ENERGY CONSUMPTION AND FINANCIAL IMPACT FROM CAPITAL PROJECTS AT UTILITIES & ENERGY SERVICES, TEXAS A&M UNIVERSITY

A Record of Study

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF ENGINEERING

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ABSTRACT

This record of study presents the intern's engineering and management experiences during her doctoral internship with Utilities & Energy Services (UES), Texas A&M University (TAMU) in partial fulfillment of the requirements for the Doctor of Engineering program. The intern was involved in the implementation of two capital projects, the chilled water system optimization project and the thermal energy storage tank project, during the internship period. Through this internship, the intern met her technical internship objectives of enhancing her understanding of the chilled water system, the "Demand Flow" optimization software, and the thermal energy storage tank operation. The efficiency of the west campus chilled water system and its avoided consumption and cost during the commissioning period were reported. The intern also acquired additional managerial skills development at UES through skill development courses by TAMU Employee & Organizational Development, and in practice as a UES manager.

In addition to her involvement in project implementation, the intern was also interested in the energy consumption and financial impacts from implemented capital projects. These two projects were part of 2013 and 2014 UES capital projects, among a series of capital projects in the past ten years. Three system efficiency and financial indicators were introduced to benchmark the impacts from implemented capital projects starting in fiscal year (FY) 2004. Energy Utilization Index (EUI), EUI Ratio, and utility rates were the three indicators for benchmarking. The impacts of the two projects along

with other capital projects were discussed through the projected results of the three indicators. The projected FY16 source and site EUIs were reduced mainly as a result of building consumption reduction efforts, while the projected EUI Ratio remained the same as previous year. The FY16 electricity and chilled water rates were decreasing because of lower purchased electricity rate and higher projected commodity consumptions. The chilled water rate reduction included the increase in debt and depreciation from chiller upgrades and other chilled water related capital projects. The FY16 heating hot water rate was increasing because of higher purchased natural gas rate.

DEDICATION

I dedicate this work to my parents, Kazuzo and Nitinart Sakurai. Without their love and support, I would not pursue and complete this degree.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Michael Pate, and my committee members, Dr. David Claridge, Dr. Timothy Jacobs, and Dr. Ben David Welch, for their guidance and support throughout my Doctor of Engineering program at Texas A&M University. I also appreciate the guidance and supervision provided by my internship supervisor, Robert Henry.

Thanks also go to my colleagues in Utilities & Energy Services (UES), Texas A&M University for making my time at UES a great experience. Special thanks go to my supervisor, Les Williams, for his mentorship and for giving me opportunities to learn and work with different groups. I would also like to thank Steven Bowman, Hui Chen, Chris Stephenson, and Dr. Lei Wang for providing data and information throughout the project implementation period. I want to extend my gratitude to my team members in Analytical Services; I could not have had a better team to positively challenge and improve my technical and managerial skills. Special gratitude goes to Rosemary Shaunfield for her support throughout the writing period of this record of study.

Finally, thanks to my mother and father for their encouragement, love, and support.

NOMENCLATURE

4CP	Four Coincident Peak
BAS	Building Automation System
CUP	Central Utility Plant
CHP	Combined Heat and Power
EOD	Employee & Organizational Development
ERCOT	Electric Reliability Council of Texas
ESCO	Energy Service Company
ESP	Energy Stewardship Program
EUI	Energy Use Intensity (in mBtu per square foot unit)
FY	Fiscal Year
GSF	Gross Square Footage
HRSG	Heat Recovery Steam Generator
mBtu	One Thousand British Thermal Units
mmBtu	One Million British Thermal Units
NLZ-SPP	North Load Zone Settlement Point Price
SUP	Satellite Utility Plant
TES	Thermal Energy Storage
UBO	UES Business Office
UES	Utilities & Energy Services

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CHAPTER I

INTRODUCTION

Texas A&M University developed a strategic plan and adopted by campus in 1999 with a vision to become a consensus leader among peer public institutions, called "Vision 2020: Creating a Culture of Excellence". Several focuses in Vision 2020 indicate campus growth both in size of student and faculty population, and in the number of academic and research conducive facilities. This led to planning construction of new buildings, existing building renovations and/or expansions, and some building demolition. In conjunction with Vision 2020, a "Campus Master Plan" was developed in 2004, which became the campus development guideline to build a campus that would "encourage and facilitate connectivity among people, places and programs", and be the bridge between the inherited traditions while striving for future excellence.

To support the development of the campus space and environment above ground, utility infrastructure both underground and inside utility plants were evaluated for their production capacity, reliability, and efficiency. A Utilities & Energy Services (UES) master plan was completed in 2006 in response to the campus master plan. The need for utility infrastructure improvements became evident considering the available production capacity, and the aging equipment and infrastructure. Another factor that made utility infrastructure improvements more appealing was the fluctuation of natural gas and electricity cost over the past fifteen years, 2000 - 2015. Natural gas and electricity are the two major commodities purchased to produce all utilities serving campus. With infrastructure improvements, better production efficiency was expected, which in turn would result in lower commodity consumption and university operating cost.

Following the 2006 UES master plan, several capital projects were developed and implemented. The largest project was the combined heat and power (CHP) upgrade that was placed in service in August 2011. The overall utility infrastructure at that time was improved and resulted in better efficiency. But there was still more that could be done. Another master plan was developed in 2012. When comparing the 2012 UES master plan to the 2006 UES master plan, which reviewed the system status and identified big item improvements, the 2012 UES master plan was smaller in scale and focused deeper on solving operational and functional issues. The updated master plan reflected changes in campus development and the direction of campus growth. Three capital projects for fiscal years (FY) 2013, 2014, and 2015 were developed and implemented in three phases to address the necessity and assure continuity of service on campus. Most of the projects under these capital plans were infrastructure upgrades and operational improvements. Plans for the addition, upgrade, or replacement of chillers and boilers were made for all utility plants. In addition to production equipment upgrades, a chilled water system operational improvement project, called the Chilled Water System Optimization project, and a Thermal Energy Storage (TES) project were also part of the capital plan.

The Chilled Water System Optimization project was developed with the expectation that the project would be paid back based on better chilled water system efficiency, hence lowering purchased utility cost for chilled water production. The TES project was also developed with the expectation that the project would be paid back, not with the improved efficiency, but with the electricity cost avoidance by lowering the peak demand by discharging the TES at peak periods, and producing chilled water at lower electricity price and using that chilled water and not running chillers during the higher electricity price times. Performance verification and an understanding of operational improvements became important to ensure the optimum project result and sustain the project performance.

This record of study documents my involvement and experience in chilled water system optimization and TES projects. This document also serves as partial fulfillment of my degree requirement for the Doctor of Engineering program.

Texas A&M Utilities & Energy Services

140 years from the original two brick buildings and five cottages in 1876, Texas A&M University has grown to more than 850 buildings and 24 million gross square feet. From the start, there was no nearby municipal services that could serve the campus sufficiently. University owned and operated Utilities Services was established and started producing energy in 1893. Since then, the utility system and services have become an integral part of campus growth. Today, UES is responsible for utilities and energy procurement, production, distribution, metering, cost recovery, and demand-side management. UES provides electricity, chilled water, heating hot water, domestic cold water, domestic hot water, and steam to buildings on campus. UES also provides

wastewater treatment services, storm drainage management, emergency generator maintenance, solid waste and recycling pick-up, and building automation control.

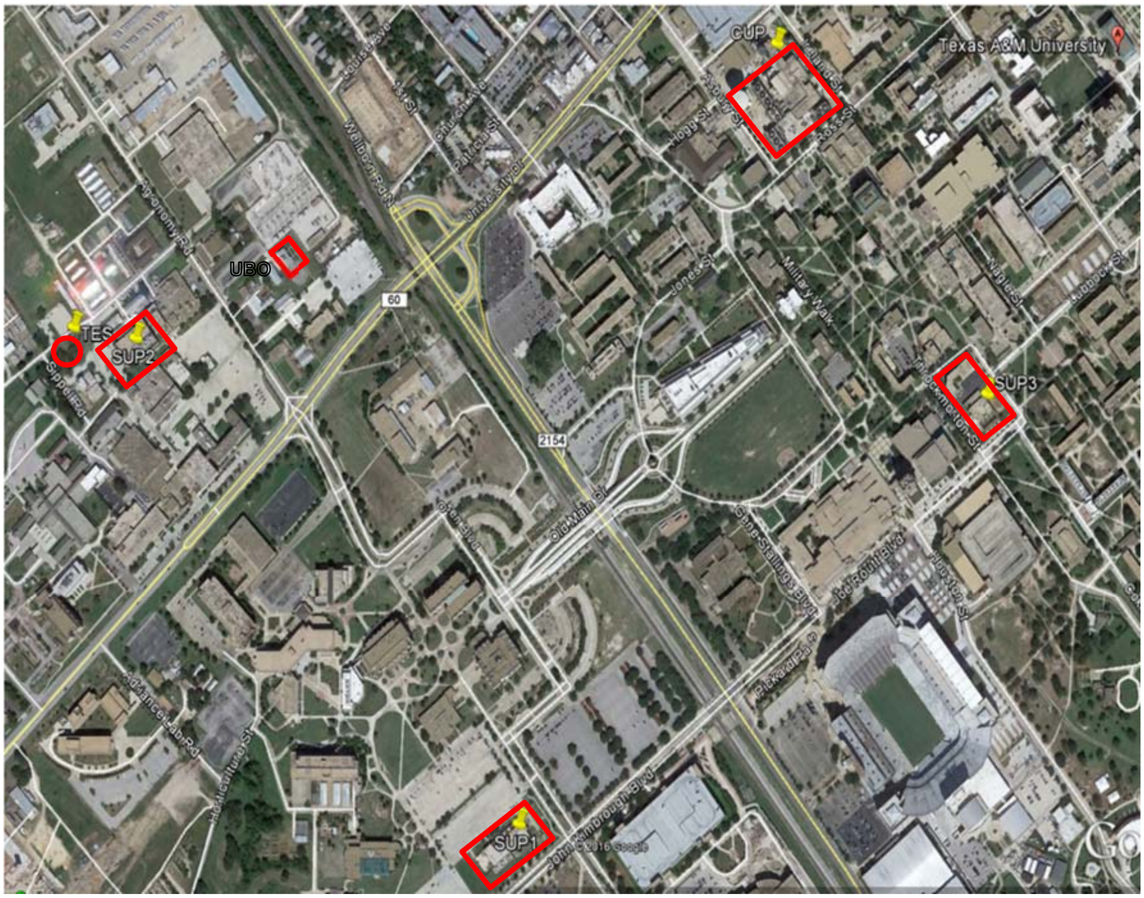

Figure 1 Location of Four Utility Plants in College Station, Texas

UES manages four campus production utilities plants, two serving east campus, Central Utility Plant (CUP) and Satellite Utility Plant 3 (SUP3), and another two serving west campus, Satellite Utility Plant 1 (SUP1) and Satellite Utility Plant 2 (SUP2). Wellborn Road indicates the division between east campus and west campus areas. Figure 1 shows the location of CUP, SUP1, SUP2, and SUP3. The newly built thermal storage tank and Utilities Business Office (UBO), which is where my office is located, are also shown in Figure 1.

All four plants supply chilled water and heating hot water to campus with east campus and west campus distribution loops being completely separated. The CUP is the main utility plant capable of producing electricity, chilled water, heating hot water, domestic hot water, and low pressure steam. A CHP upgrade at the CUP was completed in 2011. Natural gas is used to run the gas turbine. The heat from the exhaust gas is recovered by the heat recovery steam generator (HRSG), which produces 600 psig steam. The 600 psig steam can then be used to drive steam turbines and/or steam driven chillers. The low pressure steam extraction from the steam turbine can be used to produce heating hot water and domestic hot water, or used to supply campus where needed. Additional domestic hot water is produced at SUP3 to supplement and support the south side of east campus.

UES's Mission

"Providing world class service through the production, delivery, and management of safe, reliable, and efficient utility and energy systems, effectively stewarding university resources and the environment"

Organizational Structure

UES is a department in the Division of Finance and Administration, with approximately 215 employees. A four person executive leadership team and eleven managers oversee eleven functional areas of UES. Figure 2 shows UES organizational and reporting structure.

At present Jim Riley is the Executive Director. Les Williams is the Director. Homer Bruner is the Assistant Director overseeing information technology and energy services. The position of Associate Director overseeing maintenance, production, water & environmental, and electrical services is currently vacant. These four director level positions make the executive leadership team, who oversee the whole UES operation, sets UES goals and directions, and keeps UES well prepared to serve the campus today and in the future. The eleven functional areas then carry out specific tasks in each area to accomplish the UES goals with eleven managers overseeing the operations. In addition to routine work being done in each functional area, project work varying in size that needs specialties in more than one area is common. This cross function cooperation creates the environment where people from different areas can share their expertise and knowledge, and learn from each other. In each project, a project manager is assigned to oversee the project execution with active involvement of the functional area manager participating in the project.

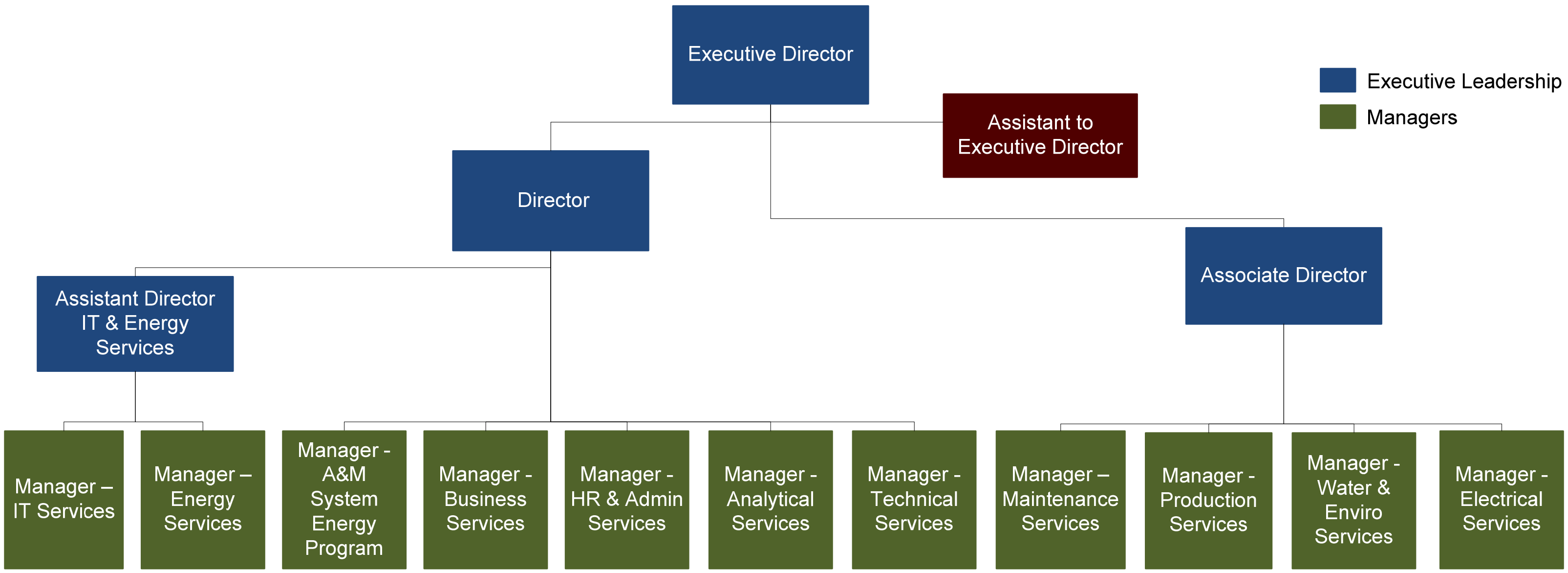

Figure 2 UES Organization Chart

The eleven functional areas as shown in Figure 2 from left to right are:

- Information Technology Services: provides UES IT service, including desktop support, server management and fiber/network infrastructure.

- Energy Services: includes Building Automation System (BAS) services, Energy Stewardship Program, and Metering services. Provides campus BAS management and first response to campus building HVAC related work requests and environmental control. Educates and raises awareness about the cost and environmental impact of energy and water consumption, and opportunities for improving energy efficiency.

- Texas A&M System Energy Management Program: supports the TAMU System campuses outside of Brazos County with energy conservation efforts and utility infrastructure needs.

- Business Services: includes Financial Reporting, and Procurement services. Provides the procurement process and inventory management, annual budgeting, and financial and budget reporting.

- Human Resources & Administrative Services: provides payroll, training, communications, vehicle fleet, telephone, and administrative support.

- Analytical Services: provides campus energy consumption and budget projections, customer utility invoicing, utility rate setting and customer budget guidance, energy analysis and reporting.

- Technical Services: provides process engineering support to production facilities, and design standards input for campus construction. Manages utility projects under $10 million, and represents UES and serves as a liaison on major capital projects (over $10 million) or campus construction projects. Manages the campus utility infrastructure drawings.

- Maintenance Services: implements the preventive/predictive program and reparative maintenance for utility plant equipment
- Production Services: manages and optimizes utility production at the CUP, three SUPs, and the Moore-Connally Building.
- Water & Environmental Services: manages the campus domestic water production and transmission systems. Manages and maintains all water distribution and collection systems, as well as waste water collection and treatment systems. Provides solid waste collection, recycling services, and environmental compliance for the production facilities.
- Electrical Services: manages the campus electrical distribution systems, campus exterior lighting, and building emergency generators. Provides instrumentation and control systems management and support in all production facilities.

Analytical Services

Analytical Services' mission is "to provide energy projections, data analysis, reporting and billing services to allow effective energy procurement, management, and billing and cost recovery to meet business requirements and provide excellent customer service." This team is comprised of a manager, a business analyst, a data analyst, two energy analysts, and five part-time (20 hours) student technicians.

This team reviews hourly data from more than 1,500 meters/sensors that monitor building energy consumption, and more than 300 meters/sensors in the production plants every month for accuracy before use in the billing process and other reports. This team also collects data from retail utility invoices for off-campus facilities, including the Texas A&M University System campuses. In addition to recovering approximately $70 million through the billing process, this consumption information can be used to track plant production efficiency, building EUI, and distribution system losses. It can be used as a basis to project future energy requirements. This information can also be used to monitor meter/sensor data quality, and as a reference for further investigation. Building energy consumption baseline models have been created to help monitor operational changes and meter/sensor issues. Once a year, Analytical Services reviews and sets proposed utility rates for the next fiscal year. Utility budget guidance with approved rates is provided to on-campus customers.

My Responsibilities

I have been working at UES in the capacity of Analytical Services manager since 2008. My responsibilities include managing the Analytical Services team activities as mentioned above, providing the monthly energy requirement projections and nominations for procurement, giving recommendations on plant operating scenarios especially during summer and the peak demand events, and providing technical support for performance improvement projects, particularly the data and/or result verification sections. In this capacity, I have worked closely with most of the work groups, and have had opportunities to participate in many projects.

The latest projects I have been involved with are the chilled water system optimization and TES projects, which Bob Henry, Technical Services manager and my internship supervisor, is the project manager. These two projects are parts of the FY13 and FY14 Utility Production Upgrade projects. These two projects were developed as a result of UES master plan study in 2012.

Internship Objectives

I have had the opportunity to work at UES and was involved in the implementation of the two major chilled water system related projects, Chilled Water System Optimization and thermal energy storage tank operation, during the internship period. As required in the Doctor of Engineering program, the technical and managerial internship objectives below were proposed. Through the assigned responsibilities described in this document, I learned to apply my knowledge and improved my skills to handle various aspects of this organization.

Technical Final Objectives

- Enhance my understanding of the chilled water system and the "Demand Flow" software. Develop a report to present the efficiency of the chilled water system and verify the avoided cost of this project
- Enhance my understanding of the thermal energy storage tank operation, its advantages and disadvantages technically and financially

Managerial Final Objectives

- Acquire the necessary skills as an Analytical Services manager at UES.

