Central Water-Cooled Chill Water Plant

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Abstract *— A medical device facility in the island needs to determine the feasibility of replacing the existing air-cooled chilled water system at their main plant with a more efficient water-system in order to reduce the electric energy consumption and realize the associated economies and reductions in air emissions. As part of this effort, monitoring equipment was installed on the existing chilled water distribution system and the data obtained was used to establish the annual cooling requirements and energy and water consumption for the alternate schemes under consideration. Two schemes will be developed for cost estimating and life cycle cost evaluation. One scheme was selected based on availability of used equipment from a recently closed nearby manufacturing facility as a secondary system for redundancy interconnected to a completely new system. The other scheme is based on keeping the existing equipment and replaced as time requires. A Life Cycle Cost Analysis for the both alternates over a 20 year period will be performed under a discount rate and energy cost scenario. The analysis will also include air emissions levels of* CO_2*,* SO_2 *and* NO_x *for the different alternates for the average US location.*

Key Terms *— Chill Water Plant, Cooling Requirements, HVAC, Life Cycle Cost.*

SCENARIOS

Alternate A is the base scenario which considers the continued use of five air-cooled chillers, three 287 ton units and two 400 ton units throughout the study period. The system would remain segregated, one being served by the three 287 ton units and the other by the two 400 ton units.

Alternate B considers the installation of new high efficiency 745 Ton water-cooled centrifugal chiller and associated cooling tower and pumps as well as the 680 Ton modular chiller room with its associated cooling tower, primary and condenser pumps. The new equipment is to be installed on a new mechanical room located on the east parking lot of the facility with the cooling tower sitting on top of the mechanical room. The modular chiller will be installed on a concrete slab adjacent to the new mechanical room. This alternate requires the interconnection of the new and modular chiller as well as installation of chilled water mains that tie into each of the two independent primary chilled water loops in the facility. In this alternate one of the existing air-cooled chillers will have to remain operational for redundancy in case the larger water-cooled system fails.

DATA ACQUISITION AND ANALYSIS

In order to calculate the cooling load requirement for the facility, a rig consisting of an ultrasonic flow meter and two temperature sensors were installed on the secondary chill water loops. The data was collected and the thermal load for the system was determined using the following formula [1]:

$$\dot{Q} = gpm * \frac{(T_{CHWR} - T_{CHWS})}{24} \quad (1)$$

where $\dot{Q}$ represents load in Tons and Temperature is in °F.

Due to the time constraint and budget for the study, data was collected for a period of one week during the month of August. In order to calculate the load requirements for an entire year, a five year trend from the outside air dry bulb temperature was generated using data collected from the temperature sensors installed in the existing air-cooled chillers. Since the internal loads of the facility maintain relatively constant throughout the entire year, load variations are due to external temperatures. From

