FINAL REPORT:

Penn State Architectural Engineering Thesis

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Mechanical Option
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INOVA South Patient Tower
Falls Church, VA
April 9, 2012

INOVA Fairfax Hospital South Patient Tower

Falls Church, VA

Michael Morder **Mechanical Option**

General Information:

Function:	Hospital Bedtower
Size:	236,000 SF
Overall Cost:	$76 Million
Delivery Method:	Design-Bid-Build
Contract:	Negotiated Lump Sum
Construction Dates:	August 2010 to June 2012

Project Team:

Owner:	INOVA Health System
Architect:	Wilmot/Sanz, Inc.
General Contractor:	Turner Construction
Structural Engineer:	Cagley & Associates
MEP Engineer:	RMF Engineering, Inc.
Civil Engineer:	Dewberry & Davis

Architecture:

- Designed to Respect Existing Tower
- Natural Daylight Essential for Patient Rooms
- Focal Point—Atrium with Fountain at Entrance
- Sustainable Concepts—Pursuing LEED Silver

Mechanical:

- Campus Loop— Chilled Water and Steam
- Four 50,000 CFM AHUs (Tower)
- 10,000 and 13,000 CFM AHUs (Podium)
- Steam to Hot Water HX to serve building

Electrical/Lighting

- Two 2000 kVA transformers
- Service Provided via 600 A Bus Ducts
- Energy Efficient Lighting Fixtures
- 2000 kW Emergency Generator

Structural:

- Typical 29' X 29' Bays Throughout
- Five Reinforced Concrete Shear Walls
- Reinforced Normal Weight Concrete
- Foundation Supported on 16" Piles

http://www.engr.psu.edu/ae/thesis/portfolios/2012/mtm5093

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1.0 Introduction

1.1 Acknowledgments

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Joseph Kranz	Project Executive, Turner Construction
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Dr. William Bahnfleth	Faculty Advisor, Penn State University
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I would also like to acknowledge my fellow Architectural Engineering peers, friends and family for all of their support throughout the thesis process. Thank you for everything you've done and always being there in times of need.

1.2 Executive Summary

The South Patient Tower at INOVA Fairfax Hospital is a thirteen (13) story, 239,000 square foot patient tower addition located in Falls Church, VA. The addition was built to provide additional patient bedrooms, some staff offices, a new kitchen and café, as well as a future clinical space.

This document is a collection of research, official documentation, and the data that were collected for the South Patient Tower primarily to analyze the effects of a mechanical system redesign. The goal of this thesis project was to design a new chilled water plant to help provide more energy efficient measures to the South Patient Tower. It was also a primary goal to analyze the effects of the centralized chilled water plant on the life cycle cost and on other building systems and components to evaluate the feasibility and economic impact that the redesign would have on the building.

The original mechanical design met all of the design criteria of the South Patient Tower at a minimal cost to the owner. The system that building is comprised of is a constant volume with reheat that includes purchased chilled water and steam that serve the four (4) 50,000 CFM air-handling units on located on the fifth floor and three (3) 10.7 MMBTU steam to hot water heat exchangers. Hot water is then supplied to the AHUs and the rest of the heating devices within the building. The kitchen and café are served by an independent air-handling unit.

The redesigned system will only affect the source of the chilled water and the purchased steam will remain the same as in the existing design. Due to the ability to optimize a chilled water plant with other mechanisms such as dedicated heat recovery chillers and condensate recovery, the study was performed and compared on cost and energy consumption when compared to the existing purchased utilities. The chilled water plant will consist of three (3) 380 ton chillers to provide for N+1 redundancy, two (2) 380 ton cooling towers, a dedicated heat recovery chiller to offset the steam consumption and an air-handling unit condensate recovery system to offset the consumption of make-up water in the cooling towers.

Multiple alternatives were considered for the plant design and the most efficient and economical choice was found to be a variable primary flow, centrifugal chillers with a 100 ton heat recovery chiller and the air-handling condensate recovery system. The effects this plant has on the electrical and structural systems were also evaluated. It was found that additional electrical equipment was necessary and additional reinforcing in the concrete slab was necessary. The overall redesign will cost an additional **$919,779**. Although it increased the capital cost, a 30-year life cycle cost shows **$2.65 million** savings when compared to the baseline, and reduces overall energy consumption by **14 MMBTU** annually. It also decreases emissions compared to the baseline by around **4%.**

2.0 Project Information

2.1 Design Goals

INOVA Fairfax Hospital was in need of more technologically advanced spaces to care for and treat patients. The owners decided to make an addition to the existing patient bed-tower to meet this demand. The designers on this project had a difficult challenge of respecting the existing structure while creating a newer, more advanced care facility. Redundancy was a must to ensure continuous operation of the facility. The engineers designed with a patient care first approach.