Organization of Report

This record of study is organized into 6 chapters. Chapter I provides the introduction and my objectives of this internship. Chapter I also describes UES history, mission, organizational structure and my role in the organization. Chapter II provides brief conclusions of the 2006 and 2012 UES master plan studies, a brief discussion of current system description as a result of UES master plan studies, and major implemented projects and their impact on campus energy use intensity (EUI) and utility rates from fiscal year 2004 through 2015. The next two chapters present in detail the two chilled water related projects implemented during my internship period. Chapter III discusses the chilled water system optimization project background, project implementation and the challenges, baseline model development, and the results during commissioning phase of this project. Chapter IV discusses the thermal energy storage project background, electricity cost structure, operational scenarios during the peak demand months, and the results. Chapter V discusses my managerial skill development during my internship period through courses provided by Employee & Organizational Development. Chapter VI discusses the conclusions of my internship period, the impacts of the two chilled water related projects to future EUI and utility rates.

CHAPTER II

UES MASTER PLANS AND IMPACTS OF CAPITAL PROJECTS

From FY04 to FY15, the Texas A&M University campus expanded from 20.6 million gross square footage (GSF) to 24.0 GSF. Close to 5 million GSF in new building space was added to campus and 1.6 million GSF building space were demolished. Several high energy consumption research/laboratory type of buildings were built during this time, such as Jack E. Brown Chemical Engineering building, Interdisciplinary Life Sciences building, and National Center for Therapeutics Manufacturing, and no parking garages were built during this period. It would be normal to expect higher total energy consumption at the building level, and subsequently higher total energy consumption including the production plants. Figure 3 shows the electricity and natural gas in mmBtu that this campus consumed each fiscal year. 8,100 mBtu per MWh is used to convert electricity into mmBtu unit. Over the 11 year period, GSF on campus increased by 17 percent, while total energy consumption combining both plant and building decreased by 22 percent, from 6.4 million mmBtu to 5.0 million mmBtu. This is the great result of years of determination to improve the production plant efficiency and execute the capital projects as recommended in the master plans.

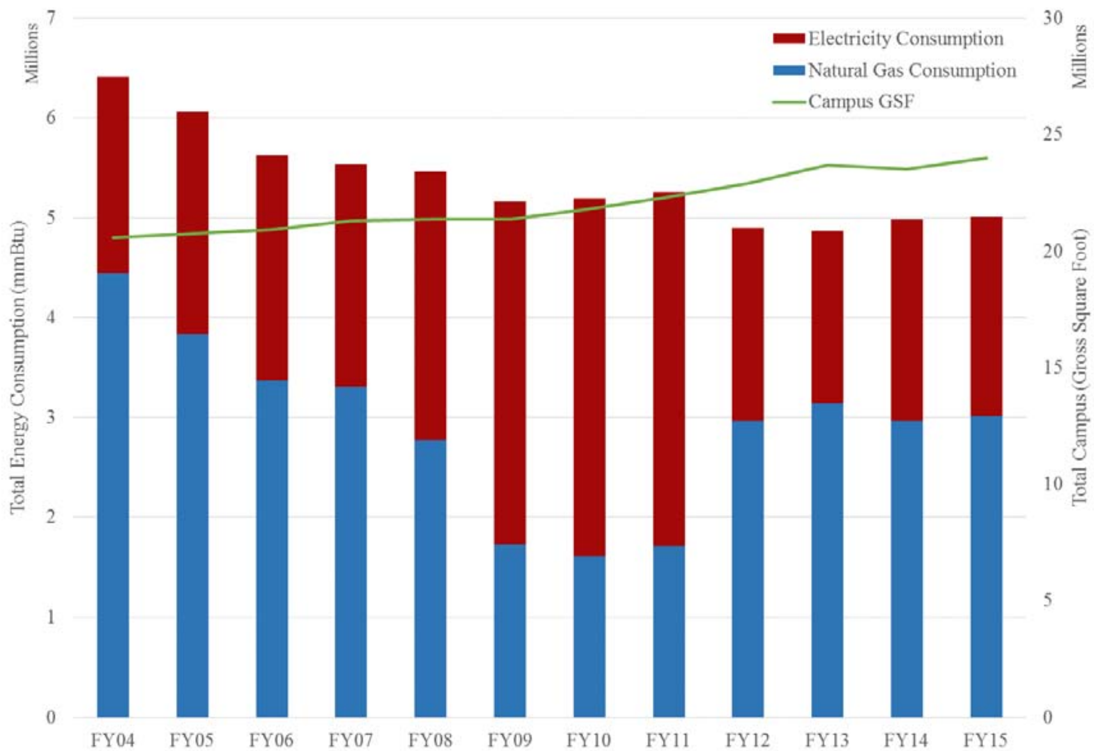

Figure 3 Total Energy Consumption by Fiscal Year

UES's Master Plan

There have been two master plan studies since 2000, the first in 2006, and the second in 2012. The first study was to evaluate the existing utility infrastructure, identify future loads, and provide utility infrastructure project recommendations to meet campus future needs. The goals were to document existing utility infrastructure, review and determine the best plan to meet future needs, and review the Design Standards. The second master plan study in 2012 was a follow-up of the 2006 study to further identify operational and functional issues regarding the existing utility infrastructure, develop a proposal for capital projects to meet future growth, and develop energy systems guidelines and standards for existing facilities and new building construction.

2006 UES Master Plan

From the 2006 master plan study, 12 groups of projects were identified and recommended as follow:

1. CHP addition: included a new gas turbine generator, a new HRSG, and a new zero voltage start diesel generator.
2. Steam turbine generator addition
3. Steam boiler evaluation and repair
4. CUP steam header system evaluation and improvements
5. SUP1 chilled water improvements: included discontinuing steam service to west campus, absorption chiller retirement, and system redundancy
6. CUP chilled water improvements: included absorption chiller retirement/replacement, and system redundancy
7. SUP3 chilled water capacity expansion
8. Cooling tower optimization
9. CUP chilled water pumping improvements
10. East campus heating hot water flow improvements
11. Electrical distribution upgrades: included a new transformer at 138 kV substation, and new current limiting reactors
12. Plant controls upgrade

Out of 12 groups of projects, all projects were implemented in varying scopes as deemed appropriate with the situation at the time. The CHP addition and steam turbine generator addition projects, when combined, are over $70 million in first cost.

2012 UES Master Plan

In the 2012 master plan study, both the five-year and thirty-year utility master plans were developed, with a set target of a 20% overall EUI reduction goal when compared to fiscal year 2013. Ten groups of projects were identified and recommended as follow:

1. Steam turbine generator overhaul

2. Chilled water system optimization: includes a network-based control technology for variable speed chiller plant operations, including convert pumps, cooling towers, and chillers from single speed to variable speed

3. Five-year plan for chilled water system improvements includes:

    a. Capacity replacement/renewal

    b. Heat recovery chiller (heat pump chiller) addition to SUP2

    c. Thermal energy storage tank at SUP1

4. Thirty-year plan for chilled water system improvements includes: capacity replacement, upgrade, and addition

5. Five-year plan for heating hot water system improvements

    a. Heat recovery chiller (heat pump chiller) addition to SUP2

    b. Capacity replacement and addition

6. Thirty-year plan for heating hot water system improvements includes: capacity replacement, upgrade, and addition
7. Thirty-year plan for domestic hot water system improvements includes: capacity replacement, upgrade, and addition
8. New Plant Site – Satellite Utility Plant 4 (SUP4)
9. Five-year plan for civil system improvements includes:
    a. Fire flow deficiency improvements
    b. Sanitary sewer system improvements
    c. Domestic water system improvements
10. Thirty-year plan for civil system improvements includes:
    a. Sanitary sewer system improvements
    b. Domestic water system improvements

As a result, three projects were created and added to the University Capital Plan or the UES Capital Plan as shown in Table 1.

Table 1 UES Capital Project Summary for Fiscal Year 2013 - 2015

PROJECT TITLE	FISCAL YEAR (INITIATION)
FY13 Utility Production Upgrade	
Managed by Facilities Planning & Construction	
Replacement of Chiller 103 @ SUP1	2013
Replacement of Chiller 09 @ CUP	2013
Addition of Heat Recovery Chiller @ SUP2	2013
Managed by UES	
Chilled Water Plant Optimization @ SUP1 & CUP	2013
FY14 Utility Production Upgrade	
Managed by Facilities Planning & Construction	
Installation of Thermal Energy Storage @ SUP1	2014
Replacement of Chiller 12 @ CUP	2014
Replacement of Chillers 301 & 302 @ SUP3	2014
Cooling Tower Upgrade @ SUP3	2014
Addition of a Heating Hot Water Boiler @ SUP1	2014
Managed by UES	
Chilled Water Plant Optimization @ SUP2 & SUP3	2014
Installation of Chiller 206 @ SUP2	2013
FY15 Utility Production Upgrade	
Managed by UES	
Refurbishment of Chiller 10 & 11 @ CUP	2015
Replacement of Chiller 201 @ SUP2	2015

Current System Description

Over the past decade, utility improvement projects were planned and implemented progressively to facilitate rapid campus growth and rising load requirements. Most of the production equipment has been upgraded or replaced with higher efficiency equipment that give UES the capacity to serve campus reliably and cost effectively. The systems that resulted in the greatest improvement were the CHP, chilled water, and heating hot water systems.

Combined Heat and Power

CHP project, as recommended in the 2006 UES master plan, started in 2009, took two years, and was completed in the summer of 2011. A new gas turbine generator, heat recovery steam generator, steam turbine generator and gas fired boiler were installed at the CUP to replace the old CHP system that had been in service for more than forty years. The new CHP system is able to produce electricity to support at least 60 percent of campus peak electricity load, approximately 75 MW, with the remainder purchased from the grid.

The current steam and power generating equipment are as follows:

- Gas Turbine Generator, GTG1: 32 MW
- Steam Turbine Generator, STG2: 11 MW, 600 psig to 20 psig by back pressure turbine, 60 psig extraction 4,000 pound per hour to campus
- Steam Turbine Generator, STG4: 5 MW, 60 psig to condensing, 20psig extraction + condensing under vacuum
- Two gas fired boilers, Boiler 2 (B2), and Boiler 12 (B12)
- One heat recovery steam generator (HRSG), B1 (210000 pound per hour, 600 psig)

Figure 4 shows steam and power schematic relationship at the CUP. Three primary steam pressures are produced at the CUP: 600 psig/600# (high-pressure), 60 psig/60# (medium-pressure), and 20 psig/20# (low-pressure).

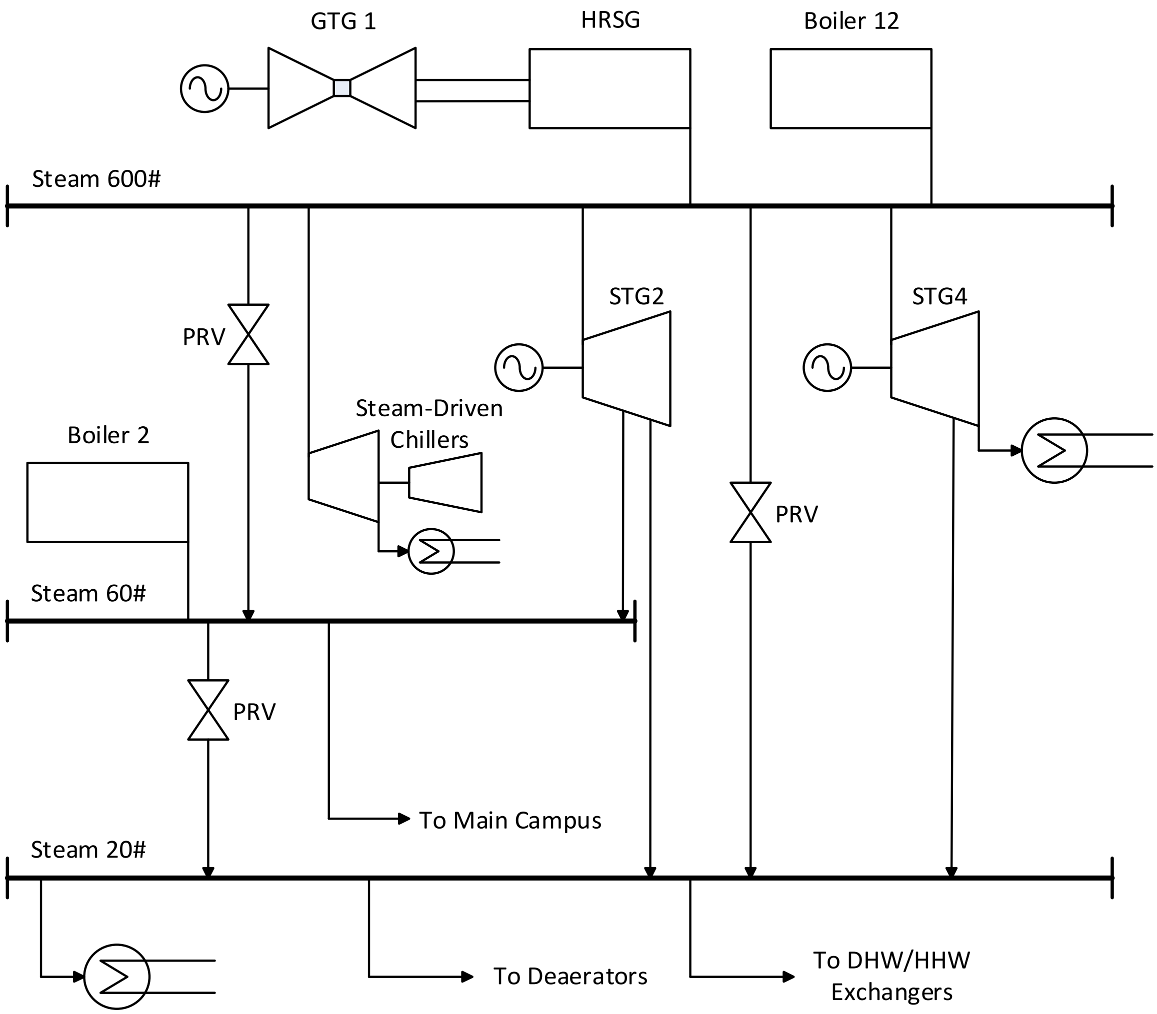

Figure 4 Central Utility Plant Steam/Power Schematic

In normal operation, GTG1 is operated to produce electricity. The HRSG uses waste heat from GTG1 exhausted gas to generate 600 psig and 750°F steam, with the capability for supplemental firing when required. B12 can be operated as a stand-alone unit when GTG1 is offline, or as an additional unit when 600 psig steam beyond the HRSG capacity is required. The 600 psig steam is fed to a common header and distributed to steam turbines, STG2 and STG4, and steam-driven chillers.

The new steam turbine generator, STG2, is designed with 20 psig exhaust and stage 2 60 psig steam extraction. This design is intended for STG2 to consume 600 psig steam and produce 60 psig and 20 psig steam to satisfy loads inside the CUP and to campus. The 60 psig extraction feature is consistent with the change in medium steam pressure from 150 to 60 psig in August 2012. This change became feasible when all equipment consuming 150 psig steam was removed, leaving steam to campus the only load requirement for medium pressure steam. In addition to STG2, B2 can also produce 60 psig steam and then let down to 20 psig steam, in case 600 psig steam is unavailable.

Low-pressure steam is utilized in the heat exchangers producing heating hot water, and in boiler deaerators.

Chilled Water

Multiple chilled water system projects were implemented as recommended in the 2006 and 2012 UES master plans. These projects resulted in higher chiller nominal capacity and better efficiency at all utility plants. Figure 5 shows chiller nominal capacity by type of chiller at each utility plant in fiscal year 2004 and 2016. The two biggest changes over the twelve years period are significant increases in chiller capacity at both east campus and west campus, and the shift from steam driven and steam absorption chillers to electric chillers. The increase in capacity is needed to support the campus growth and to provide the cooling system redundancy at each plant, which was not in place before. The shift to electric chillers was also recommended as the absorption chillers at CUP were at the end of their useful life, and delivering high pressure steam from the CUP to SUP1 was not cost effective. In addition, absorption chillers utilized more cooling tower capacity per ton compared to centrifugal chillers. With this benefit, cooling tower upgrades at the CUP and SUP1 could be delayed.

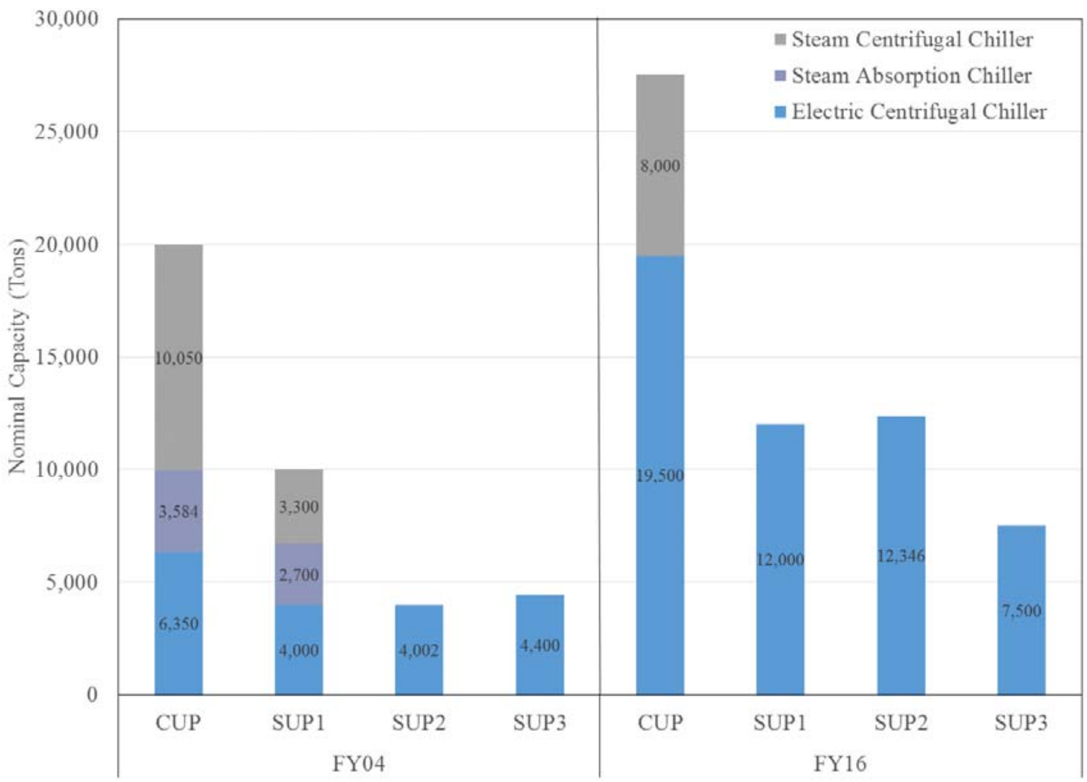

Figure 5 Chiller Nominal Capacity Comparison

The number of years in service for all chillers has also reduced significantly. In FY04, 15,684 tons of chillers were ten years or younger, 7,302 tons more than ten years but less than twenty years, and 15,400 tons more than twenty years. In FY16, 49,178 tons of chillers are ten years or younger, 6,400 tons more than ten years but less than twenty years, and 3,768 tons more than twenty years. Table 2 summarizes the University's existing chillers

Table 2 Existing Chillers

LOC/ TAG	MANUF.	DRIVE/TYPE	NOM. CAP. (TONS)	INST. YEAR	PUBLISHED EFFICIENCY
CUP					
001	Carrier	ELE/CNTRF	1,500	1999	0.606 kW/Ton @85F
002	Carrier	ELE/CNTRF	1,500	1999	0.606 kW/Ton @85F
003	York	ELE/CNTRF	2,500	2008	0.615 kW/Ton @85F
004	York	ELE/CNTRF	2,500	2008	0.615 kW/Ton @85F
005	York	ELE/CNTRF	2,500	2008	0.613 kW/Ton @85F
006	York	ELE/CNTRF	2,500	2008	0.613 kW/Ton @85F
007	York	ELE/CNTRF	3,350	2015	0.613 kW/Ton @87F
008	Carrier	STM/CNTRF	4,000	2016	Note 1
009	Carrier	STM/CNTRF	4,000	2016	Note 1
010	York	ELE/CNTRF	3,150	2015	0.595 kW/Ton @87F
		CUP Total:	**27,500**		
SUP3					
301	York	ELE/CNTRF	2,500	2015	0.611 kW/Ton @88F
302	York	ELE/CNTRF	2,500	2015	0.611 kW/Ton @88F
303	Trane	ELE/CNTRF	1,100	1989	0.615 kW/Ton @85F
304	Trane	ELE/CNTRF	1,400	2004	0.599 kW/Ton @85F
		SUP3 Total:	**7,500**		
		East Campus Total:	**35,000**		
SUP1					
101	Trane	ELE/CNTRF	1,000	2000	0.759 kW/Ton @87F
102	Trane	ELE/CNTRF	1,000	2000	0.759 kW/Ton @87F
103	York	ELE/CNTRF	2,500	2015	0.610 kW/Ton @86F
104	Trane	ELE/CNTRF	2,500	2010	0.582 kW/Ton @87F
105	Trane	ELE/CNTRF	2,500	2010	0.582 kW/Ton @87F
106	Trane	ELE/CNTRF	2,500	2010	0.582 kW/Ton @87F
		SUP1 Total:	**12,000**		
SUP2					
201	Trane	ELE/CNTRF	1,334	1984	0.603 kW/Ton @86F
202	Trane	ELE/CNTRF	1,500	2009	0.588 kW/Ton @86F
203	Trane	ELE/CNTRF	1,334	1984	0.603 kW/Ton @86F
204	York	ELE/CNTRF	2,250	2007	0.618 kW/Ton @85F
205	York	ELE/CNTRF	2,250	2007	0.618 kW/Ton @85F
206	York	ELE/CNTRF	2,500	2015	0.604 kW/Ton @85F
207	York	ELE/CNTRF	1,178	2015	1.538 kW/Ton @135F
		SUP2 Total:	**12,346**		
		West Campus Total:	**24,346**		

Note: 1. Published coefficient of performance had not made available
2. Chiller 201 upgrade is scheduled to be completed in 2016

Heating Hot Water

Multiple heating hot water system projects were implemented as recommended in the 2006 and 2012 UES master plan. East campus heating hot water load can be met comfortably considering heat exchangers capacity at the CUP. The heat exchangers transfer energy from low-pressure steam generated as a by-product from CHP to heating hot water in closed-loop systems. Six shell and tube heat exchangers at the CUP have combined capacity estimated at 330 mmBtu/hr. Even though they are still functioning satisfactorily, these heat exchangers have been in service for more than forty years. Heat exchanger replacement is recommended after year 2020. Historically, the CUP was the only heating hot water production facility on east campus. As the east campus expanded in size and growth was farther away from the CUP, another challenge was presented; due to restricted heating hot water distribution especially to buildings on the south side of east campus. It was recommended that a heating hot water source be added to SUP3. A boiler was installed at SUP3 in 2007 and six additional boilers were added in 2010 with a combined capacity of 33 mmBtu/hr. The heating hot water distribution system was also upgraded to accommodate the SUP3 boiler addition. The peak east campus heating hot water load was less than 150 mmBtu/hr in FY15.

