
Off-Peak	11pm-7am	9pm-7am

Now that the rates being paid for energy consumption are known, only the amount of energy being used is left to be determined. Since the HBCCH is not yet completed, no real data is available. This meant that a building model was required so that the necessary analysis could be carried out. In order to obtain hourly energy data, a detailed model of the HBCCH was created using eQuest 3-6.

Step One: Constructing the Virtual HBCCH

First, the HBCCH was "constructed" in the model. Each type of space in the building was inputted into the model along with its associated occupancy schedule, dimensions, location in the building, and lighting and equipment heat gain criteria. For schedules and criteria used please see Appendix A of this report. Utility rates for electricity and steam were also included. District chilled water rates could not be modeled in eQuest, so an extensive Excel spreadsheet was created to carry out that task. This spreadsheet will be discussed in greater detail later in this report. Once the building model was finished, nothing outside of the chiller plant was altered. This ensured that all of the design alternatives were considered on a level playing field.

Step Two: Generating Hourly Energy Usage Data

After finalizing the building model, the chilled water plant information was altered to reflect the differences in the alternative designs considered. First, information from the absorption chillers and all associated equipment was entered into eQuest, and a simulation was run. This simulation calculated the electrical and thermal energy uses for the HBCCH during each hour of the simulated year.

Once the absorption cooling simulation was completed, the chilled water plant information was changed to reflect the system characteristics of the centrifugal chillers and associated equipment. Again, a simulation was run which calculated the electrical and thermal energy uses for the HBCCH during each hour of the simulated year.

Both of the design alternatives simulated thus far, on site absorption cooling and on site centrifugal cooling, could be entirely simulated in eQuest since district chilled water utility rates were not required. As a result, yearly operating costs were calculated by eQuest directly. The results of these two simulations are shown in Table-6 below. In order to model the other two design alternatives and the base case scenario, the results from the original two simulations were exported into Microsoft Excel.

Step Three: Modeling the District System in Excel

The data obtained from the on site centrifugal chilling design alternative was used to model the base case district chilled water and steam scenario in Excel. Hourly eQuest output data for total electrical usage, cooling electrical usage, and total thermal usage was exported into an Excel spreadsheet. The cooling electrical usage was subtracted from the total electrical usage to determine how much of the electrical energy used by the HBCCH was for non-cooling purposes (lighting, plug loads, etc…). Using the spreadsheet, the standard Baltimore Gas & Electric rate was applied to this amount of energy usage.

The remainder of the electrical energy, the amount used to cool the HBCCH, was converted back into Btu/Hr and Tons using EER. The ComfortLink district chilled water rate was then applied to the tons of cooling required for the HBCCH. The district steam rate for this design alternative is equal to the rate calculated in the previous centrifugal cooling simulation. A portion of the Excel spreadsheet used to simulate the district system can be seen in Appendix C of this report. Due to its length (one line for every hour of the year), the entire spreadsheet is not included. The results of this simulation are shown in Table-6 below.

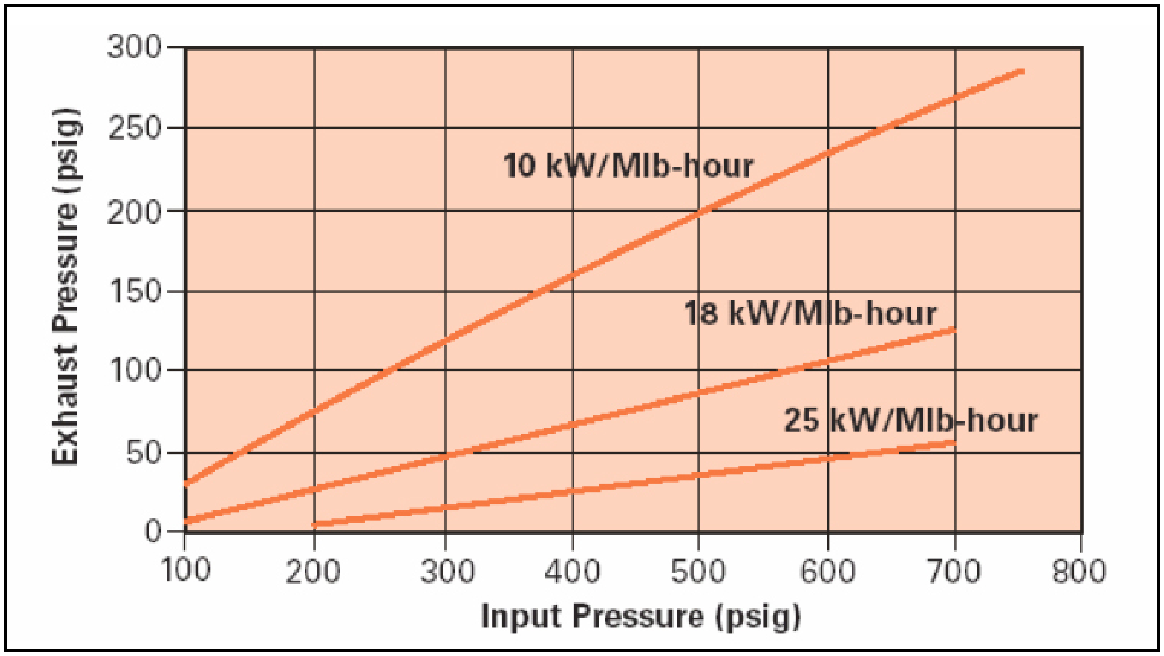
Step Four: Modeling the Backpressure Steam Turbine in Excel