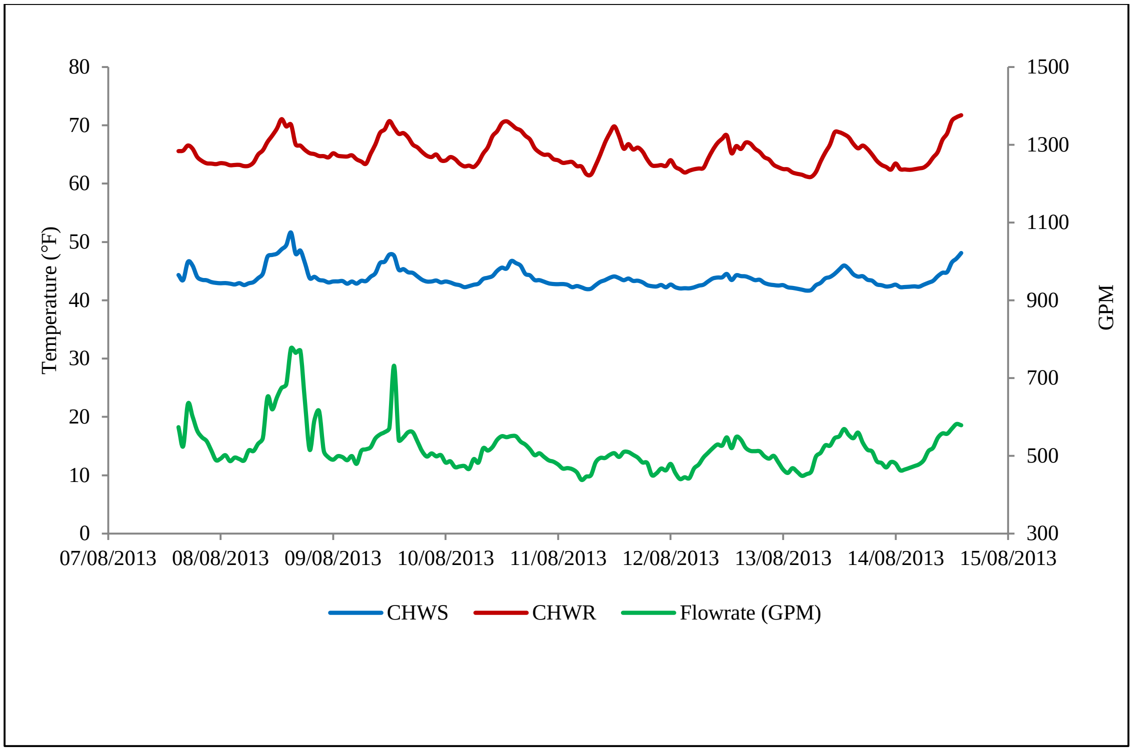

Figure 1

Original Building Chill Water System Measured Temperature and Flow

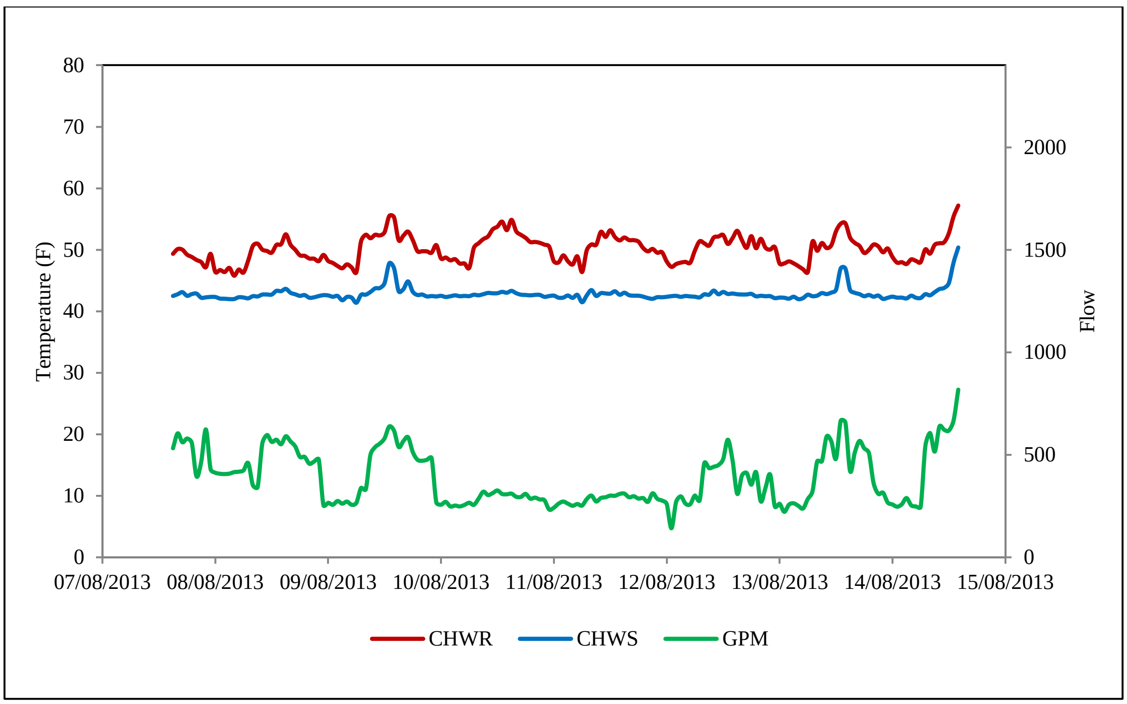

Figure 2

Expansion Building Chill Water System Measured Temperature and Flow

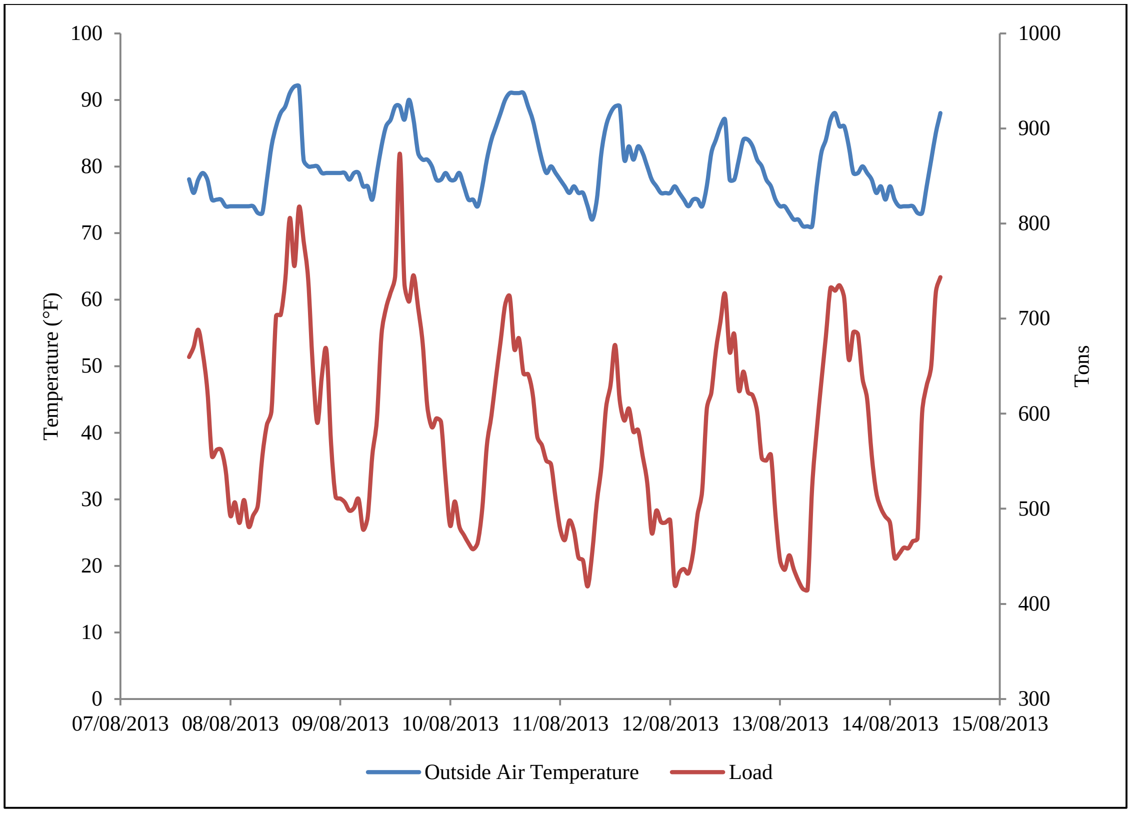

Figure 3
Combined Load and Outside Air Temperature

this data it was identified which was the peak, shoulder, and low seasons.

Figure 1 and Figure 2 illustrate the recorded data, chill water supply and return temperatures and flow rate, of the week under study for both secondary chill water loops. Figure 3 represents the combined calculated load given from the collected data during the week were the systems were monitored. The data obtained reveals a load pattern that was expected, showing a sharp increase in the load during the mornings as the building gets occupied and the envelop builds up during the day. The load peaks in the afternoon and gradually decreases in the late evening/night hours. The low load period is at night while the building remains fairly unoccupied and the envelope loads are greatly reduced. It can be observed that there are two days where peak loads are extremely high. Those peak loads were excluded from the selection of the equipment since it was identified that this behavior was due to electrical failures from the utility provider. Normal peak load was estimated to be near 735tons while low load estimate at 415Ton.