In FY04, the load on west campus was met by SUP1 boilers and supplemented with rental boilers at SUP2, and heat exchangers at west plant 4, which is no longer a production facility. It was recommended in the 2006 UES master plan to discontinue heating hot water production at this facility due to operational limitations at west plant 4 especially during the winter months. The high-pressure steam distribution system from the CUP to west campus, SUP1 and west plant 4, was also affected by steam leaks and steam trap failures resulting in higher operational costs. SUP1 was the only location with decent boilers at 43 mmBtu/hr capacity and has had no boilers added until recent years. Six 5.6 mmBtu/hr boilers were installed at SUP1 in 2015. Rental boilers were utilized at SUP2 to support the west campus demand, and were recommended to be replaced with permanent boilers. Eight boilers were installed at SUP2 in 2009 and 2010 with combined capacity at 50 mmBtu/hr. The peak west campus heating hot water load was less than 80 mmBtu/hr in FY15.

System Efficiency and Financial Indicator

Energy Use Intensity and EUI Ratio

To benchmark UES operational efficiency against ourselves over a period of time, the Energy Use Intensity (EUI), which is a simple normalization of total annual energy consumed per GSF in mBtu per GSF unit, will be used. There are two different EUIs mentioned in this record of study, Source EUI and Site EUI. Both EUIs are energy consumption over the same GSF, total energy consumption at the plant production level is considered for Source EUI, while total energy consumption at the building level, including distribution losses, is considered for Site EUI. For Texas A&M University, grid purchase electricity and natural gas are the two energy sources for this campus, and are used in Source EUI calculation. This information was collected from the monthly utility invoices. The energy consumption at the building level to be considered in the Site EUI calculation are electricity, chilled water, heating hot water, steam, and domestic hot water. This information is based on plant production measurements excluding any plant consumption for utility production. The only two utilities produced and consumed by the plants for utility production are electricity and chilled water.

Site Electricity = Purchased + Produced – Plant consumed Electricity

Site Chilled Water (CHW) = CHW Production – CHW consumed at Gas Turbine

The space data is provided by Office of Facilities Coordination to UES for use in the billing process. The building information, including building number, name, location, gross area, number of floors, and building status, is sent once a year before September 2006, and once a month after. UES uses this information to identify the total gross area of the buildings that received utility service or are off-campus utility services paid by UES.

The unit of measurement for electricity is different from other utilities. It is measured in kilowatt-hour (kWh) or megawatt-hour (MWh), while others are measured in mmBtu. To convert electricity to mmBtu, in this record of study, 8,100 mBtu per MWh is used for Source EUI calculation, and 3,412 mBtu per MWh is used for Site EUI calculation. 8,100 mBtu per MWh was the constant purchased power heat rate quoted in the electric agreement in 2004.

Figure 6 shows that the campus has grown from 20.6 million GSF to 24.0 million GSF, or 17 percent, from FY04 to FY15. For the same period of time, the Source EUI has decreased from 312 mBtu per GSF to 208 mBtu per GSF, or 33 percent. Site EUI has decreased as well but in a smaller proportion from 185 mBtu per GSF to 164 mBtu per GSF, or 12 percent. FY04 and FY05 Site EUI were estimated because the plant production information was not completed for these two fiscal years.

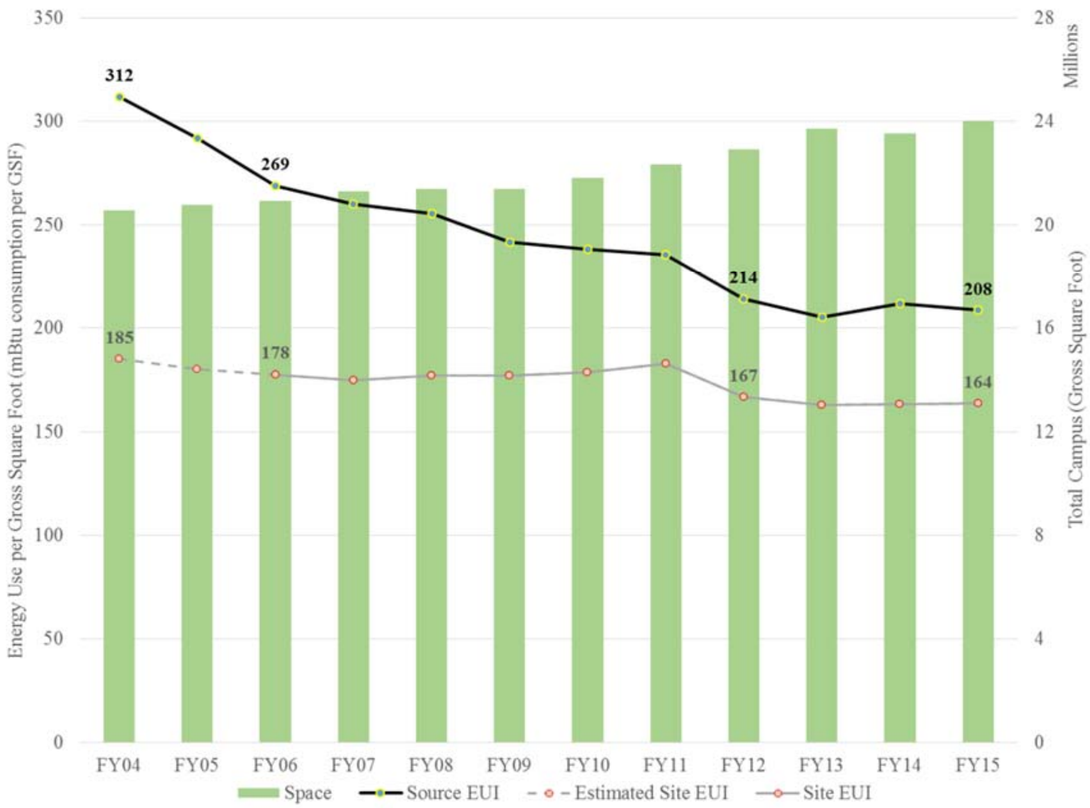

Figure 6 Texas A&M Energy Use Intensity

Site EUI indicates that the building consumption intensity has reduced gradually over the past 10 years. Several initiatives were implemented in the buildings in an attempt to reduce energy consumption while maintaining building comfort levels. Some major initiatives were Retro-commissioning implementation, Energy Stewardship Program (ESP), and Energy Service Company (ESCO) projects. FY12 is the first year with ESP fully implemented, and ESCO projects phase 1 and 2 completed. The reduction was significant in FY12 making it the first fiscal year the Site EUI was below 170 mBtu per GSF.

In the same fiscal year, the Source EUI fell below 220 mBtu per GSF, for the first time also. The CHP project was completed in late FY11 and fully operational in FY12. The decrease in Source EUI cannot be attributed only to the CHP project, but was also impacted by ESP and ESCO projects. The EUI ratio is calculated to represent the plant production efficiency and defined as:

$$\text{EUI ratio} = \frac{\text{Site EUI}}{\text{Source EUI}}$$

Figure 7 shows the plant production efficiency from FY04 to FY15. The first two fiscal years were estimated because of estimated Site EUI. The higher the EUI Ratio, the better the plant production efficiency, because for the same amount of building consumption, the higher EUI ratio would have lower Source EUI, which indicates lower total energy consumption. The EUI Ratio increased from 0.59 in FY04 to 0.78 in FY15. This increase can be attributed to improvements in production efficiency because of operational changes to be more energy efficient, and equipment upgrades or replacements with higher efficiency equipment.

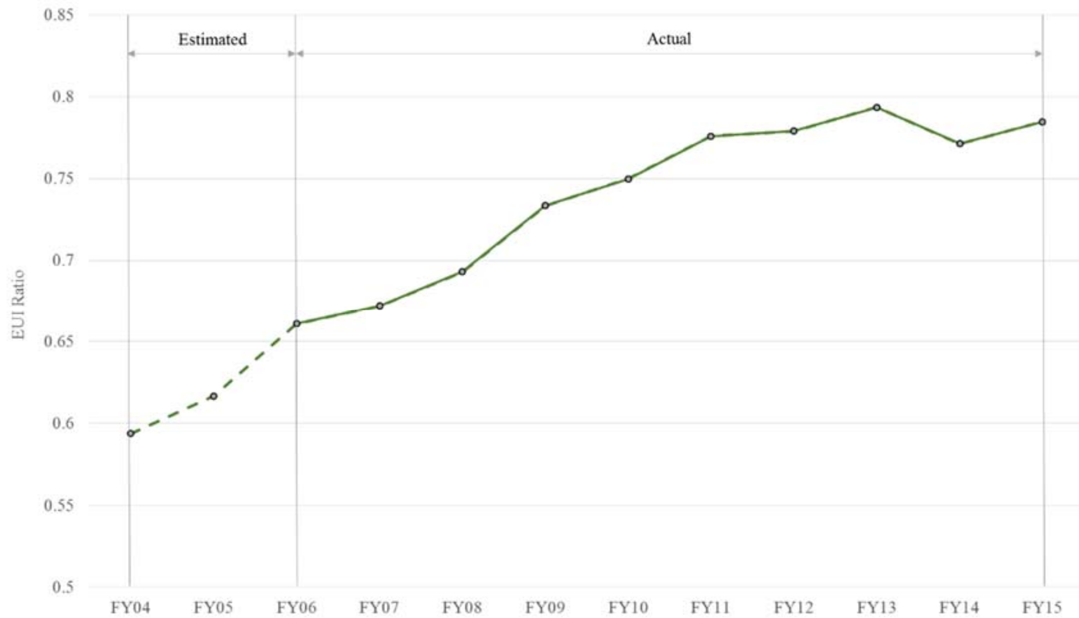

Figure 7 TAMU Energy Utilization Intensity Ratio

Capital Project Implementation and Plant Operation Changes Impact on EUI Ratio

Considering FY04 as the baseline year with EUI at 312 mBtu per GSF and EUI Ratio at 0.59, the operation plan at that time was to run base load on majority of the steam generation equipment to provide enough steam to power production through steam generators, and chilled water production through steam driven chillers and absorption chillers. At least two out of three boilers at the CUP would run all the time in addition to the gas turbine generator and HRSG to produce high pressure steam. Two steam turbine generators were operated at the same time in the first half of the fiscal year, during the second half only one was operated. Steam absorption chillers and steam driven chillers at the CUP and SUP1 were operated throughout the year, but minimized during winter.

The baseline year operation plan attempted to satisfy the chilled water load on campus with existing chillers, and base load power generation for production reliability.

This plan achieved the overall system reliability but not giving a high priority to the economic and energy efficiency of this operation. An analysis on the chilled water production options including power source consideration was done in the 2006 UES master plan. With existing conditions at the time, running electric chillers with purchased power was the most economical and energy efficient way to operate. Running steam driven chillers came in second place. And, the case of running absorption chiller was not recommended based on the efficiency evaluation. The conclusion of this analysis called for changes in the plant operation plan. Some changes could be done right away without additional preparation, but other changes needed additional consideration and preparation to ensure no impact of services to campus.

Table 3 shows changes in plant operation compared to the previous fiscal year. The relationships and operational changes of steam generation and consumption, and chilled water production of electric chillers, steam driven chillers, and absorption chillers are presented in this table. Table 3 also shows the list of equipment upgrades/ replacements by fiscal year and how it impacted the operational plan in the past.

With the analysis from the 2006 UES master plan that indicated preference toward electric chillers, Table 3 clearly shows the attempts to reduce chilled water production using steam starting in FY05. October 2004 was the last month that absorption chillers at the CUP were operated. The east campus chilled water load was satisfied by electric chillers, steam driven chillers, and rental electric chillers. In the same fiscal year, the west campus chilled water load was also satisfied by more electric chiller production and less chiller production using steam. The lesser consumption in steam called for reduction in steam production and reducing the number of boilers running. Consequently, only one steam turbine generator was required and consumed the remaining steam. A similar pattern of reducing steam production and chilled water production using steam lasted through FY07. When additional electric chillers were completely installed at SUP2, the west campus chilled water load could be satisfied by all electric chillers and ended the chilled water production using steam and steam delivery from the CUP to west campus. The changes in electric chillers at SUP1 has not been considered further since FY07, because from that point on there was no efficiency improvement because of the switch from steam to electric operation. The EUI Ratio was improved significantly to 0.67 in FY07 by reducing steam production and chilled water production using steam.

In FY08, when electric chillers 3, 4, 5 and 6 were completely installed at the CUP, electric chiller capacity on east campus was sufficient to serve the east campus load nearly year-round. Steam-driven chillers were required less and subsequently operated less in this fiscal year. This was one of the reasons why steam generation and power production from steam generator decreased. Another reason was the relatively lower contract electricity price compared to the natural gas price. Purchasing power was more economical than producing electricity with the one year electricity contract price. The EUI Ratio kept improving to 0.69 in FY08.

Table 3 Plant Operation Changes and New Equipment by Fiscal Year

Fiscal Year	CUP					SUP1		Equipment Upgrade/Replacement
	B	GTG	STG	E CHLR	S CHLR	E CHLR	S CHLR	
04	Baseline Year							
05	↓	→	↓	↑	↓	↑	↓	
06	↓	→	↓	↑	↓	→	→	
07	↓	→	→	→	→	↑	↓	Chiller 204 and 205
08	↓	→	↓	↑	↓			Chiller 3, 4, 5 and 6
09	→	↓	↓	↑	↓			Chiller 202, and SUP2 and SUP3 Boilers
10	↓		↓	↑	↓			Chiller 104, 105 and 106, and SUP2 and SUP3 Boilers
11	→	CHP		→	↑			CHP
12	↓	→	↑	↓	↑			
13	↓	↑	↓	↓	↑			
14	↑	↓	↑	↑	↓			
15	↓	↑	↑	↑	↓			Chiller 7, 10, 103, 206, 301 and 302, and Heat Recovery Chiller 207

B = Boiler
GTG = Gas Turbine Generator
STG = Steam Turbine Generator
E CHLR = Electric Chiller
S CHLR = Chiller using Steam

↓ = Decrease compare to previous fiscal year
↑ = Increase compare to previous fiscal year
→ = Approximately the same as previous fiscal year

FY09 through FY11 were preparation and implementation years for the CHP project. The gas turbine generator was out of service part of the year in FY09. It was back in operation through the summer of 2009. September 2009 was the last month before the old gas turbine generator was retired on November 13, 2009 to make space for the new gas turbine generator. The steam production for these two years was decreased to the level where the heating hot water load on east campus was satisfied and minimal additional steam was produced for other purposes. The EUI Ratios improved significantly from FY09 through FY11 indicating the lower efficiency of produced power compared to purchased power. By FY11, the EUI Ratio was improved to 0.78, the highest number before the CHP project.

The CHP project was completed in late FY11, with the first fire in June 2011. FY12 was the first full year with CHP operation. With the new gas turbine generator and HRSG, steam generation was more than the amount required to satisfy the east campus heating hot water load. As a result, the existing boiler was not operated most of the time, more power production from steam turbine generator, more chilled water production from steam driven chillers in summer months, and less chilled water production from electric chillers overall. The EUI Ratio in FY12 was about the same as FY11 indicating that the efficiency of production with CHP was comparable to the efficiency of production using grid power. With local production efficiency improvement, risks of being exposed to grid power availability and electricity price fluctuation were mitigated.

FY13 through FY15 were the years to fine tune the operation with CHP. The gas turbine was base loaded most of the time with some ramp-up to satisfy thermal load on campus, or to take advantage of higher electricity prices. The only exception was the reduction in gas turbine usage in FY14 caused by its down time for maintenance, which accounted for two months of that year. The thermal load was satisfied by operating a boiler, a steam turbine generator, and electric chillers. The EUI Ratio was down slightly because of this unscheduled down time and the lower efficiency operation using the boiler and steam turbine generator. The highest EUI Ratio after the CHP project so far was in FY13 at 0.79.

The impact of operational changes and equipment additions and upgrades as part of the capital project implementation on EUI Ratio is explained in this section. The impact on the overall financial management indicator, utility rate, will be explained in the next section.

TAMU Utility Rates

Utility rates are considered to be an overall financial management indicator in the UES department. It is the unit cost of utility production and services to customers on campus. The cost considered in rate calculation includes projected purchased utility cost, operation and maintenance cost, interest expense in debt service, and depreciation. Each of these costs can be controlled or influenced by how UES operates. UES operation and management is then reflected in the utility rates, and can be benchmarked and compared from year to year.

Before FY06, utility rates on campus were not calculated using the same Rate Model that is currently in place. A rate study was completed by an engineering firm in FY04. The Rate Model was developed as a tool to allocate costs appropriately to each commodity. It was not until FY06 that the rates developed by this Rate Model were fully reviewed and approved for billing on campus. Figure 8 shows the electricity, chilled water, and heating hot water rates from FY06 through FY15. Direct and indirect rates are also shown to illustrate the impact of operational changes and capital project implementations during these years. Only electricity, chilled water, and heating hot water rates are discussed in this record of study because of the related capital project implementation.

Direct and Indirect Rate

As shown in Figure 8, a utility rate is comprised of two components, direct and indirect components. The direct rate is defined as the unit cost of purchased utilities and locally generated utilities. The indirect rate is then defined as the unit cost of all other costs. The separation of costs and rates helps us see the impact of changes throughout the years.

Considering direct rate, purchased utility cost is based on the natural gas and electricity consumption and commodity rates. When locally generated utility cost is also a function of commodity rates, then it can be simplified that the direct rate is a function of the commodity rates and the commodity production efficiency, which is commodity produced over utility consumed. The EUI Ratio is the combined commodities production efficiency of all production plants. With the improvement of the EUI Ratio, commodity production efficiency improvement is also expected. For commodity rates, while UES cannot influence the natural gas rate, some part of the electricity rate can be influenced by UES such as demand cost.