In order to model the backpressure steam turbine in the two design alternatives which utilize it, Microsoft Excel was again employed. Hourly eQuest output data for total electrical usage, cooling electrical usage, and total thermal usage was exported into an Excel spreadsheet. First, the amount of thermal energy required was converted to lbs of steam used during each hour of the year using the following conversion:

$$(X \text{ Btu})*(1 \text{ ft}^3 / 1{,}000 \text{ Btu})*(0.332 \text{ lb} / 1 \text{ ft}^3) = Y \text{ lb of steam}$$

Once the amount of steam being used was determined, it was next necessary to find out how much electricity could be produced with that amount of steam passing through the backpressure steam turbine. Figure-13, listed below and found on both government and manufacturer handouts, was used to determine how much electricity would be produced under the given conditions. For the HBCCH, roughly 10 kW of electricity can be produced for every 1,000 pounds of steam-hour that passes through the backpressure steam turbine.

Figure 13: Electricity Produced by Backpressure Steam Turbine



This electricity, produced without the help of the Baltimore Gas & Electric grid, then had to be considered in the electrical utility costs for the HBCCH. Using the Excel spreadsheet, the produced electricity was subtracted from the required electricity value. This allowed both the demand and usage charges to change every month, saving the HBCCH money in the process. Again, a portion of the Excel spreadsheet used to simulate the backpressure steam turbine in both the district and absorption systems can be seen in Appendix C of this report. Due to their length (one line for every hour of the year), the entire spreadsheets are not included. The results of these simulations are shown in Table-6 below.

Step Five: Totaling the Mechanical System Operating Costs

Once all five simulations were completed, the resulting yearly operating costs were totaled and compared. The results of all five simulations can be seen in Table-6 below. Surprisingly, the centrifugal chilling design alternative has the lowest operating cost, with the absorption cooling with extraction backpressure steam turbine following as the next lowest. As expected, the district systems have the highest yearly operating costs.

Table-6: Mechanical System Operating Cost

Mechanical System Operating Costs					
	District System, no CHP	District System w/ CHP	Centrifugal Chilling	Absorption Chilling, no CHP	Absorption Chilling w/ CHP
Electrical Utility Cost	$519,061	$511,225	$628,147	$537,072	$520,438
Steam Utility Cost	$344,812	$344,812	$344,812	$477,028	$477,028
Chilled Water Utility Cost	$450,924	$450,924	$0	$0	$0
Yearly Operating Cost	**$1,314,797**	**$1,306,961**	**$972,959**	**$1,014,100**	**$997,466**
Overall Rank	**5**	**4**	**1**	**3**	**2**

Life-Cycle Cost Analysis

Now that both the first cost and yearly operating cost of each system is known, a life-cycle cost analysis can be carried out. In order to compare values of money spent at different times during the life-cycle of the system, all costs must be brought back to the present. The present worth of all costs was calculated using the following equation:

$$PV = A * [(1+i)^n - 1] / [i(1+i)^n]$$

Where:

PV = Present Value
A = Annual Payment
n = Life-Cycle Duration
i = Discount Rate

No equation for present worth of the first costs was required since first costs already occur during the assumed present. For this report, a life-cycle of twenty years with a discount rate of five percent is assumed. The results of the life-cycle cost analysis can be seen in Table-7 below.

Table-7: Life-Cycle Cost Analysis

Life-Cycle Cost Analysis					
	District System, no CHP	**District System w/ CHP**	**Centrifugal Chilling**	**Absorption Chilling, no CHP**	**Absorption Chilling w/ CHP**
Mechanical First Cost	$0	$21,000	$1,166,000	$1,551,750	$1,581,750
Electrical Utility Cost	$519,061	$511,225	$628,147	$537,072	$520,438
Steam Utility Cost	$344,812	$344,812	$344,812	$477,028	$477,028
Chilled Water Utility Cost	$450,924	$450,924	$0	$0	$0
Discount Rate	0.05	0.05	0.05	0.05	0.05
Life-Cycle Length	20	20	20	20	20
PV of Utility Costs	$16,385,277	$16,287,623	$12,125,220	$12,637,928	$12,430,631
Total Life-Cycle Cost	**$16,385,277**	**$16,308,623**	**$13,291,220**	**$14,189,678**	**$14,012,381**
Overall Rank	**5**	**4**	**1**	**3**	**2**

Conclusion

For the HBCCH, the design alternative using on site centrifugal cooling is the most cost-effective. Its life-cycle cost of $13,291,220 is over $700,000 less expensive than the next best option. This came as somewhat of a surprise. Throughout the completion of the chiller plant optimization study this semester, it was always assumed that the on site absorption cooling with backpressure steam turbine design alternative would prove to be the most cost-effective. A more detailed conclusion/analysis as to why the results turned out the way they did can be found in Section 8.0 (Conclusions and Final Recommendations) of this Report. It's also interesting to note that the base case scenario (the design actually being employed for the project), using district steam and district chilled water without any form of combined heat and power, is the most expensive of all the design alternatives considered.