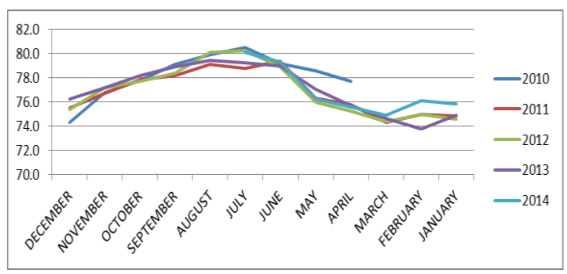

Figure 4
Outside Air Temperature 5yr Trend

Figure 4 shows the dry bulb temperature distributions for the outside air of the city were the facility is located. This trend was generated using actual temperature sensors located in the existing air-cooled chillers. From this data, a percentage of the peak load was assigned to each week of the year as follows:

- July/August – Peak Season (9wks)
- Sept./June – 99% from Peak (8wks)
- October – 98% from Peak (5wks)

- May/Nov. – 96% from Peak (9wks)
- April – 95% from Peak (4wks)
- Jan./Feb/Dec. – 94% from Peak (13wks)
- March – 93% from Peak (4wks)

This data makes the total number of hours of operation per year to be 8,736. The loads were the calculated for each month. Loads were then organized in bins as shown in Table 1 and the annual cooling requirement was calculated.

Table 1
Annual Cooling Bins for Combined System

Tons	Hrs/yr	Average Tons	Ton-hrs/yr
<399	93	200	18,553.50
400-499	2967	450	1,333,666.50
500-599	2471	550	1,357,814.50
600-699	2241	650	1,455,529.50
700-799	872	750	653,564.00
>800	92	800	73,600.00

Annual cooling load requirement was estimated to be at 4, 892, 728 tons-hrs/yr.

LIFE CYCLE COST ANALYSIS

The National Institute of Standards and Technology developed the Building Life Cycle Cost program [2]. The same was used to calculate the life cycle cost of both alternatives under a 20year period. This study includes energy costs, water cost, initial investment, capital replacements, and Operating/Maintenance and Repair costs.

To calculate the energy cost of the equipment for the first year, the equipment efficiencies from both alternatives were used together with the cooling bins in order to convert Ton-hrs/yr to kW-hrs/yr. From those results and the actual dollar per kW currently charged by the local utility provider, $0.22/kW-hr, it was determined the operating energy cost for both systems. The energy cost calculations also include energy price escalation rates as established by the U.S. Department of Energy to evaluate the total energy cost for the period under study [3].

The life cycle cost also includes costs water usage and sewer costs which also concur with actual prices on the island. For Alternative A, there are no costs allocated to this option since it is an air-cooled system. For Alternative B, water consumption was determined based on the cooling towers make up and blowdown, expressed in GPMs. The following equations were used to determine the make-up and blowdown [4].

$$M = E + BD + DR \qquad (2)$$

$$E = Water\ flow\ rate\ (GPM) \times Range\ (°F) \times 0.001 \qquad (3)$$

$$BD = \frac{E}{(C-1)} \qquad (4)$$

$$DR = Water\ flow\ rate\ (GPM) \times drift\ loss \qquad (5)$$

Where E is the evaporation loss, BD is the blowdown, and DR is the drift rate. The water flow rate was assumed to be 3.0gpm per ton and range is the temperature difference between the supply and return water from the tower. C is the cycles of concentration and according to a general rule, may be assume to be between 3 and 5. For this study it was assumed a value of 4. Drift loss is given by the cooling tower manufacturers.

For initial investment, capital replacements, and OM&R quotes from various suppliers where discussed in order to have a more realistic budget.

SUMMARY OF RESULTS

Table 2 presents the lifecycle costs for both alternates and simple payback for Alternate A vs. B. The paybacks are shown for a discount rate of 13% as stipulated by the client and electrical energy costs ranging from $0.20/kW-hr up to $0.28/kW-hr. The estimated energy and water use are presented in Table 3 and Table 4 presents air emissions for both alternates. As previously mentioned, the levels of air emissions are estimates for the US average location.