As for all other costs, operation and maintenance cost contains both variable and fixed costs. Interest expense in debt service, and depreciation are more related to infrastructure capacity than production commodity unit. Some of these costs can be influenced by UES through being a good steward of university financial resources. Debt service and depreciation are the results of project selection. Appropriate system capacity and infrastructure improvements were selected from the UES master plan recommendation. In the case of capital project infrastructure improvements, better efficiency is normally expected. As a result, the indirect rate will increase because of the increase in debt service and depreciation. The direct rate will decrease because of the improved production efficiency. The impact to direct and indirect rate because of operational changes and capital project implementations will be discussed in the next section.

Figure 8 Historical Data on UES Utility Rates

Capital Project Implementation and Plant Operation Changes Impact on Utility Rate

Figure 8 shows a similar trend of all commodity rates being lower in FY15 compared to FY06. During this period of time, the purchased natural gas rate declined from $8.51/mmBtu in FY06 to $4.69/mmBtu in FY15. Purchased electricity rate also decreased from $0.085/kWh to $0.064/kWh. The electricity and heating hot water consumption increased approximately 10% from FY06 to FY15, while the chilled water consumption remained roughly the same.

From FY06 to FY15, the electricity direct rate declined from $0.090/kWh to $0.047/kWh. The two main reasons were the decline of purchased natural gas and electricity rates, and the improved power production efficiency. The chilled water direct rate also declined from $9.341/mmBtu to $4.496/mmBtu. This was the result of the improvements in chilled water production efficiency switching from using steam to using electric chillers, and the lower purchased natural gas rate and the combined (purchased and produced) electricity rate. The heating hot water direct rate reduced from $12.430/mmBtu to $6.010/mmBtu. The main reason for this reduction was the purchased natural gas rate.

In contrast to the decreasing direct rates, the electricity indirect rate was increased from $0.027/kWh to $0.040/kWh from FY06 to FY15. The main reason for the increase in indirect cost was because of electrical infrastructure upgrades and additional equipment including the CHP project, electrical system capacity and reliability upgrades, and electrical extension for newly developed areas. Moreover, the percent increase of the indirect cost was more than the percent increase in electricity consumption. This is common among capital projects with capacity upgrades since the consumption is not expected to reach the upgraded capacity from the first year. As the consumption increases with campus growth, the indirect rate will decrease assuming no additional capital project costs are incurred until the next capacity upgrade is required. The chilled water indirect rate has also increased from \$6.483/mmBtu to \$10.767/mmBtu. This was caused by the increase in indirect cost because of chiller additions and upgrades as shown in Table 3. Additionally, because of energy conservation initiatives in the buildings, chilled water consumption remained the same from FY06 to FY15. The higher indirect cost and same consumption levels makes the chilled water indirect rate appear significantly higher. The heating hot water indirect rate was increased from \$5.356/mmBtu to \$8.961/mmBtu. This was caused by the increase in indirect cost because of boiler additions as shown in Table 3. Similar to the electricity indirect rate, the percent increase of the indirect cost was more than the percent increase in heating hot water consumption.

The proportion of the direct and indirect rate of each commodity can indicate the nature of the commodity production and its system. The system with a higher percent of self-generation seems to bear a higher indirect rate portion. With the CHP project, the ratio between power produced and power purchased has changed from 37:63 in FY06 to 50:50 in FY15. Therefore, 50 percent of total power was then exposed to the market price and the remaining 50 percent pays the debt and depreciation for power generation. The electricity indirect rate was 23 percent of the electricity rate in FY06 and 46 percent of the electricity rate in FY15. On the other hand, chilled water and heating hot water are 100 percent self-generated. The chilled water indirect rate was 71 percent of the chilled water rate in FY15. The heating hot water indirect rate was 60 percent of the heating hot water rate in FY15. The indirect rate portion of self-generated commodities was significantly higher at given purchased utility rates.

CHAPTER III

CHILLED WATER SYSTEM OPTIMIZATION

The Chilled water system optimization was reviewed and recommended in both 2006 and 2012 UES master plans from two different perspectives. The condition of the system in 2004, which called for capacity expansion and system upgrade, restricted the number of viable options for providing chilled water service to campus both efficiently and cost effectively. It was apparent that the chilled water system with electric centrifugal and steam centrifugal chillers had better efficiency compared to the chilled water system with absorption chillers. East campus and west campus sequences of chiller operations ranked by efficiency were recommended in the 2006 UES master plan. Even though cooling tower optimization by controlling entering condenser water temperature and distribution pump improvement by converting from constant speed to variable speed drives was mentioned in this master plan, it was not implemented. The necessity to replace and add new chillers and the amount of work to eliminate steam service to west campus and retire the absorption chiller as a result of master plan study was overwhelming. The implementation of chilled water system optimization starting in 2006 was achieved by utilizing the existing chillers by order of efficiency.

Most of the chiller upgrades and additions recommended by the 2012 UES master plan were intended to be installed by 2015. With the new equipment, system reliability has been improved and more capacity added. The new equipment allows more combinations of plant operations, which can be designed for the highest efficiency based on different campus load conditions. In addition to new equipment and infrastructure upgrades, it is believed that there is still opportunity for even better efficiency by adding control strategies and optimizing chiller and chilled water system operations.

The chilled water system optimization project was proposed and approved for implementation in 2013 and is explained in the next section. The project implementation started at the beginning of my internship period in May 2014. My first interest was the impact of this project to plant electricity consumption reduction because of the implications to the rate setup for the year the project completed. After learning about the result of the project, my interest was expanded to Demand Flow and the project implementation itself. Demand Flow proposes to achieve chilled water system optimization by minimizing the total energy consumption through the control of chilled water and condenser water temperatures, chilled water and condenser water pump speeds, and cooling tower fan speeds. I was given the opportunity to work on this project with other UES team members from the start. My involvement during the first two phases, project development and installation as described in the following section, was to understand how Demand Flow would work with our system, monitor Siemens work progress, and supply building and plant information per request. My involvement was limited as the project progressed and the commissioning work was performed and communicated among production services, technical services, electrical services, and Siemens. I started working on this project again toward the end of the commissioning phase when the avoided cost and baseline model needed to be reviewed. The summary of this review is shown in the “Baseline Model and Results” section. This chapter is to demonstrate my understanding of the chilled water system and the Demand Flow software, and to summarize the system performance and cost avoidance during the commissioning period as stated in the internship objectives.

Chilled Water System Optimization Project

A request for proposal (RFP) of Chiller Optimization project was issued in October 2013. Three sections of this RFP are presented in the appendices. The specifications and requirements of the project, including scope of work, are shown in Appendix A. The information on west campus existing equipment of the project, including chillers, chilled water pumps, condenser water pumps, and cooling towers, is shown in Appendix B. The west campus existing equipment diagrams showing chilled water and condensing water flow diagrams at each production plant are in Appendix C. The proposals were reviewed and the project was awarded to Siemens Industry, Inc. A software and system implementation, called “Demand Flow”, was proposed to be the optimization program for all four chilled water production plants.

Demand Flow Concept

The overall energy consumption of the chilled water system is comprised of the energy consumption of these four sub-systems: chillers, chilled water pumps, condenser water pumps, and cooling tower fans. The Demand Flow process requires variable speed pumps and variable speed cooling tower fans to be in service. The reduction of energy is expected to occur in each sub-system, but even more in the chillers. The average west campus chilled water system efficiency for the baseline year period, July 1st, 2012 – June 30th, 2013, was 0.734 kW/ton. The average chiller efficiency for the same time period was 0.527 kW/ton. Chiller energy consumption was 72 percent of the overall chilled water system energy consumption, while chilled water pumps consumed 9 percent, condenser water pumps consumed 13 percent, and cooling tower fans consumed 6 percent. The impacts to the chilled water system efficiency by varying chilled water and condenser water temperatures, chilled water and condenser water pump speeds, and cooling tower fan speeds will be discussed in the next section.

Chilled Water Temperature and Chilled Water Flow Rate

The impacts of varying chilled water supply temperature to chilled water system efficiency have been discussed in several studies. Electric centrifugal chiller efficiency is normally improved with higher chilled water supply temperature. But this benefit is penalized by the higher energy consumption of chilled water pumps because of the higher flow required to compensate for a given load. Another compromise on energy consumption that is not included in this project scope of chilled water system is the possible higher energy consumption in buildings. A building pump with variable frequency drive (VFD) would consume more energy at higher flow to the building. In a variable-air-volume system, to maintain the same load requirement, higher air volume and subsequently higher fan energy consumption may be required with higher chilled water supply temperature. The net impact to the chilled water system energy consumption should be the goal and not just shifting energy from the chilled water system to the building system.

Condenser Water Temperature and Condenser Water Flow Rate

Figure 9 presents a 2,500 ton variable speed chiller performance curves at various condenser water entering temperatures producing 42°F chilled water supply temperature. By lowering condenser water entering temperature, a better chiller efficiency can be achieved. One drawback is the higher load on cooling tower fan, which in turn requires more air flow, higher fan speed (assuming variable speed fan is in operation), and higher fan energy consumption.

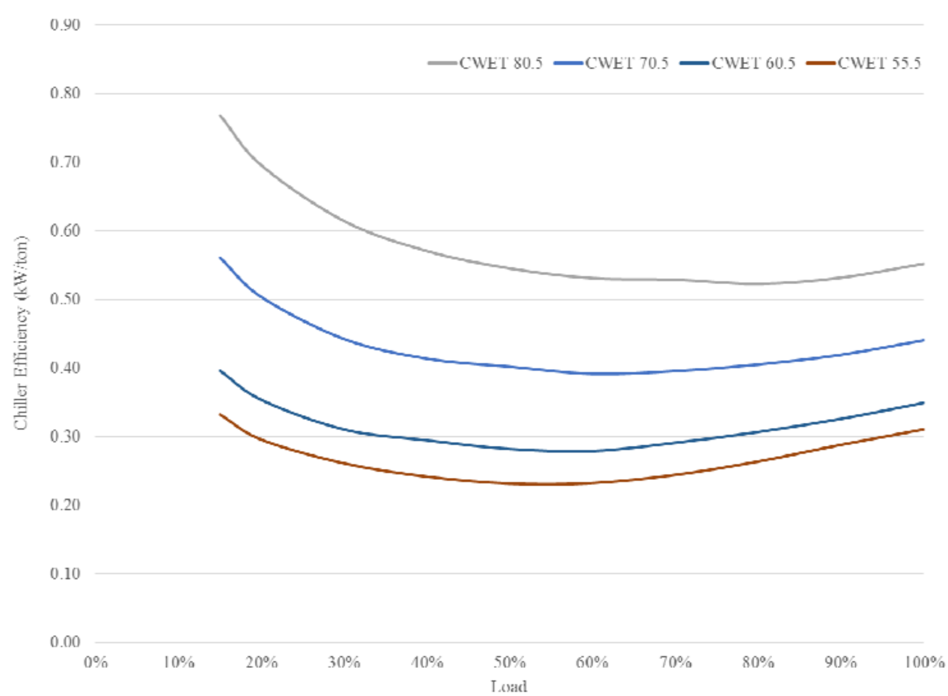

Figure 9 A Chiller Performance Curve

Chiller efficiency can also be impacted by chiller lift. Chiller lift is defined as the difference between condenser refrigerant pressure and evaporator refrigerant pressure. The difference between condenser water leaving temperature and chilled water supply temperature can be used in place of lift. The lower the lift temperature, the better the chiller efficiency is expected, which indicates the lower condenser water leaving temperature is preferred. To achieve lower condenser water leaving temperature, lower condenser water entering temperature and/or higher condenser water flow are required. A better heat exchange between condenser water and air at the cooling tower can drive the condenser water entering temperature down. Cooling tower approach temperature is defined as the difference between condenser water entering temperature and ambient wet bulb temperature. The lower the cooling tower approach temperature, the better cooling tower heat exchange effectiveness and the higher the fan energy consumption. At a given cooling tower approach temperature, lower condenser water leaving temperature can be achieved by increasing condenser water flow and condenser pump energy consumption, when a variable speed condenser water pump is available.

Cooling Tower Fan Speed Control

Fan power is proportional to the cube of airflow rate, or fan speed. For systems with multiple cooling tower cells, operating multiple fans at a lower speed can yield lower overall fan power consumption compared to operating fewer fans at a higher speed for the same amount air flow required. Understanding the airflow requirement and fan characteristics can help minimize the overall energy consumption.

In summary, Demand Flow program takes into account the impacts of varying the chilled water and condenser water temperatures, chilled water and condenser water pump speeds, and cooling tower fan speeds as discussed above. A real-time feedback control program resets the temperatures setpoint and recommends sequences of operation for each piece of equipment optimizing the overall chilled water system performance, and meeting the chilled water requirement in the buildings at the same time.

Project Timeline

The Chilled Water System Optimization project started with a kick-off meeting on April 24th, 2014. At the beginning, the plan was to complete the project within six months. This goal was changed a few months into the project because of unexpected additional work on the existing chilled water system control program. This issue lasted throughout the project and was one of the challenges that will be discussed in the "Project Implementation and Challenges" section. The revised goal was to complete the project in August 2015. The implementation of the project was concluded in August 2015 and was transferred from one Siemens project engineer to another project engineer for commissioning. Some operational issues arose during this time and called for further review of the implementation process. Siemens Demand Flow control logic deployment for west campus was completed in October 2015, and for east campus in May 2016.

Project Implementation and Challenges

Demand Flow is not just a programming implementation to optimize chilled water system. It is a process of learning about the chilled water system, the existing operation, then modifying and optimizing the chilled water system operation, and commissioning and fine-tuning the system to meet the building cooling requirement. There were four phases of this implementation.

Phase I: Project Development

The development phase involved gathering the chilled water system and building chilled water requirement information, developing the project implementation plan and check list, developing the performance models, and developing the programming concept specific for the project. This phase took about 2 months to complete the framework of the project implementation. During this phase, the first challenge was identified.

Challenge #1 Insufficient Chilled Water System Control

Through the system information gathering and project planning process, it was found that the base chilled water system control on Ovation was not sufficient for chilled water optimization automation and need to be upgraded and standardized for all existing control sequences of chillers, chilled water pumps, condenser water pumps, cooling towers and any related valves for all four utility plants. Proposed standardized control sequences were developed by Siemens and communicated to Emerson and UES for implementation. Additional physical work, such as the implementation of remote start/stop of two older chillers at CUP, and chilled water pump variable-frequency drive connection into the control system, were also identified and completed supplemental to the control sequence work.   All upgrades were required before the Demand Flow program testing in Phase II could commence. The base Emerson control upgrades were completed for east campus utility plants in November 2014, and west campus utility plants in February 2015. The upgrades included testing time in addition to implementation time, while other planned work in Phase I and II was completed in parallel. The commissioning of the upgraded base chilled water system control is still on-going as new findings have arisen.

Phase II Installation

The installation phase included both hardware and software installation. A new Siemens panel hosting Demand Flow was installed and integrated to the existing Siemens APOGEE system and Emerson Ovation system. Demand Flow control logic was developed based on the concept and information gathered from Phase I, and implemented at each utility plant one at a time. SUP3 was selected to be the first plant to have Demand Flow implementation and testing, followed by SUP2, SUP1, and CUP. Graphic pages were created for each utility plant. A trend was also setup for all key indicator data. There were two challenges identified in this phase.

Challenge #2 System Communication Issue

Emerson's Ovation is the plant control system for all four utility plants including the chilled water system operation control. Demand Flow control logic is hosted on the Siemens APOGEE building automation system. Demand Flow received the plant operation information from Ovation, processed it, and sent the setpoints and operation sequence indicators back to Ovation to control the chilled water system operation. Communication between the two systems, data transfer methodology and frequency from one system to another and within Siemens system itself, was a concern. Modbus was suggested to be the first choice of communication protocol. During the Demand Flow implementation in Phase II, there were a few incidents of network instability on the Siemens system. At the end, communications through OPC among Siemens servers were implemented and corrected the issue.

Challenge #3 Failed/Unavailable Sensor Reading Issue

More than 400 meters and sensors are used to monitor the key indicators for all four utility plants. More than 200 data points are used to monitor and indicate buildings comfort. Some issues are expected such as failed sensors, or missing communication during system start-up. At the beginning of this phase, all key information was reviewed and two matrices, plant action matrix and building action matrix, were created for on-going follow up on each issue. Some were known issues that needed to be addressed and some were new issues that needed further investigation. Additional to existing meters and sensors, eight new chillers were installed during Phase II implementation.

This added complication to the existing chilled water system control, since the majority of the time, new meters and sensors would not be available on-line right after installation.

Phase III Commissioning

After the Demand Flow control logic was developed and tested for functionality, it was deployed and tested on the actual chilled water system. East campus utility plants were commissioned first. The operators were requested to run the chilled water plants in Demand Flow mode as much as they could, and give feedback and concerns on system responses with the implementation of the new control sequences and setpoints. With some operational issues and changes in Siemens personnel, the Demand Flow control logic was reviewed and revised. West campus utility plants were evaluated first. The revised control logic for west campus has been in place and under commissioning since October 2015, while east campus has been in place and under commissioning since May 2016.

Challenge #4 Operation Issues

Through the commissioning period, which started in April 2015, operational issues were logged and reported to Siemens for further investigation and programming correction. Some of the issues were related to the chillers or other equipment staging. Some others issues were related to system responding negatively to varying setpoints. These are some examples:

- Excessive chiller start/stop, chiller short cycling, chiller trips
- Chilled water loop differential pressure (DP) spiked up very high at chiller start up
- Chiller was not commanded to start with high chilled water loop supply temperature because of perceived no cooling need on that loop, or chiller was commanded to start because of perceived cooling need from one building
- Chilled water loop DP swung because of abrupt setpoint changes
- Low or negative chilled water loop DP
- Condenser water over pumping

Siemens recognized the problems and in all cases found root causes and implemented corrective actions.

Challenge #5 Personnel Change during Project Implementation

Two UES engineer were assigned to work closely with Siemens project engineer in May 2015. The Siemens project engineer who implemented this project from the beginning left in August 2015, when it was believed to be the end of commissioning phase. Another project engineer was assigned to complete the project. Some operational issues as mentioned in Challenge #4 occurred during his first month on this project and called for further investigation. After his investigation, some parts of the control logic were re-written and re-organized. Even though, working on another person's control logic and programming did take more time, but with different perspectives and close examination of the program from both Siemens and UES engineers, all control logic, control setpoints, and deadbands were verified and the Demand Flow program seemed to be functioning well.

Challenge #6 Reporting Issue

The Siemens chilled water optimization performance report, which was expected to be used as their measurement and verification tool was first scheduled and distributed weekly in June 2015 for west campus utility plants. This report summarized the chilled water production performance data of the past week, including chilled water production amount, actual electricity consumption, baseline electricity consumption, predicted electricity consumption, electricity consumption savings, and chilled water plant efficiencies. The majority of the data could be verified and accepted, with the exception of the new chiller data and baseline model for the savings calculation. When a new chiller is added to a chilled water system, it normally utilizes and shares the existing capacity of chilled water pumps, condenser water pumps, and cooling towers. While the existing equipment is metered or measured, the new chiller is not. The incomplete information could skew the production performance. The baseline models included in this report were also in question. The team agreed to use baseline models developed by the UES team as a part of the verification process. The baseline models will be discussed in "Baseline Models and Results" section.

Phase IV Training and Turnover

After satisfactory testing and verification during the commissioning period, the last phase of this project can be scheduled. This includes training all operators and technicians, setting up remote access for Siemens, and beginning the monitoring based commissioning to conclude the project implementation. This phase is scheduled to start in summer 2016.

Baseline Models and Results

Siemens started chilled water system performance baseline model development for east campus and west campus using July 1st, 2012 – June 30th, 2013 data during the first phase. The total chilled water system performance, in kW/ton, was modeled as a function of wet bulb temperature, in degrees Fahrenheit. These models were not used for any verification during the installation and commissioning until June 2015. The report showed that the implementation was unable to achieve the expected system efficiency and the avoided consumption. Two main issues were discovered after further review. First, the optimization program itself was not functioning properly and second, the baseline model used to calculate the avoided consumption was questionable. The next section will discuss how the west campus baseline models were developed. The results from the November 2015 – May 2016 commissioning period will be discussed and compared to baseline model.