2.2 Building Information/Location

The South Patient Tower is located on the INOVA Fairfax Hospital campus in Falls Church, Virginia. The tower is a 236,000 SF, thirteen (13) story (12 above grade and 1 below) hospital patient bed tower that expands the existing hospital patient building. The project was contracted under a single prime with negotiated lump-sum contract valued around $76 million overall project cost and delivered via a design-bid-build method.

2.3 Project Team

- **Owner:** INOVA Health System
- **Architect:** Wilmot/Sanz Inc.
- **General Contractor:** Turner Construction Company
- **Structural Engineer:** Cagley & Associates
- **Mechanical Engineer:** RMF Engineering, Inc.
- **Electrical Engineer**: RMF Engineering, Inc.
- **Civil Engineer**: Dewberry & Davis

3.0 Building Overview & Existing Conditions

3.1 Architecture

The South Patient Tower was designed to complement and respect the recent Heart Institute to the building's west, while maintaining an architectural style that is consistent with the rest of the INOVA Fairfax Hospital Campus. The building can be broken into two distinctive architectural parts; the lower four floors (podium) and the upper nine floors (tower). The podium section of the building hosts the entrance lobby, cafeteria, kitchen, services, offices and ultrasound exam rooms while the tower is strictly for patient bedrooms. A two floored atrium is used for the entrance lobby and has a circular fountain located on the ground level. The mechanical systems are located on the fifth floor due to a trauma helicopter pad located on the roof of the tower.

3.2 Building Façade

The façade of the tower is made up of a curtain wall system. This curtain wall consists of three elements that help to respect the existing patient bed tower while mirroring the newer Heart Institute's façade style. Precast concrete panels, aluminum curtain wall with glazing and metal panels all work together to create this building's façade. There are two varieties of precast concrete panels. One is a panel formed into thin brick laid in soldier courses and help to tie the building into the older all brick patient tower, and the other is a basic precast panel in the center of each elevation and on the façade of the podium level. The aluminum curtain wall with glazing helps to provide ample amounts of daylight for the interior patient rooms and other interior spaces. Metal panels are used to continue to look of the building but help to hide some of the interior elements such as columns or the mechanical fifth floor.

3.3 Zoning

The INOVA South Patient Tower is located in Fairfax County, Virginia and falls under the *I, Merrifield Suburban Center, Land Unit M, Sub-Unit M1* planning area and district. Innovative energy efficiency and conservation strategies should be incorporated into all new buildings in this district. A setback of 100 feet on the western boundary of the district and a maximum height of 165 feet are requirements within Sub-Unit M1.

3.4 Roofing

The roofing for the South Patient Tower consists of a similar base of a 9-1/2" reinforced concrete slab, insulation, and a 4" light-weight concrete topping for the three types of roofing materials on the project. These materials include; polyvinyl-chloride (PVC), a fluid-applied protected membrane, and a vegetated roof system. The lower podium roof consists of both the vegetated roof system and the fluid-applied protected membrane, while the higher tower roof is made of the polyvinyl-chloride (PVC) material.

3.5 Sustainability

The INOVA Hospital South Patient Tower is pursuing LEED Silver certification which exceeds the zoning requirement to be LEED Certified. This project has an energy reduction goal of at least 24.5% based on a database of similar buildings. Some aspects to help the project reach this goal include a vegetated green roof covering most of the low podium roof, a white reflective PVC roofing material on the upper tower roofs, water efficient landscaping using no potable water, automatic sensors on sinks and dual flush valves on toilets, recycled and local materials and community connectivity by building a new bus stop for the hospital

3.6 Electrical System

The south patient tower is fed by two 2000 kVA transformers provided from the utility company to the site. The transformers are located to the west of the tower on the site and the feeders run underground into the basement electrical room and include a 3000 A circuit breaker on each feeder. The feeders are made up of seven (7) sets of 4-#750 MCM wires from each transformer. In the basement electrical room, the feeders connect to the main building switchgear which then distributes the power to various parts of the building. To get power up to the patient floors, the south patient tower's electrical system utilizes two bus ducts (600A each), one to the north half of the tower and one to the south half. Transformers are placed where needed in the building to step down the voltage from the supply voltage to that is needed by various equipment and lighting.