Table 2
LCC Analysis Summary (PV)

Discount Factor	Energy Cost ($/kWhr)	$ 0.20	$ 0.22	$ 0.24	$ 0.26	$ 0.28
13%						
	Alternate A	$ 10,861,009	$ 11,767,489	$ 12,673,970	$ 13,580,450	$ 14,486,930
	Alternate B	$ 8,916,091	$ 9,430,520	$ 9,944,948	$ 10,459,377	$ 10,973,806
	B vs A Discouted Payback (yrs)	4	4	3	3	3

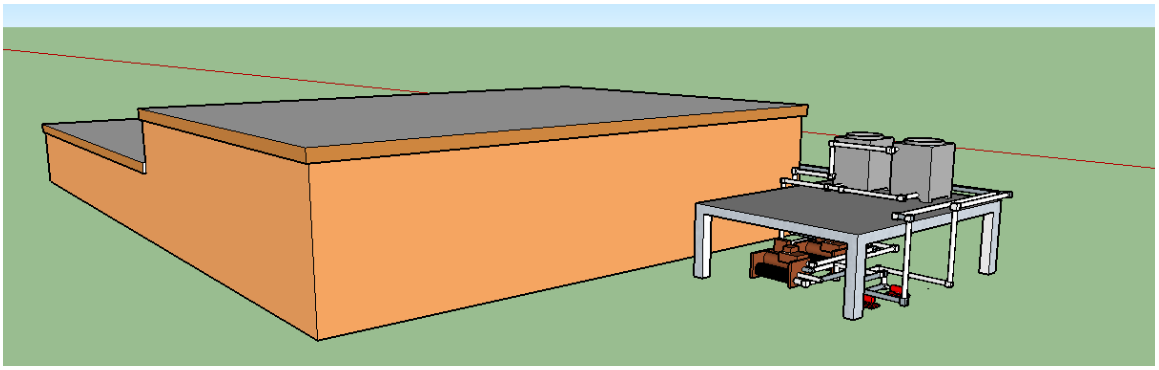

Figure 5
Chill Water Plant Concept Design – Southeast View

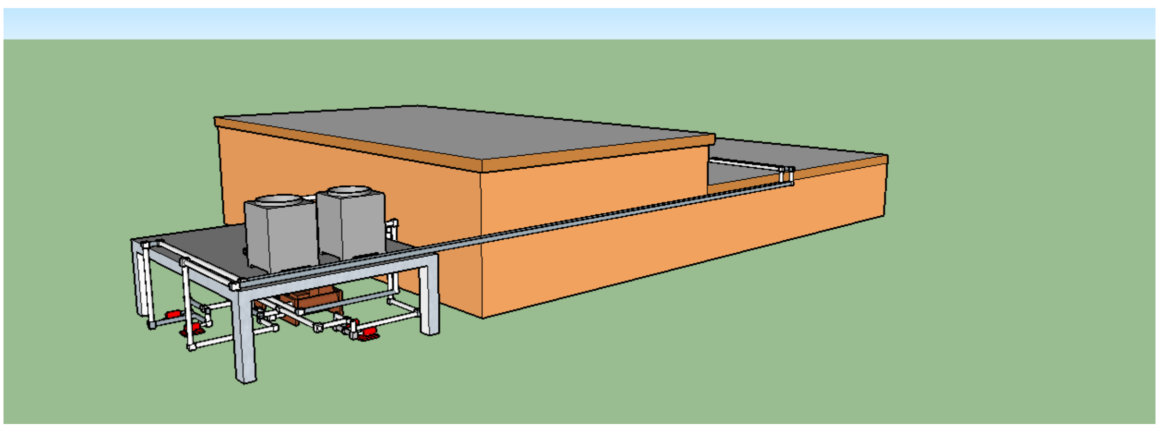

Figure 6
Chill Water Plant Concept Design - Northeast View

Table 3
Estimated Energy and Water Use

Scheme	Items		
	Energy Use (kW-hr/yr)	Utility Water Use (Gal/yr)	Sewer (Gal/yr)
Alternate A	6,951,956	0	0
Alternate B	3,945,243	13,390,361	3,344,568