Chilled Water System Baseline Models for West Campus

Originally, the UES developed chilled water system baseline models were intended for project avoided cost verification purposes. These models have been developed for the same baseline period, July 1st, 2012 – June 30th, 2013. The baseline data given in the RFP included hourly data of each chiller tonnage production and efficiency in kW/ton, total condenser water flow and condenser water pump power for each utility plant, total chilled water flow and chilled water pump power for each utility plant, and total cooling tower fan power for each utility plant. The total chilled water system performance for each campus location is the sum of total power over the sum of chilled water production of that campus. Therefore, total west campus chilled water system performance ($Perf_{West,Total}$) can be expressed as follow:

$$Perf_{West,Total} = \frac{Total\ Power_{SUP1} + Total\ Power_{SUP2}}{Total\ CHW\ Production_{SUP1} + Total\ CHW\ Production_{SUP2}}$$

Where,

$$Total\ Power_n = \sum P_{Chiller,mn} + \sum P_{CWP,mn} + \sum P_{CHWP,mn} + \sum P_{CTF,mn}$$

$Total\ Power_n$	=	Total power consumption at location n
$P_{Chiller,mn}$	=	Chiller m power consumption at location n
$P_{CWP,mn}$	=	Condenser water pump m power consumption at location n
$P_{CHWP,mn}$	=	Chilled water pump m power consumption at location n
$P_{CTF,mn}$	=	Cooling tower fan m power consumption at location n

$$Total\ CHW\ Production_n = \sum Tonnage_{Chiller,mn}$$

Where,

Total CHW $Production_n$	=	Total chilled water production at location n
$Tonnage_{Chiller,mn}$	=	Tonnage production from chiller m at location n

As mentioned in the "Demand Flow Concept" section, the chilled water performance of each sub-system can be improved by adjusting operating conditions. With appropriate setpoints and deadbands, all sub-systems can perform together at an optimal point for certain weather conditions. The weather-based model was selected as a result of the Demand Flow concept and implementation. The chilled water system performance models were created against ambient wet-bulb temperature and enthalpy. It was determined that the chilled water system performance curves fit better using enthalpy compared to wet-bulb temperature. The west campus chilled water system performance baseline is shown in Figure 10 as the orange line, where the blue markers represent the hourly west campus chilled water system performance during the baseline period.

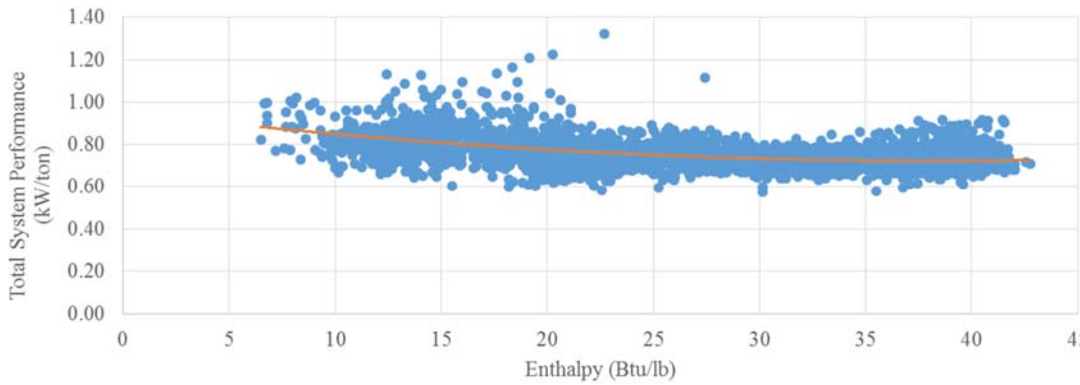

Figure 10 West Campus Chilled Water System Performance Baseline Data and Model

In addition to the total system performance baseline model that will be used in the cost avoidance calculation, each sub-system baseline model was also developed and will be used to track the improvement of each sub-system. The west campus chilled water sub-system performance baselines are shown in Figure 11. Similar to the description in Figure 10, in Figure 11, the orange line represents the baseline of each sub-system and the blue markers represent the hourly west campus chilled water sub-system performance during the baseline period.

The baseline model in Figure 10 suggests that the system performance during the baseline period was at the same level nearly the whole time, with slightly worse performance, which was higher kW/ton, at low enthalpy. This statement is supported by baseline models in Figure 11 showing chiller performance being level, and condenser water pump and chilled water pump performance being worse at low enthalpy.

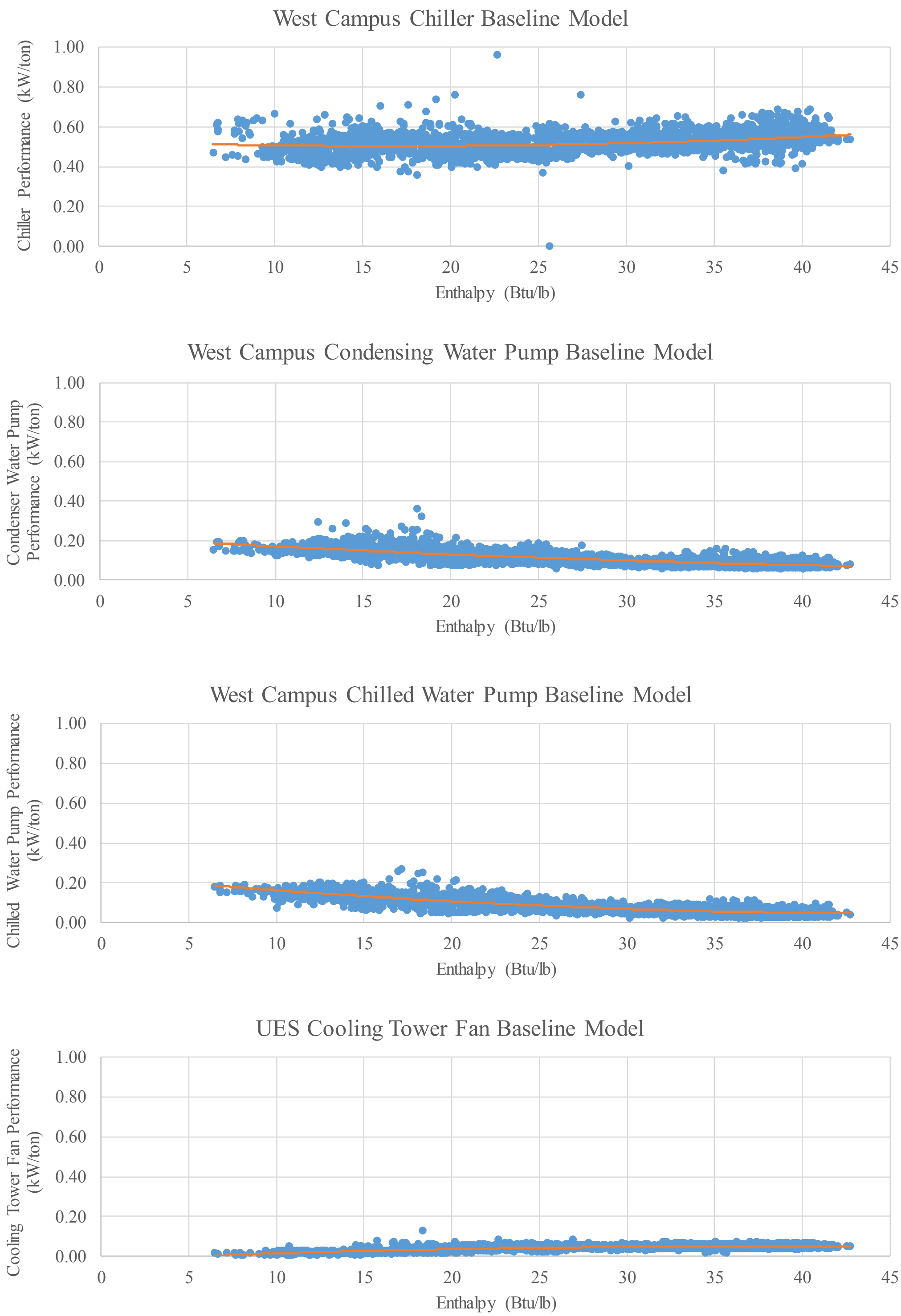

Figure 11 West Campus Chilled Water Sub-System Performance Baseline Data and Models

Results

The actual west campus chilled water system performance during the commissioning period compared to the baseline performance is shown in Figure 12. The orange line represents the baseline system performance based on enthalpy during the commissioning period, and the green markers represent the hourly west campus chilled water system performance during the same period.

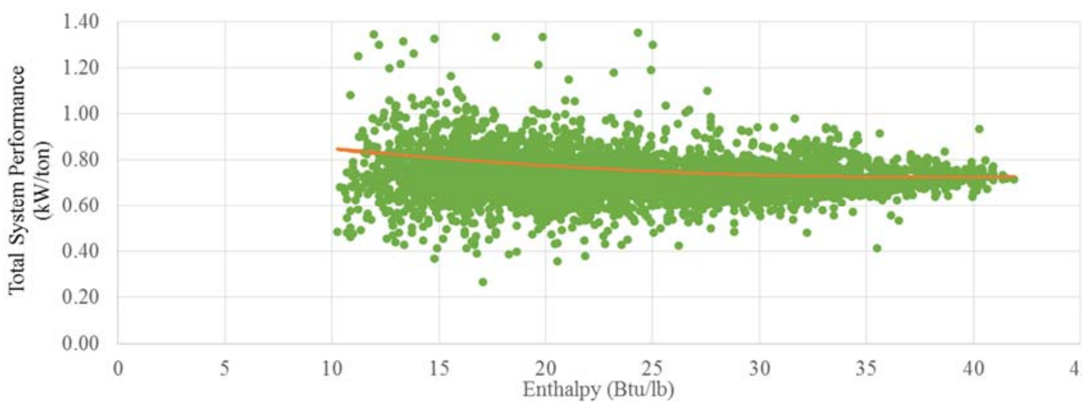

Figure 12 West Campus Chilled Water System Performance Commissioning Period Data and Baseline Model

The system performance during the commissioning period in Figure 12 fluctuated over a wider range compared to the system performance during the baseline period in Figure 10. The fluctuation could be explained by the attempts and struggles to operate the system in the Demand Flow mode. When comparing month by month, overall system performances have improved every month except March 2016 as shown in Table 4. The total electricity consumption avoided through the commissioning period was 762,929 kWh or an average of 4 percent.

Table 4 West Campus Chilled Water System Performance Summary During Commissioning Period

	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16
Baseline	0.747	0.755	0.783	0.765	0.744	0.737	0.730
Commissioning	0.716	0.714	0.746	0.708	0.748	0.691	0.703
% Improvement	4.2%	5.5%	4.7%	7.5%	-0.4%	6.2%	3.6%
% Demand Flow Mode	42%	51%	49%	70%	47%	66%	51%

Another observation during the commissioning period was that the % Demand Flow mode was lower than preferred. % Demand Flow mode was the percent of tonnage that was produced by the chiller and controlled in the Demand Flow mode. The higher the % Demand Flow mode, the more the improvement was expected. This is illustrated in Figure 13. The system performance data during the commissioning period was organized into four ranges of % Demand Flow mode, greater than 75% (DF > 75%), between 50 – 75% (50% < DF <= 75%), between 25 – 50% (25% < DF <= 50%), and less than 25% (DF <= 25%). Each group of data has a curve fitted to represent the system performance characteristics of that range. The four curves represent various ranges of % Demand Flow mode and are compared to the baseline model in Figure 13.

The system performance with % Demand Flow mode higher than 50% clearly shows improvement compared to baseline model, which is the system performance before the Demand Flow project was implemented. This leads us to the final challenge, Demand Flow runtime issue.

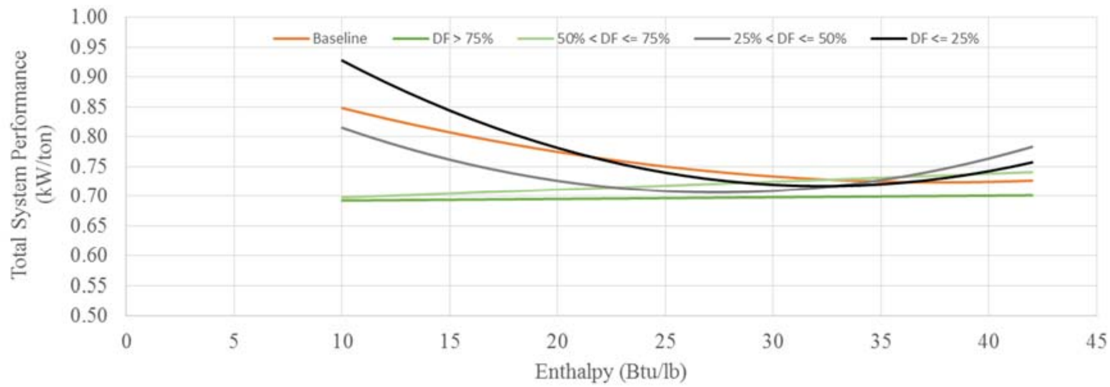

Figure 13 West Campus Chilled Water System Performance Curves at Various % Demand Flow Mode Range

Challenge #7 Demand Flow Runtime Issue

The lower than preferred % Demand Flow mode, or low runtime, was a result of multiple challenges that existed during the commissioning period. Some challenges were known and waiting to be resolved. With limited resources and competing priorities among different projects and routine works, these challenges remained unresolved longer than preferred. Operators had to work with a limited set of equipment, which in some situations discouraged them from operating in the Demand Flow mode. With low runtime, the possibility to discover unknown challenges was reduced.

A list of on-going challenges has been created and communicated to each of the parties by the project engineer. Revised automated daily reports on the system status, performance, and achieved avoided consumption are recommended and in progress.

CHAPTER IV

THERMAL ENERGY STORAGE TANK

Thermal energy storage tank was reviewed and recommended in 2012 UES master plan. A 2.1 million gallon TES was first suggested for installation at SUP1 but was not approved for that location because of aesthetic concerns as well as avoiding setting precedence for future buildings in highly visible locations on the west campus. The TES tank was later approved at a location next to SUP2.

The main purpose of the recommended TES was to reduce the peak demand by shifting the electricity load because of chilled water production from peak demand time during the day to night time. The higher the peak demand recorded this year, the higher the demand cost paid in the next year. In addition to the financial incentive, TES would increase redundancy and operational flexibility, as well as providing an opportunity in case of demand response participation.

The TES tank construction phase was completed in April 2016. The tank was connected to SUP2 and filled with water late April 2016. It was under commissioning during May 2016 and placed in operation in time for the months that the TAMU peak demand would be set. This peak demand is called four coincident peak (4CP), which is calculated as an average of the TAMU peak demands recorded at the time of ERCOT system peak demand during the months of June, July, August, and September. 4CP and other electricity cost components will be discussed in the "TAMU Electricity Cost" section.

My involvement in this project started during the tank construction period when regular meetings were scheduled to follow the project progress and start planning tank operation scenarios. The charge/discharge control sequence, and time of operation were discussed in these meetings. My participation helped me gain an understanding about the nature of operation and the system specifications. I then applied my understanding on the electric price pattern analysis and developed strategies that will be used to determine the TES operational mode and will be discussed in the "Thermal Storage Tank Operation" section. The tank operation impact to 4CP in June 2016 will also be discussed in this section. Figure 14 is a picture of the TES tank after completion.

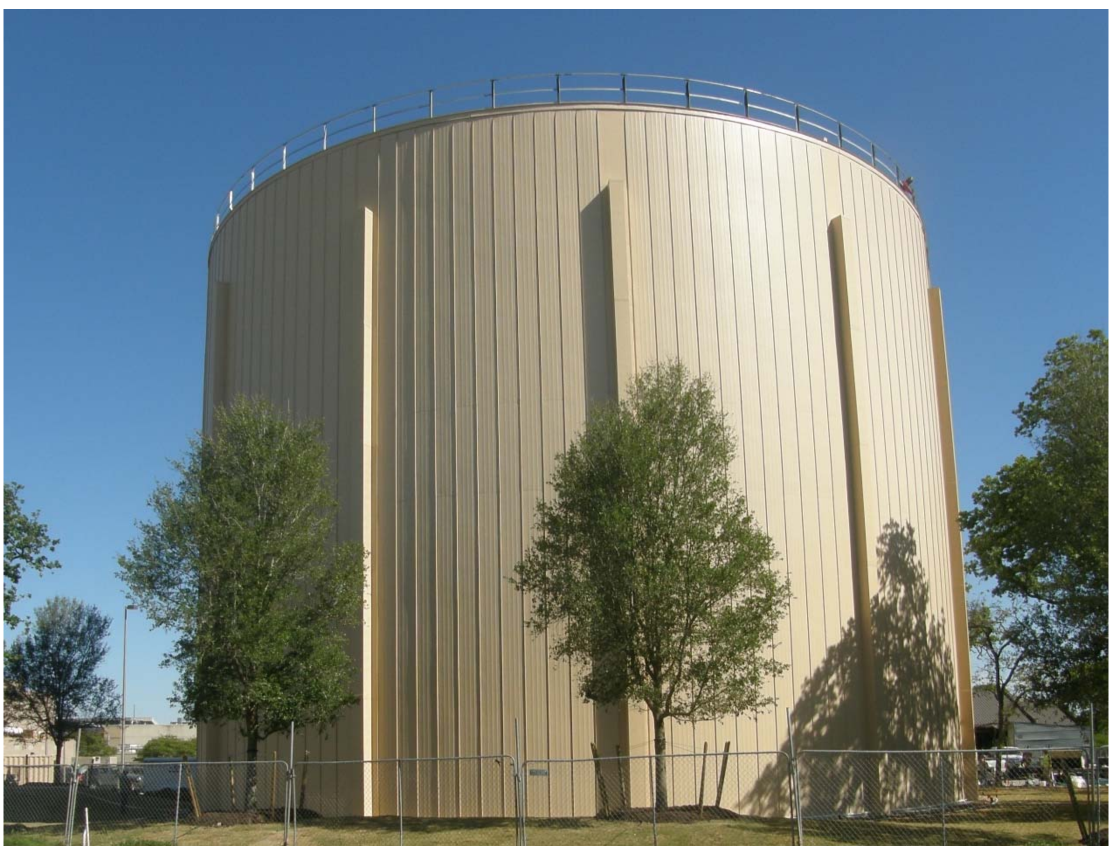

Figure 14 TAMU Thermal Storage Tank

TAMU Electricity Cost

This section will describe the purchased electricity cost through the 138 kV transformer for on-campus usage, excluding off-campus usage provided through other electrical retailers. In FY15, purchased electricity was close to 50 percent of the total electricity consumed on campus, including utility plants, and accounted for $11.4 million. This purchased electricity cost can be separated into three components, energy cost, demand cost, and other costs.

Energy Cost

Energy cost is the cost of electrical energy usage, which is the product of electricity consumption and electricity price. In the case of TAMU, the electricity price is not a constant price and varies following the ERCOT North Load Zone Settlement Point Price (NLZ-SPP). 70 percent or more of electricity consumption each month is scheduled for certain contract quantities and contract prices. The remaining unscheduled electricity consumption is settled after the month end at the NLZ-SPP. The SPP is a price for each 15 minutes duration. Table 5 shows the average NLZ-SPP in the unit of $/MWh by hour by month for the period of September 1st, 2014 – August 31st, 2015. Microsoft Excel conditional formatting was applied individually for each month to compare the prices within its' own month. Red indicates higher price and blue indicates lower price relatively within that month. In general, 11pm – 6am was the period with lower prices in all months. This price pattern creates a financial opportunity to charge the TES tank at lower price and discharge it at higher price during the daytime hours.

Table 5 FY15 Hourly Average North Load Zone Settlement Point Price

Hour	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
0	27.87	27.98	21.37	21.58	19.80	16.73	22.00	23.06	19.06	19.50	20.65	19.64
1	25.84	26.30	20.14	19.17	19.50	16.81	22.64	17.42	16.44	17.24	18.92	18.04
2	24.76	20.89	20.57	18.87	19.38	16.80	21.22	16.03	14.32	16.29	17.27	16.72
3	23.77	21.05	21.35	19.07	19.91	17.47	16.79	16.37	14.42	16.28	16.38	15.50
4	24.67	22.04	22.51	19.91	20.73	18.59	21.72	17.59	15.91	16.64	16.53	16.43
5	26.28	23.92	29.30	22.07	22.89	20.66	23.98	20.16	16.89	17.65	16.89	17.60
6	28.77	26.37	39.44	27.16	37.03	33.87	41.21	20.12	18.58	17.48	17.57	18.54
7	27.18	26.45	30.05	24.80	25.98	24.61	25.23	19.65	19.51	18.88	18.93	18.61
8	28.32	26.62	32.27	24.72	25.46	40.75	24.61	20.59	20.39	20.23	20.95	20.18
9	29.36	28.49	33.76	26.42	27.07	51.39	32.75	21.93	20.87	21.35	22.56	22.23
10	31.32	29.76	36.43	26.27	25.72	39.13	31.65	23.04	22.73	25.73	24.82	26.59
11	33.25	30.68	30.93	24.74	23.23	24.40	28.38	22.96	25.42	24.63	27.96	28.11
12	40.82	34.17	31.61	23.74	22.45	22.36	29.91	24.19	30.80	26.87	31.21	32.51
13	40.21	42.93	30.29	23.42	21.72	22.05	34.04	26.93	38.11	28.72	34.53	38.79
14	46.58	48.35	28.29	23.09	20.81	20.96	32.13	27.88	51.77	30.59	42.02	66.24
15	54.95	58.65	28.03	22.76	20.88	20.67	30.10	33.81	47.17	32.91	57.20	116.64
16	46.64	56.94	28.88	23.17	21.55	20.92	29.52	36.47	36.63	33.76	52.28	101.59
17	42.28	42.00	78.48	47.03	27.77	23.83	31.06	32.92	30.31	30.05	39.05	52.39
18	35.53	40.04	52.00	30.90	26.25	43.76	39.10	22.79	24.90	26.08	33.59	33.78
19	35.90	45.61	43.25	27.15	24.68	25.26	41.21	22.38	24.12	24.29	28.03	28.62
20	34.29	30.84	30.98	26.24	24.90	31.46	29.57	30.29	27.65	23.79	26.81	28.01
21	31.33	28.25	29.14	24.42	22.83	26.23	24.55	21.06	24.18	22.80	25.28	24.64
22	29.43	28.91	31.44	35.92	22.01	21.19	23.20	19.94	24.26	21.95	23.78	22.40
23	28.25	25.66	23.77	26.93	20.62	18.12	20.65	21.49	24.33	20.82	21.61	20.53

Demand Cost

As mentioned above, TAMU demand cost is based on the average 4CP set the previous year during June, July, August, and September. For calendar year 2016, TAMU demand cost is based on the average 4CP of June – September 2015. Table 6 lists the date and time that ERCOT peak demand occurred for each of the four months. TAMU peak loads, or the power purchase loads, were recorded at those times and used in the calculation for the average 4CP.

Table 6 2015 TAMU Peak Load and Average 4CP

Date	Hour Ending	TAMU Peak Load (MW)
6/10/2015	16:45	20.94
7/30/2015	16:45	24.79
8/10/2015	17:00	18.93
9/8/2015	16:30	27.36
TAMU Average 4CP (MW)		23.01

With the addition of CHP in 2011, the TAMU average 4CP since 2012 has maintained in the range of 23 – 25 MW. This level of load is significantly lower than normal power purchase load. Figure 15 compares the TAMU power purchase load profile of two similar weekdays in August 2015. August 10th was a Monday with ERCOT peak demand expectations. Economic dispatch activities, including power generation ramp-up, shifting chilled water production from electric to steam driven chillers, and chilled water supply temperature adjustments, were planned and implemented starting before noon that day. The result of the economic dispatch significantly reduced the power purchase load on August 10th, 2015 more than 15 MW compared to normal day operations. An average 4CP costs around $50,000/MW/year in 2016.

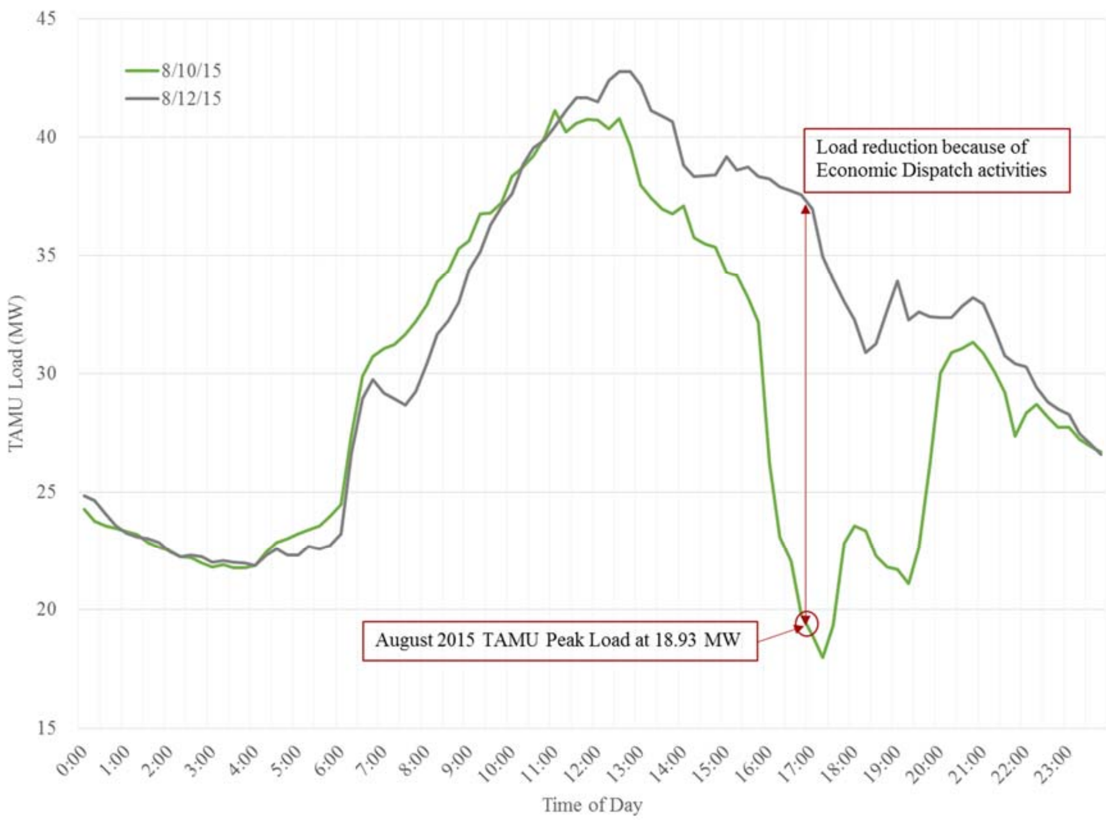

Figure 15 TAMU Load Profile on Day With and Without Economic Dispatch

In addition to the existing economic dispatch activities, TES tank utilization is expected to reduce the power purchase load even more by turning off electric chillers during peak demand period and discharging chilled water from the TES tank. Economic dispatch was also implemented if the real-time market price, which is the price before settlement, spiked-up price exceeding the set price for the 30 minute period.

Other Costs

Other than energy cost and demand cost, there were some other fees included in electricity invoices. Some of these are fixed monthly cost and some vary based on consumption. This cost component is fixed and straightforward, and there is little we can do to reduce this cost component other than reducing electricity consumption. If total other costs is calculated per MWh of electricity purchased, it was $4.18/MWh in FY15, and has ranged from $4.18 – $4.60/MWh since FY12.

Thermal Storage Tank Operation

A 3 million gallon TES tank was designed for 24,000 ton-hour capacity with chilled water operating temperature ranging of 42 – 54 degrees Fahrenheit, and maximum flow rate at 16,000 gpm. The tank was installed with two 8,000 gpm, 450 hp pumps with VFD to assist in charging and discharging the tank. At the maximum flow rate, it takes three hours to fully deplete or charge the tank one round.

TES tank is planned for operation based on time of day during the first year. This is to simplify the sequence of operations and give UES operators time to understand and work with the system, while achieving financial benefits by reducing demand cost. My analysis in this record of study is specifically for the operation during peak demand months, June through September.

The goals for the TES tank during the peak demand months are first and foremost to reduce TAMU peak load on the ERCOT peak demand days by turning off chillers at SUP1 and SUP2, and utilizing chilled water from the TES tank. The second goal is to take advantage of market electricity price fluctuations by producing chilled water at low electricity price and using it when electricity prices are high. The break-even price and price projection will be discussed in “Market Price Consideration – Peak Demand Months” sections.

Expected ERCOT Peak Demand Day

We cannot predict into the future which day in the peak demand months the peak load will happen, but with the historical peak load information, weather forecast, and ERCOT load forecast, we can focus on a number of days during the month in attempt to reduce TAMU peak load through economic dispatch including discharging the TES tank.

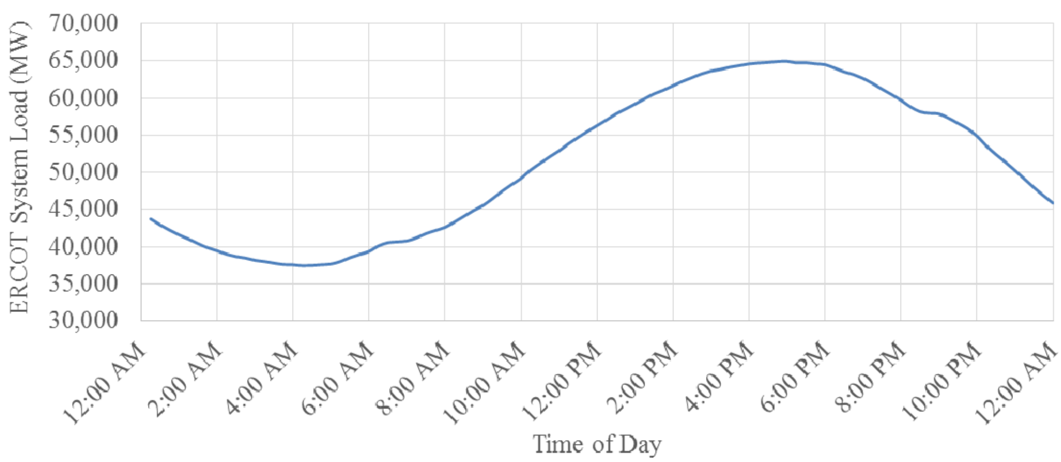

Figure 16 ERCOT System Load Profile on June 15th, 2016

From 2011 to 2015, all ERCOT peak loads from June through September occurred between 4pm – 5pm. This fact indicates a higher probability of the peak load period between 4pm – 5pm and lower probability of the peak load for the hour before and after. ERCOT system load profile on June 15th, 2016 is shown in Figure 16, where the system load climbed up in the afternoon and reached the system peak load at 5pm. June 15th, 2016 was believed to be the day with ERCOT peak load for the month. The ERCOT peak loads are not officially reported until after the peak demand months end.

With the expected peak load hours from historical information, the TES tank was planned to be in discharge mode and have most if not all of the chillers at SUP1 and SUP2 turned off during these hours. At maximum flow rate, TES can serve 8,000 tons of chilled water at 12 degree differential temperature for three hours. With this information, the discharge time for the expected ERCOT peak load day is narrowed down to a few start times. The 2:30pm – 5:30pm was selected and supported by the historical price information that will be discussed in the next section.

Market Price Consideration – Peak Demand Months

As shown in Table 5, the FY15 average market price especially in the peak demand months presented a consistent trend of a span of lower price during the early morning hours, and a span of higher price during the afternoon hours. The historical pricing data from FY15 will be used to indicate the financial possibility of daily charging and discharging the tank to take advantages of pricing differences. The break-even prices will be reviewed first.

To calculate the break-even cost, the cost of chilled water production and avoided cost from turning off chillers will be considered. The cost of chilled water production is based on the amount of tonnage produced, chilled water system performance during production including the TES pump, and the electricity price at the time of production. The avoided cost from turning off chillers is based on the amount of tonnage dropped from turning the chillers off, the chilled water system performance excluding the chilled water pump, and the electricity price at time of TES discharge. The total amount of tonnage produced is not equal to the total amount of tonnage dropped from turning the chillers off. The differences, which will be referred to as losses, can be thermal losses, or the unusable chilled water because of low return temperature. The data has been collected and the system losses will be calculated and analyzed for further actions to minimize these losses. The chilled water system performance during charge and discharge mode in kW/ton is also different. In the charge mode, the electricity consumption of chillers, chilled water pumps, condenser water pumps, cooling tower fans, and TES tank pumps is included in the system performance. In the discharge mode, when chillers are turned off, chilled water pumps and TES tank pumps both have to run to maintain the chilled water loop pressure. Table 7 indicates the break-even price ratio of the discharge price over the charge price at different losses, system performance during charge mode (Charge Perf), and the difference between system performance during the charge and discharge mode (0.05 kW/ton or 0.10 kW/ton).

Table 7 Discharge:Charge Break-Even Price Ratio for Various Scenarios

Discharge Perf = Charge Perf - 0.05			
Charge Perf (kW/ton)	Losses		
	2%	5%	10%
0.65	1.105	1.140	1.204
0.70	1.099	1.134	1.197
0.75	1.093	1.128	1.190

Discharg Perf = Charge Perf - 0.10			
Charge Perf (kW/ton)	Losses		
	2%	5%	10%
0.65	1.206	1.244	1.313
0.70	1.190	1.228	1.296
0.75	1.177	1.215	1.282

At 5% losses, 0.75 kW/ton system performance during charge mode, and 0.65 kW/ton system performance dropped during discharge mode, the TES operation will break-even if the discharge price is 21.5% higher than charge price. These are the conditions that the current system is assumed to be for this summer. 1.215 price ratio is used in this analysis. From Table 5, the hours of interest for low and high electricity pricing are from 10pm – 8am, and 10am – 8pm. The 15 minute average price of September 2014, and June through August 2015 are shown in Table 8.

From an operational discussion, the TES tank is preferred to be charged at lower than the maximum rate to produce a lower chilled water temperature. It is also preferred for the tank to be completely charged before 5am when buildings start competing for chilled water. Midnight – 5am is selected for charge mode period. For discharge mode, the minimum of three consecutive highest priced hours is selected. 2:30 – 5:30pm is consistently the hours with highest prices. These hours also covers the possible ERCOT peak load time.

The ratio between the average charge and discharge mode price was 1.903, 2.844, 5.444, and 1.942 for June, July, August, and September, respectively. Since the ratios are higher than 1.215 in all months, the simplified operating plan is to charge and discharge the TES tank daily. Midnight – 5am was recommended for charge mode and 2:30 – 5:30 was recommended for discharge mode.

Table 8 FY15 15 Minutes Average North Load Zone SPP for Peak Demand Months

Time	Sep	Jun	Jul	Aug
10:15 PM	29.91	22.73	24.54	22.99
10:30 PM	28.75	21.46	23.06	21.96
10:45 PM	28.27	20.86	22.39	21.45
11:00 PM	28.79	20.76	22.28	21.41
11:15 PM	28.96	21.48	22.14	20.79
11:30 PM	28.04	20.72	21.20	20.14
11:45 PM	27.22	20.33	20.82	19.78
12:00 AM	29.12	20.19	21.03	20.18
12:15 AM	28.30	19.83	21.30	19.95
12:30 AM	27.35	19.21	20.36	19.41
12:45 AM	26.70	18.78	19.89	19.00
1:00 AM	26.38	18.15	19.44	18.71
1:15 AM	26.07	17.36	19.05	18.15
1:30 AM	25.61	16.87	18.75	17.78
1:45 AM	25.30	16.56	18.43	17.53
2:00 AM	25.19	16.54	18.05	17.30
2:15 AM	24.97	16.32	17.43	16.81
2:30 AM	24.53	16.23	17.00	16.46
2:45 AM	24.35	16.08	16.61	16.32
3:00 AM	23.99	16.28	16.61	16.11
3:15 AM	23.60	16.14	16.38	15.30
3:30 AM	23.74	16.34	16.43	15.22
3:45 AM	23.77	16.37	16.09	15.38
4:00 AM	24.67	16.76	15.95	15.98
4:15 AM	24.35	16.45	16.24	16.21
4:30 AM	24.71	16.68	16.82	16.51
4:45 AM	24.93	16.67	17.11	17.01
5:00 AM	25.85	17.45	16.97	17.17
5:15 AM	26.01	17.58	16.60	17.36
5:30 AM	27.04	18.24	16.82	17.75
5:45 AM	26.21	17.31	17.18	18.12
6:00 AM	27.55	16.31	17.83	18.36
6:15 AM	28.21	17.45	17.67	18.59
6:30 AM	28.92	18.08	17.51	18.73
6:45 AM	30.40	18.06	17.27	18.46
7:00 AM	27.96	18.46	18.20	18.44
7:15 AM	27.12	18.71	18.75	18.42
7:30 AM	26.90	19.07	19.19	18.62
7:45 AM	26.75	19.26	19.56	18.96
8:00 AM	27.53	19.74	20.25	19.37

Time	Sep	Jun	Jul	Aug
10:15 AM	30.62	23.08	24.34	24.66
10:30 AM	31.74	33.44	25.50	25.25
10:45 AM	32.95	24.46	26.24	32.46
11:00 AM	31.37	23.55	26.28	26.46
11:15 AM	32.87	24.50	27.41	27.68
11:30 AM	33.56	25.34	28.27	28.73
11:45 AM	35.21	25.13	29.90	29.56
12:00 PM	33.90	24.93	29.53	30.71
12:15 PM	35.97	25.78	30.53	31.15
12:30 PM	45.89	28.05	31.90	32.77
12:45 PM	47.52	28.71	32.88	35.41
1:00 PM	38.00	28.13	32.00	34.35
1:15 PM	39.39	28.43	33.29	35.92
1:30 PM	40.64	29.82	35.45	38.78
1:45 PM	42.81	28.49	37.37	46.13
2:00 PM	43.06	29.32	37.01	47.85
2:15 PM	41.24	30.03	39.71	63.16
2:30 PM	49.87	31.57	43.71	75.55
2:45 PM	52.14	31.46	47.66	78.40
3:00 PM	51.05	31.67	48.12	115.16
3:15 PM	54.30	33.63	58.31	111.96
3:30 PM	58.04	31.13	61.79	104.57
3:45 PM	56.41	35.19	60.57	134.87
4:00 PM	44.25	35.66	54.35	110.89
4:15 PM	53.05	34.58	57.50	119.78
4:30 PM	44.37	33.11	52.00	92.06
4:45 PM	44.90	31.70	45.27	83.62
5:00 PM	42.36	31.08	40.59	61.84
5:15 PM	44.79	30.87	41.69	57.12
5:30 PM	42.06	29.40	37.86	47.96
5:45 PM	39.89	28.86	36.05	42.62
6:00 PM	37.57	27.25	33.86	36.09
6:15 PM	36.17	26.77	39.45	35.01
6:30 PM	34.49	25.51	31.64	33.49
6:45 PM	33.87	24.79	29.39	30.51
7:00 PM	35.32	24.96	28.88	29.75
7:15 PM	34.97	24.63	28.62	28.94
7:30 PM	36.38	23.95	27.71	28.10
7:45 PM	36.94	23.62	26.89	27.69
8:00 PM	35.96	23.44	27.01	28.25

Time of Day Operation and Results

By the time this record of study was written, the TES tank has operated based on the charge and discharge time recommended schedule. TAMU load as a result of economic dispatch and TES operation on June 15th, 2016, which was believed to be the ERCOT peak load day for June 2016 is shown as the green solid line in Figure 17 compared to the TAMU load profile without TES tank in operation as the dotted red line. Assume 0.75 kW/ton system performance during charge mode, and 0.65 kW/ton system performance dropped during discharge mode, in the impact on electricity consumption calculation. The charged (positive) and discharged (negative) chilled water tonnage during that day was also shown in Figure 17 as the dashed gray line.