Table 4
Estimated Air Emissions

Scheme	Gas		
	CO_2 (kg/yr)	SO_2 (kg/yr)	NO_x (kg/yr)
Alternate A	4,545,681.83	22,905.52	6,784.04
Alternate B	2,579,679.83	12,998.91	3,849.95

NIST BLCC 5.3-13: Comparative Analysis

Consistent with Federal Life Cycle Cost Methodology in OMB Circular A-94

Base Case: CHW PLANT_Alternative A

Alternative: CHW PLANT_Alternative B

General Information

File Name:	C:\Users\HernaD18\Desktop\DT\thesis\NEW CHW Plant Design\ARTICLE\BLCC.xml
Date of Study:	Sat Apr 18 23:15:18 GMT-04:00 2015
Project Name:	CHW PLANT
Project Location:	U.S. Average
Analysis Type:	OMB Analysis, Non-Energy Project
Analysis Purpose:	Cost Effectiveness, Lease Purchase, Government Investment or Asset Sale Analysis
Analyst:	Daniel A Hernandez
Base Date:	May 1, 2015
Service Date:	May 1, 2016
Study Period:	20 years 0 months(May 1, 2015 through April 30, 2035)
Discount Rate:	13%
Discounting Convention:	End-of-Year

Figure 7
BLCC Software Summary

Comparison of Present-Value Costs

PV Life-Cycle Cost

	Base Case	Alternative	Savings from Alternative
Initial Investment Costs:			
Capital Requirements as of Base Date	$0	$1,864,858	-$1,864,858
Future Costs:			
Energy Consumption Costs	$10,877,763	$6,173,144	$4,704,620
Energy Demand Charges	$714,639	$357,320	$357,320
Energy Utility Rebates	$0	$0	$0
Water Costs	$0	$874,426	-$874,426
Recurring and Non-Recurring OM&R Costs	$482,008	$497,471	-$15,463
Capital Replacements	$599,560	$177,731	$421,829
Residual Value at End of Study Period	$0	$0	$0
	------------	------------	------------
Subtotal (for Future Cost Items)	$12,673,970	$8,080,091	$4,593,879
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Total PV Life-Cycle Cost	$12,673,970	$9,944,948	$2,729,021

Net Savings from Alternative Compared with Base Case

PV of Non-Investment Savings	$4,172,050
- Increased Total Investment	$1,443,029

Net Savings	$2,729,021

Figure 8
BLCC Software Summary

CONCLUSION

Even though Alternate B has a high initial investment and an increase in water usage, savings will start to be noticed at the end of the third year. From the environmental perspective, the analysis indicates a reduction of significant air emissions. The emissions are subject to the accuracies of the calculations and possible implementation of advanced devices to measure such emissions. Water usage can be improved with further studies for the implementation condensate recovery from all air handling units located at the roof top and possible rain water harvesting. Alternate B also yields lower electric energy consumption.

Figure 5 and figure 6 illustrates what the final construction of the new chill water plant might look. The walls of the mechanical room were left out in order to illustrate the chillers, one primary and another as backup, and pumps. The wall of the mechanical room will be rolling doors in order to easily remove any equipment in case of substitution of any of them or repair. The rooftop illustrates both cooling towers, understanding that one cooling tower will serve as the main system and a secondary tower as back up for any possible downtime and/or preventive maintenance. This concept is subject to change as per clients' request.

Figure 7 and 8 both illustrates general information and present value cost comparison for both alternates used with the BLCC software developed by NIST.

REFERENCES

[1] F. C. McQuiston, et al., *Heating, Ventilating, and Air Conditioning Analysis and Design*, 6th ed., New Jersey: Wiley, 2005, pp. 299-365.

[2] *Life Cycle Costing Manual for the Federal Energy Management Program*, 1995 ed., National Institute of Standards and Technology, Gaithersburg, MD, 1996.

[3] *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2014*, National Institute of Standard and Technology, Gaithersburg, MD, 2014.

[4] *Mesan Engineering Handbook*, Mesan USA, Doral FL 2013.