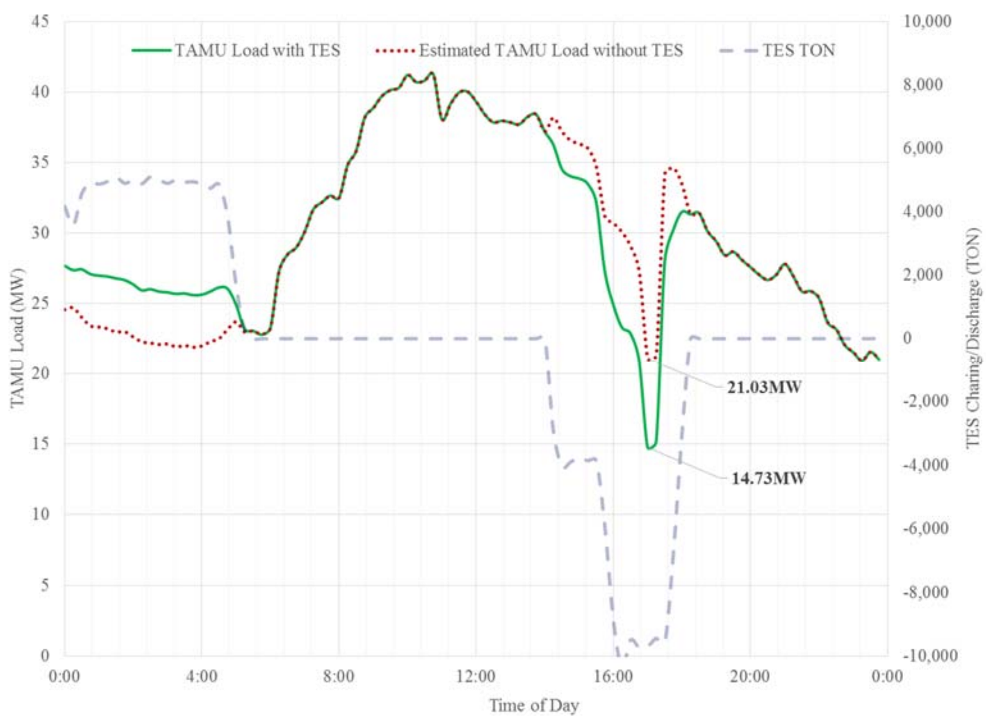

Figure 17 TAMU Load Profile With and Without TES Tank

The TAMU load or purchased power was higher from midnight to 5am before it dropped down to the load level without TES tank. The only economic dispatch impact showed in Figure 17 is from TES tank. The tank started discharging chilled water around 2:30pm close to 4,000 ton before ramping up before 4:00pm and provide chilled water close to 10,000 ton. At this time, most of the chillers on west campus except one chiller at SUP1 were turned off, resulting in setting a record low of 14.73 MW on a peak demand month instead of 21.03 MW when no TES was in operation. The June 2016 ratio between the average charge and discharge mode price based on the recommendation time of day operation was 2.169. So it was still economical to be operated during those time.

Advantages and Disadvantage of TES

As mentioned above, the main advantages of TES are to reduce the peak demand cost, and increase redundancy and operational flexibility of the west campus chilled water operation. A few disadvantages that required further investigation are the losses, additional electricity consumption of the TES pumps because of the charge and discharge process, and the additional pump electrical consumption used to maintain the chilled water loop pressure. Another disadvantage from the chilled water system operation standpoint, it was decided that west campus chilled water system would be operated locally and not on Demand Flow during the charge and discharge mode to minimize the impact from operational issues. The integration of the chilled water system optimization and TES tank operation was under review.

CHAPTER V

MANAGERIAL SKILL DEVELOPMENT

Skill development either technical or managerial is a continuing process to handle changes in any organization. Similar to the capital project UES implemented to support the campus growth, skill development needs to be acquired to expand our capabilities to be ready when changes occur. Being a UES manager gives me opportunities to participate in a series of skill development courses provided by Employee & Organizational Development (EOD) and practice what I learned from these courses and from my own and others' real-life situations by adapting and applying them in my own management style. EOD courses and my skill development will be discussed in this chapter.

Skill Development Courses by Employee & Organizational Development

UES executive leadership team initiated a partnership with EOD to enhance supervisors and managers team building and communication skills through a series of courses over eight months. Table 9 lists courses completed during this period of time. This series of courses was offered in either a large conference room or an assembly room to enable all UES supervisors and managers to attend at the same time. The structure of these courses encouraged open participation and opportunities to get to know colleagues better or in another setting.

Table 9 Employee & Organizational Development Courses Completed

Course Name	Completion Date
Leading Change	10/30/2015
It's About Respect!	11/20/2015
Rallying the Flock: Understanding Communication Styles	1/15/2016
Leadership Styles	2/5/2016
Effective Delegation	3/3/2016
PATHways: Supervisory Best Practices	4/22/2016
Building Trust	6/17/2016

These courses were selected to serve as a platform for dialogue by introducing the key topics and related theory, recognizing individual personalities through exercises, understanding how individuality affects communication and leadership styles, and acknowledging other ideas and perceptions from key topic discussions.

"Leading Change" was the first course in this series and set a good basis for future dialogue. UES staff has experienced changes at all different levels as a result of campus and division initiatives and restructuring, new equipment and software in place to effectively serve the campus, or personnel turnover. Understanding of personal change styles, stages of change transition, and change management actions could prepare us and lead others through an improved change management process.

"It's About Respect!" was a good refresher course to remind all of us of how jokes, negative stereotyping, and innocent comments could negatively impact employee morale and workplace productivity. Everyone wants to be valued and respected. Respectful behavior should be demonstrated. We also learned how to provide feedback using STAR/AR model (Situation or Task, Action, Result, Alternate Action and

Enhance Result). With this feedback model, it helped us structure and deliver constructive feedback, even in difficult situations.

"Rallying the Flock: Understanding Communication Styles" and "Leadership Styles" were two entertaining courses guiding us through processes of learning about our communication and leadership styles. The strengths and weaknesses of each style and how we could adapt each style to fit a given task, situation, and employee.

"Effective Delegation" was another course that we learned about our preferred delegation style and how to adapt our styles according to employees' skills and organizational needs.

We had "PATHways: Supervisory Best Practices" course in April when we were in the middle of the annual performance evaluation process. This course discussed the PCER (Plan, Coach, Evaluate, and Reward) model for managing employee performance. The feedback model STAR/AR was reintroduced as a suitable communication structure for coaching and feedback.

"Building Trust" was the last course in this series. A video illustrated two leaders of two organizations, how each leader's behaviors and communications built or damaged trust in the workplace environment, and the benefits of a trusting environment and liabilities of little trust. We could identify with a lot of the situations shown on the video and understand the implications. At the end of the course, we were given a few minutes to reflect on our behaviors and what type of role model we are to our team.

This series of courses was very informative and helpful. It provided me with communication tools and the framework that I can adapt to my own style. It also helped me learn about my colleagues and myself, and understanding our differences and how we can improve communication in the future. The next series of courses for 2016 – 2017 has been selected. All supervisors and managers will participate in The EOD Supervisory Essentials certificate program. These courses will blend foundational knowledge with hands-on activities and put emphasis on the supervisory essential day-to-day skills to create a productive work environment and communicate effectively with colleagues.

Skill Development in Practice

The Analytical Services team is a small team of five full-time employees, including me as the team manager, and five part-time student technicians. The nature of our work requires each of the team member to possess computer skills, analytical skills, and basic knowledge of metering, building energy consumption, and plant production. A new team member is not expected to already possess all of these skills and knowledge when they join the team. They can be learned through on-the-job training. Investment in a new team member by putting in our time and effort in the on-the-job training is necessary. Investment in current team members by encouraging their involvement, and to maintain or acquire new skills and knowledge is just as important. I consider my team members the most valuable resource in my team. It is only logical to spend most of my time and effort on my team members. Roughly 50 percent of my time was spent meeting with team members and working on data or requests to facilitate my team members to achieve their goals. Another 30 percent of my time was spent on other meetings and different projects related work. The remaining 20 percent was spent on my assignments, trainings, and other managerial related tasks.

I scheduled all my full-time team members' weekly meetings at the beginning of the calendar year. Each individual gave me feedback on their preferred meeting frequency. Some members prefer to meet once a week for one hour while others, whose work needs more discussion and feedback, prefer twice weekly of one hour each time. In these weekly meetings we discuss their work progress and challenges, and support that they needed, or to use as a work session if necessary. Part-time student technicians worked on building energy consumption modeling or data reporting, I also had a one hour weekly meetings scheduled at the beginning of each semester to use as a work session and review their past weeks' work.

These weekly meetings provided me opportunities to communicate with each team member and put the STAR/AR model and PERC model to use. Each team member was expected to have his/her weekly work report ready for discussion. This report included the past weeks' progress and future work that we planned to do. Most of this work or projects were discussed and agreed upon as performance goals during their annual performance evaluation session. Having performance goals section added to the annual performance evaluation document in PATH (Portal Access for Total HR), which is a performance management tool, provided me an official framework to plan, document, and communicate to my team members effectively. Several skill developments and improvements during my internship period have occurred because of changes in the organization. PATH is one of the examples how changes in the organization can encourage skill development or improvement, in this case, improving my planning and goal setting skills.

Another change that encouraged my mentoring and training skill development greatly in the past two years was the introduction of new members to the team. The current five full-time employees and five part-time student technicians, was three full-time employees with two vacant positions, and three part-time student technicians two years ago. In addition to the complexity of mentoring and training the growing number of team members, student technician turnover was common and is expected at the time of their graduation. Clear scopes of work were defined and communicated, training material was also developed and presented, and on-the-job training was also provided. This process was repeated and refined several times over the past two years. It helped us evaluate our work flow and made it more efficient with each revision.

CHAPTER VI

CONCLUSION

This record of study describes my experiences during my internship period while serving as Manager for Analytical Services at Utilities & Energy Services, Texas A&M University to fulfill the internship requirement for Doctor of Engineering program. The two major projects that I took part in during the internship period were the chilled water system optimization and thermal energy storage tank projects. I also described the managerial skill development activities that I participated in. This record of study shows how I have achieved my internship objectives to enhance my understanding of the chilled water system and “Demand Flow” process, and the thermal energy storage tank operation, and acquire necessary managerial skills. The avoided consumption and cost during the commissioning period of chilled water system optimization were discussed. This record of study also describes the UES mission, organizational structure, two master plan studies, and the current system description. Three indicators were introduced in Chapter II to benchmark the impact from capital projects on the total energy consumption and UES’ financial management through FY15. As of June 2016, the chilled water system optimization project was still in progress with the west campus utility plants under commissioning phase for more than six months, and thermal energy storage tank in full operation for the first month. The impacts of these two projects along with other capital projects in FY16 are shown by the three indicators that follow.

Impact on Energy Use Intensity

The source and site EUIs are projected to be 200 mBtu per GSF, and 157 mBtu per GSF by end of fiscal year 2016 as shown in Figure 18. This projection includes nine months of actual consumption and space data, and projections for the last three months of the fiscal year. The projected site EUI reduction is a result of the implementation of ESCO phase 3, which was completed in April 2015, and more aggressive efforts from the BAS team and energy stewards to reduce the consumption in the top 50 highest building energy consumers. The main reason for the source EUI reduction is because of the building consumption reduction as shown in site EUI. EUI Ratio will indicate the plant production efficiency for FY16.

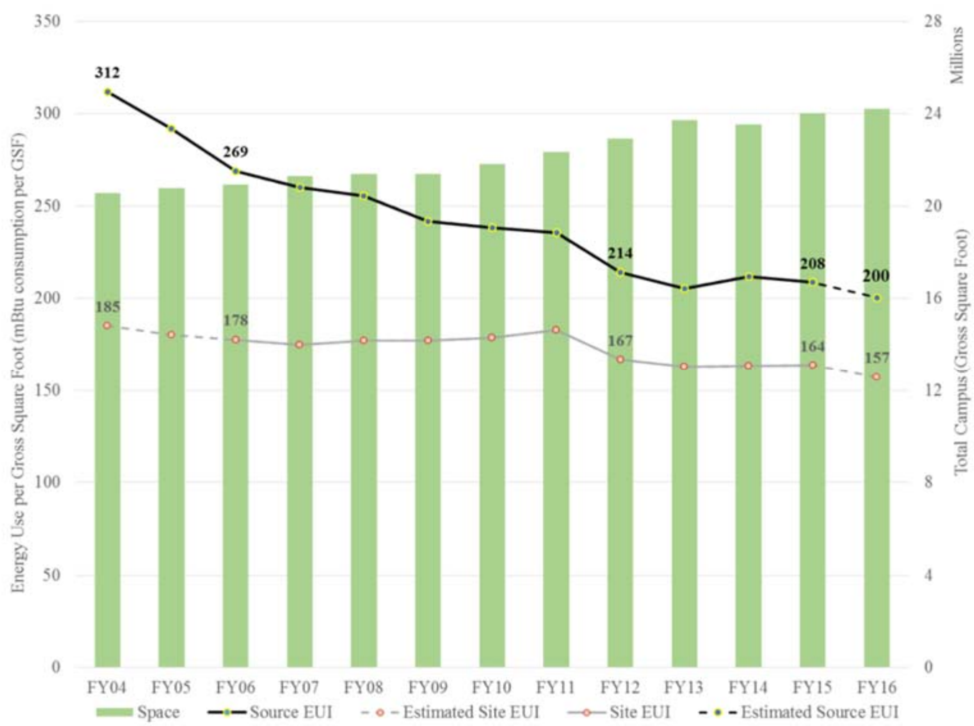

Figure 18 Texas A&M Energy Use Intensity Including FY16 Projection

Impact on EUI Ratio

The EUI Ratio is projected to be 0.78 in FY16, the same as FY15 as shown in Figure 19. The plant operation was not significantly changed from FY15 to FY16. A few positive changes in FY16 that should improve the results in FY17 are 1) work completed on HRSG resulting in 15 percent lower minimum HRSG steam production, and 2) Chilled water system optimization project full completion. In FY16, chilled water system optimization project was in place and under commissioning but the average 4 percent avoided consumption for west campus chilled water production during the commissioning period did not have a great impact on the EUI Ratio. West campus chilled water production from November through May accounted for approximately 15 percent of the annual chilled water production for both east and west campus.

Figure 19 TAMU Energy Utilization Intensity Ratio Including FY16 Projection

Impact on Utility Rates

The electricity and chilled water rates are decreasing from $0.082/kWh in FY15 to $0.080/kWh in FY16, and $15.250/mmBtu in FY15 to $15.186/mmBtu in FY16, while the FY16 heating hot water rate increased less than 3 percent from $15.030 to $15.432/mmBtu, as shown in Figure 20. The FY16 purchased electricity and natural gas rates were projected to be $0.0592 /kWh and $4.86/mmBtu, 9 percent lower for purchased electricity rate and 3.5 percent higher for natural gas rate compared to FY15. The consumption of all three major commodities was projected to increase approximately 10% from FY15 to FY16. The increases in consumption reflected the consumption from new buildings scheduled to be on-line in FY16, and the buildings on-line in FY15 that were not known when FY15 rates were developed.

It was expected that the direct rate of commodities using natural gas would be higher because of natural gas rate increases, and lower for commodities using purchased electricity. For electricity and chilled water production, where purchased electricity consumption was projected to be higher in proportion to natural gas consumption, the direct rate of both commodities was projected to be decreasing. The FY16 electricity direct and indirect rates were $0.046 and $0.037/kWh. The FY16 chilled water direct and indirect rates were $3.855 and $11.396/mmBtu. The FY16 heating hot water direct and indirect rates were $6.295 and $8.735/mmBtu. The increase in chilled water indirect rate was because of the increase in debt and depreciation from chiller upgrades and additional capital projects. The decreases in electricity and heating hot water indirect rates were the result of increases in campus consumption.

Figure 20 FY06 - FY16 UES Utility Rates

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APPENDIX A

THE SPECIFICATIONS AND REQUIREMENTS OF THE CHILLED WATER SYSTEM OPTIMIZATION PROJECT

SECTION 2 SPECIFICATIONS AND REQUIREMENTS

2.1 Scope of Work

UES is seeking to optimize their campus chilled water production facilities that provide central cooling to approximately 18 million gross square feet of campus facilities. Chilled water is produced at the Central Utility Plant (CUP) and three satellite utility plants, Satellite Utility Plant 1 (SUP1), Satellite Utility Plant 2 (SUP2), and Satellite Utility Plant 3 (SUP3). With the large size of the current Texas A&M campus and planned future growth, a potentially significant amount of savings can be achieved by minimizing costs associated with producing and distributing chilled water for campus cooling. The existing configuration consists of nearly 52,000 tons of chilled water production capacity, with half (26,000 tons) at the CUP. 10,000 tons of the 26,000 tons of capacity at the CUP is from three steam turbine-driven chillers. One steam turbine-driven unit will be replaced by October 2014 with an electric motor-driven chiller and the other two steam-driven units are not planned for integration into the optimization program. **All electric-motor driven chillers in all four utility plants (both existing and new from present through 2016) will be included in the scope of the optimization program.**

UES is seeking the services of a firm to optimize the Texas A&M campus chilled water production and delivery system to ensure high reliability while minimizing the cost of production and distribution. The firm will provide any necessary control strategies as well as any software and hardware needed to implement these modifications. Any optimization strategy must be capable of "closed loop" operation and shall not require any operator input. Integration with the existing Emerson Ovation distributed control system (DCS) will be an integral part of the control strategy. The control strategy should allow Texas A&M personnel to switch between the optimized sequence and the current sequence at their discretion. The firm will also provide training for the production services staff to support the successful sustainment of the improvements following the completion of the project. The utility plants will remain in operation throughout the duration of the project, so phasing of the work to prevent service interruptions will need to be considered. All electric motor-driven chillers in the four campus utility plants will be included in the optimization program, both existing chillers together with chillers and thermal storage system listed below. Coordination will also be required to integrate upcoming capital improvement projects with planned additions, replacements, and upgrades to the chilled water system, including the addition of multiple new chillers in all four utility plants and a chilled water thermal energy storage (TES) system.

Chilled Water System Capital Upgrades to be Included with Optimization Program

<u>CUP</u>

Chiller 9 Replacement – 3,350 Ton Electric Motor-Driven with VFD	Oct 2014 Start-up
Chiller 12 Replacement – 3,350 Ton Electric Motor-Driven with VFD	Oct 2015 Start-up

<u>SUP1</u>

Chiller 103 Replacement – 2,500 Ton Electric Motor-Driven with VFD	Oct 2014 Start-up

<u>SUP2</u>

Chiller 206 Installation – 2,500 Ton Electric Motor Driven with VFD	Oct 2014 Start-up
Chiller 207 Heat Recovery Chiller to Generate CHW and HHW	Oct 2014 Start-up

Chiller 201 Replacement – 2,500 ton Electric Motor-Driven with VFD Oct 2016 Start-up

TES System - Connected to SUP1 and SUP2 CHEW System

3 million gallon CHW storage system with associated tank and pumping Oct 2015 Start-up

SUP3

Chiller 301, 302 & 303 Replacement with two 2,500 ton Electric Motor-Driven with VFD Oct 2015 Start-up

Interested firms will be provided with 12 months of utility plant data and information in order to provide a detailed scope of work, project cost, and projected performance improvement. A six month verification period will follow each phase of the project, during which time the optimization results will be verified, including the comparison of the estimated savings and the actual savings. The firm will need to provide an initial engineering assessment for the full scope of equipment and systems to be optimized, with an assessment report including a detailed summary of recommendations and upgrades needed to maximize the effectiveness of the overall program. This assessment report will include electrical and mechanical upgrades, together with any metering or instrumentation that are recommended to enhance or improve results achieved. The optimization firm will then work with the owner's engineering firm and UES management to determine which upgrades will be implemented under a separate project work scope to maximize the capabilities of the optimization program.

The selected contractor's pay schedule shall be based on the following milestones:

- Delivery of engineering assessment and report with specific optimization recommendations and implementation schedule – 20%
- Delivery of completed optimization system (2014)- 30%
- Delivery of completed optimization system (2015)- 15%
- Delivery of completed optimization system (2016)- 10%
- Completion of six month review and verification period (2014) – 10%
- Completion of six month review and verification period (2015) – 10%
- Completion of six month review and verification period (2016) – 5%

The optimization firm selected must have extensive experience in successful optimization of large chiller plants and delivery systems, including delivery systems with more than one interconnected chiller plant, thermal energy storage systems, steam-driven centrifugal chillers, constant and variable speed chillers, variable-primary pumping systems, and dynamic distribution needs with varying delta T and delta P. The firm must demonstrate that they have the resources required to successfully complete a project of this scale with outstanding results and provide support throughout project planning, design, and implementation. The potential exists for a short list of qualified contractors to be developed and evaluated further based on the response to this Request for Proposal.

APPENDIX B

THE INFORMATION ON EXISTING EQUIPMENT

5.2 SATELLITE UTILITY PLANT 1 (SUP1)

The chilled water equipment at SUP1 includes six electric centrifugal chillers with a total design capacity of 12,000 tons as shown in Table 5-5. All chillers are constant speed with the exception of CHLR 103, which is a variable speed chiller.

Table 5-5: SUP1 Existing Chiller Summary

Tag	Manuf.	Drive/Type	Nom. Cap (Tons)	Inst. Year	Refrig.	Published Efficiency	VFD	Notes
CHLR101	Trane	ELE/CNTRF	1000	2000	R-123	0.759 kW/Ton @ 87°F	N	
CHLR102	Trane	ELE/CNTRF	1000	2000	R-123	0.759 kW/Ton @ 87°F	N	
CHLR103	TBD	ELE/CNTRF	2500	2014	TBD	0.639 kW/Ton @ 85.5°F	Y	1
CHLR104	Trane	ELE/CNTRF	2500	2010	R-123	0.582 kW/Ton @ 87°F	N	
CHLR105	Trane	ELE/CNTRF	2500	2010	R-123	0.582 kW/Ton @ 87°F	N	
CHLR106	Trane	ELE/CNTRF	2500	2010	R-123	0.582 kW/Ton @ 87°F	N	
		SUP1 Total:	12,000					

Notes:
1. To be replaced by Oct 2014.
2. Listed efficiency is projected minimum full load efficiency at zero tolerance.

SUP1 operates a variable-primary chilled water system with the pumps shown in Table 5-6. All three CHWP are headered together and can serve any of the six chillers. This arrangement is illustrated in M-3 of Appendix A.

Table 5-6: SUP1 Existing Chilled Water Pumps

Tag	Manuf.	Drive	Head (ft)	Flow (GPM)	Speed (RPM)	HP	VFD	Notes
CHWP101	Bell & Gossett	ELE	170	11000	1190	600	Y	1
CHWP102	Bell & Gossett	ELE	170	11000	1190	600	Y	1
CHWP103	Bell & Gossett	ELE	170	11000	1190	600	Y	2

Notes:
1. Head assumed based on flow, HP.
2. Pump is VFD equipped but VFD is not currently operational.

Condenser water pumps and cooling towers at SUPl are shown in Table 5-7 and 5-8, respectively. The condenser water piping arrangement is a mix of headered arrangements and dedicated cooling towers. Refer to M-4 of Appendix A for a schematic of the condenser water arrangement at SUPl.

Table 5-7: SUP1 Existing Condenser Water Pumps

Tag	Manuf.	Drive	Head (FT)	Flow (GPM)	Speed (RPM)	HP	VFD	Notes
CWP101	Johnston Pumps	ELE	80	3000	1780	100	N	
CWP102	Johnston Pumps	ELE	80	3000	1780	100	N	
CWP103A	TBD	ELE	70	3750	1780*	100	N	1
CWP103B	TBD	ELE	70	3750	1780*	100	N	1
CWP104	Floway	ELE	100	3000	1786	250	N	
CWP105	Floway	ELE	100	3000	1786	250	N	
CWP106	Floway	ELE	100	3000	1786	250	N	

Notes:

1. To be replaced by Oct 2014

* Indicates projected value

Table 5-8: SUP1 Existing Cooling Towers

Tag	Service	Flow (GPM)	Design WB (°F)	Design ECWT (°F)	Design LCWT (°F)	Fan Motor HP	VFD	Notes
CT101	CW	3000	80	97	87	60	Y	
CT102	CW	3000	80	97	87	60	Y	
CT103A	CW	3750	80	95.5	85	60	Y	1
CT103B	CW	3750	80	95.5	85	60	Y	1
CT104	CW	7000	80	98	86	150	Y	
CT105	CW	7000	80	98	86	150	Y	
CT106	CW	7000	80	98	86	150	Y	

Notes:

1. To be replaced or refurbished by Oct 2014

5.3 SATELLITE UTILITY PLANT 2 (SUP2)

The chilled water equipment at SUP2 includes six electric centrifugal chillers and a heat pump chiller with a total design capacity of12,346 tons as shown in Table 5-9. All chillers are constant speed with the exception of CHLR 206 and 201, which are variable speed chillers. CHLR 204 and 205 are able to be operated as either one-pass or two-pass machines on the chilled water side. HRCHLR207 is a heat pump chiller. It is designed to be run whenever there is sufficient heating load to accept the heat pump chiller's rejected heat.

Table 5-9: SUP2 Existing Chiller Summary

Tag	Manuf.	Drive/Type	Nom. Cap (Tons)	Inst. Year	Refrig.	Published Efficiency	VFD	Notes
CHLR201	TBD	ELE/CNTRF	2500	2016	TBD	0.639 kW/Ton @ 85.5°F	Y	3
CHLR202	Trane	ELE/CNTRF	1500	2009	R-123	0.588 kW/Ton @ 86°F	N	
CHLR203	Trane	ELE/CNTRF	1334	1984	R-11	0.603 kW/Ton @ 86°F	N	
CHLR204	York	ELE/CNTRF	2250	2007	R-134a	0.618 kW/Ton @ 85°F	N	
CHLR205	York	ELE/CNTRF	2250	2007	R-134a	0.618 kW/Ton @ 85°F	N	
CHLR206	TBD	ELE/CNTRF	2500	2014	TBD	0.639 kW/Ton @ 85.5°F	Y	2
HRCHLR207	York	ELE/CNTRF	1178	2014	R-134a	5.52 COP	N	1
		SUP2 Total:	13,512					

Notes:
1. To be installed by Oct 2014. COP includes heat rejected to HHW loop and is minimum full load efficiency at zero tolerance.
2. To be installed by Oct 2014. Listed efficiency is projected minimum full load efficiency at zero tolerance.
3. To be replaced by Oct 2016. Listed efficiency is projected minimum full load efficiency at zero tolerance.

There are six chilled water pumps at SUP2. Five of these pumps (CHWP 201 through 204 and 206) operate on a variable-primary setup and are able to serve any of the chillers except for HRCHLR 207. CHWP 205, a variable speed pump, is directly coupled with HRCHLR 207.The setup for the SUP2 chilled water system is shown in M-5 of Appendix A.

Table 5-10: SUP2 Existing Chilled Water Pumps

Tag	Manuf.	Drive	Head (ft)	Flow (GPM)	Speed (RPM)	HP	VFD	Notes
CHWP201	TBD	ELE	140*	5000*	1780*	250*	Y	3
CHWP202	Allis Chalmers	ELE	140	4000	1785	200	Y	
CHWP203	Unknown	ELE	140	6750	1780	300	Y	
CHWP204	Unknown	ELE	140	6750	1780	300	Y	
CHWP205	TBD	ELE	180	3333	1750*	200	Y	1
CHWP206	TBD	ELE	140*	6750*	1780*	300*	Y	2

Notes:
1. To be installed by Oct 2014.
2. To be installed by Oct 2014.
3. To be installed by Oct 2016.
* Indicated projected value.

Tables 5-11 and 5-12 contain the SUP2 condenser water pumps and cooling towers, respectively. M-6 of Appendix A shows the condenser water arrangement at SUP2. The heat pump chiller (HRCHLR 207) does not require any condenser water under normal operation since it rejects heat to the heating hot water system. As part of the FY2015 upgrade project (by Oct 2016), all existing constant-speed CWPs at SUP2 will be retrofitted with VFDs.

Table 5-11: SUP2 Existing Condenser Water Pumps

Tag	Manuf.	Drive	Head (FT)	Flow (GPM)	Speed (RPM)	HP	VFD	Notes
CWP201	TBD	ELE	95*	5500*	1780*	200*	Y	2
CWP202	TBD	ELE	95*	5500*	1780*	200*	Y	2
CWP203	TBD	ELE	95*	5500*	1780*	200*	Y	2
CWP204	Layne	ELE	100	6000	1770	200	Y	3
CWP205	Layne	ELE	100	6000	1770	200	Y	3
CWP206	TBD	ELE	100	6225	1780*	200	Y	1,3

Notes:
1. To be installed by Oct 2014
2. To be installed with VFD by Oct 2016.
3. To be retrofitted with VFD by Oct 2016.

* Indicated projected value.

Table 5-12: SUP2 Existing Cooling Towers

Tag	Service	Flow (GPM)	Design WB (°F)	Design ECWT (°F)	Design LCWT (°F)	Fan Motor HP	VFD	Notes
CT201	CHW	5500*	79*	96*	86*	75*	Y	2
CT202	CHW	5500*	79*	96*	86*	75*	Y	2
CT203	CHW	5500*	79*	96*	86*	75*	Y	2
CT204	CHW	6000	80	95.6	85	125	Y	
CT205	CHW	6000	80	95.6	85	125	Y	
CT206	CHW	6225	80	95.6	85	125	Y	1

Notes:
1. To be installed by Oct 2014.
2. To be replaced or refurbished by Oct 2016.

* Indicated projected value.

APPENDIX C

THE EXISTING EQUIPMENT DIAGRAMS

GENERAL NOTES

1. EQUIPMENT SHOWN IS SUBSEQUENT TO COMPLETION OF FY2015 UPGRADES AND IS SUBJECT TO CHANGE.

2. DIAGRAMS ARE SCHEMATIC IN NATURE AND DO NOT REPRESENT ACTUAL EQUIPMENT AND PIPING LAYOUTS. DIAGRAMS ARE NOT TO SCALE.

INDEX

SYMBOLS

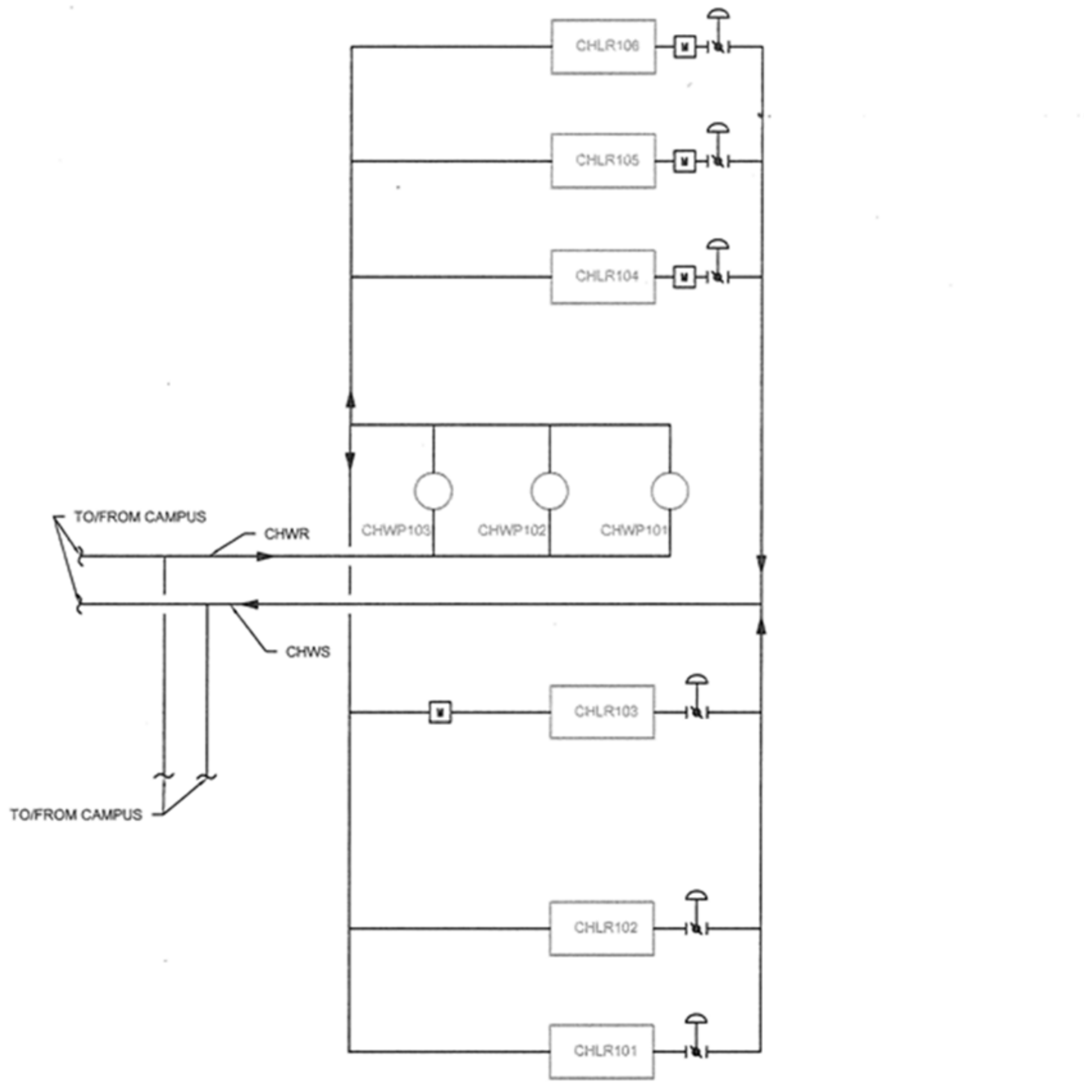

MODULATING FLOW CONTROL VALVE


FLOW METER

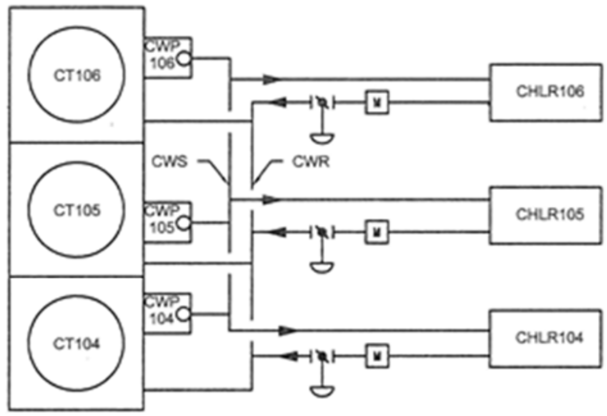
ABBREVIATIONS

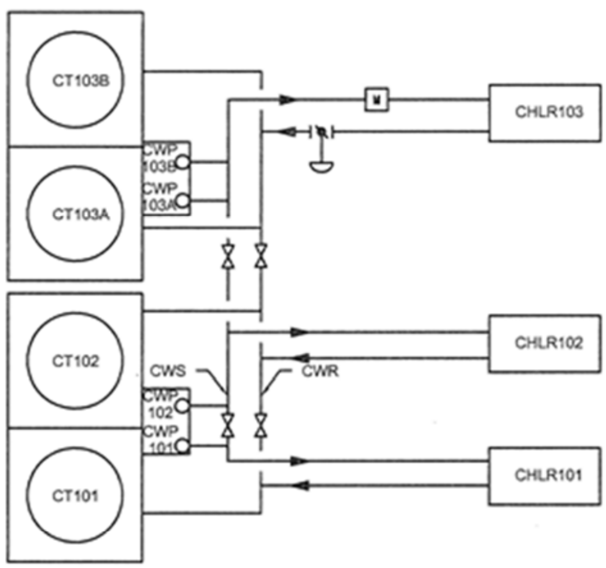
CHLR	CHILLER
CHW	CHILLED WATER
CHWP	CHILLED WATER PUMP
CHWR	CHILLED WATER RETURN
CHWS	CHILLED WATER SUPPLY
CT	COOLING TOWER
CUP	CENTRAL UTILITY PLANT
CW	CONDENSER WATER
CWP	CONDENSER WATER PUMP
CWR	CONDENSER WATER RETURN
CWS	CONDENSER WATER SUPPLY
HRCHLR	HEAT RECOVERY CHILLER
SUP1	SATELLITE UTILITY PLANT 1
SUP2	SATELLITE UTILITY PLANT 2
SUP3	SATELLITE UTILITY PLANT 3

Burns & McDonnell SINCE 1898	**SYMBOLS AND ABBREVIATIONS**	**M-0**



Burns & McDonnell SINCE 1898	**SUP1 CHW FLOW DIAGRAM**	**M-3**

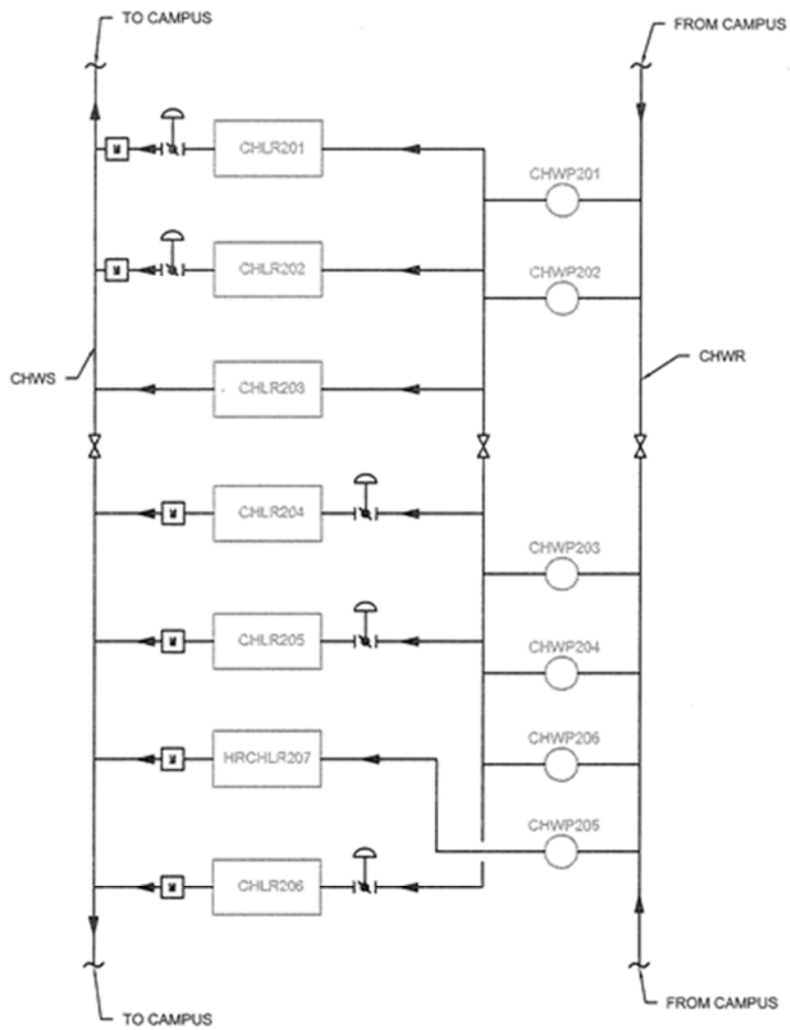




Burns & McDonnell SINCE 1898

SUP1 CW FLOW DIAGRAM

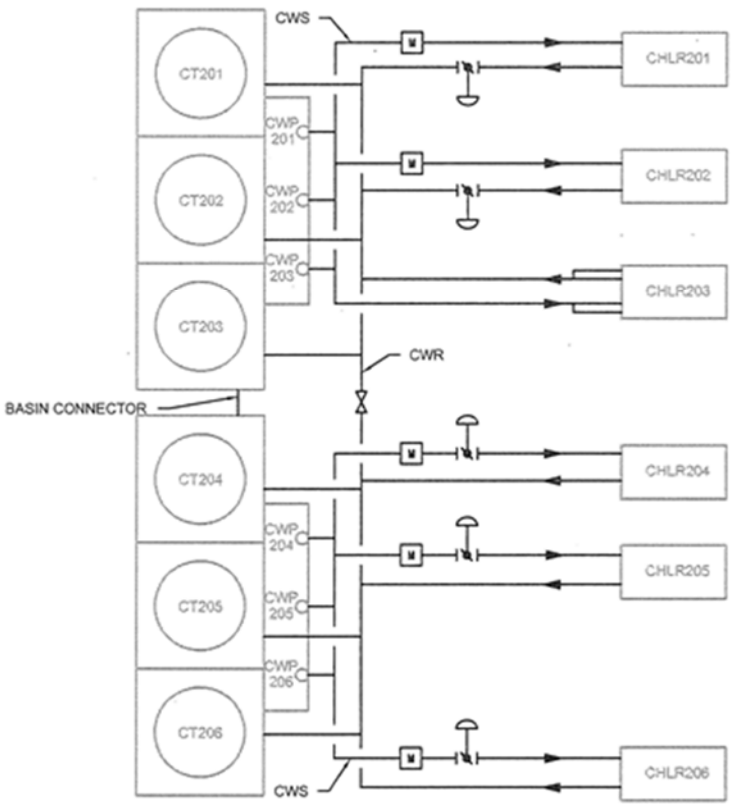
M-4



Burns & McDonnell SINCE 1898

SUP2 CHW FLOW DIAGRAM

M-5



Burns & McDonnell SINCE 1898	**SUP2 CW FLOW DIAGRAM**	**M-6**