An emergency 2000 kW generator serves the south patient tower. The generated power is stepped down by a 2000 kVA transformer and serves an emergency power switchgear. Transfer switches are located on each main electrical branch throughout the building to help serve all the loads as necessary.

3.7 Lighting

There are 54 different lighting fixtures in the South Patient Tower. They range from fluorescents to LED and Incandescent lamps. All the fluorescents are T8 or T5 lamps due to their efficient usage of energy. All lights are served from a lighting panel on each floor. Typical lighting in a patient rooms include a 2x4 recessed fixture with two 40 watt twin tube (TT5) bulbs surrounded by four 6 inch 24 watt double dulux tube (DDT) down-lights. The hallways consist of recessed wall slot fixtures that utilize a 32 watt T8 linear fluorescent to graze the outer wall where the patient rooms are located. Nurse's stations are located within the building's central service area and 6 inch down-lights with 24 watt double dulux tube (DDT) lamps provide the necessary ambient lighting for these spaces.

South Patient Tower's cafeteria serving and eating area utilize track lighting and a lensed down-light with two 26 watt double dulux tube (DDT) lamps.

3.8 Structural System

The main structural system in the South Patient Tower is reinforced concrete with shear walls. The tower is supported on 16 inch diameter piles with pile caps and grade beams. Each pile cap consists of 2-11 piles depending on the location in the building. The concrete slab in the basement is a 5" reinforced slab and the floor slabs on the upper floors are typically a 9-1/2" reinforced two way slab. Typical column layout is consistent throughout the entire tower and is 29'x 29' with a few exceptions near the southern and western side of the building in the podium (level B-3). The main columns throughout the tower are of a typical 24" x 24" size with reinforcing that varies as it goes up through the building.

The lateral support in the South Patient Tower consists of five 12" reinforced concrete shear walls. These walls are located around the elevator core near the connection to the existing patient tower and provide resistance in all four cardinal directions.

3.9 Medical Gas

Since the tower is mostly patient bed rooms, medical gases are necessary to facilitate care. The South Patient Tower includes services for Oxygen, Medical Vacuum, and Medical Air that are piped into patient rooms via an integrated headwall system. Additional medical gases will be brought in as necessary. The oxygen service is provided through the existing hospital. The medical vacuum is provided by four (4) medical vacuum pumps located in the basement. Together these pumps provide a system capacity of 369 standard cubic feet per minute (SCFM) and have a 220 gallon storage tank tied into the distribution system. The medical air is provided by a system of three (3) medical air compressors that together provide a system capacity of 100 standard cubic feet per minute (SCFM) and has a 200 gallon receiving tank tied into the system.

3.10 Construction

The project scope of the South Patient Tower not only includes the tower but also includes a new site layout to provide a newer approach to the hospital entrance. The construction team is responsible for the civil project scope along with the building construction scope. Since the new construction is taking place on a large hospital campus, there will be locations available for staging and laydown. The following are some statistics about the construction:

- **Construction Dates:** August 2010 to June 2012
- **Overall Project Cost:** $76 million
- **Delivery Method:** Design-Bid-Build
- **Contract:** Single Prime with negotiated Lump-Sum contract

4.0 Existing Mechanical System

4.1 Introduction

The South Patient Tower at INOVA Fairfax Hospital serves as an addition to the existing patient tower. With an overall size of 233,000 square feet, the new tower serves as additional patient recovery rooms, a new cafeteria, and a state of the art ultrasound suite located on the ground floor. Mechanical services are mainly located on the fifth floor of the hospital to minimize the need for mechanical penthouses on the roof, so that a new emergency helipad can be located on top of the tower.

4.2 Design Criteria

The main design objective of the South Patient Tower was to create a world-class patient bed-tower to help serve the INOVA Fairfax Hospital and its growth towards being one of the top trauma centers in Virginia. In order to achieve this, the hospital is expanding and updating buildings to reach the level of care currently expected from patients and families. From a mechanical standpoint, the designers reached the elevated design goal by providing full redundancy on all the systems put in place. The air-handlers are on a loop system and headered together to help serve the various loads of the hospital under normal conditions. If the building were to lose an air-handler due to failure or maintenance, the redundancy would help maintain the load. Since the building is connected to a campus loop system, redundancy is already built in with the additional loads picked up by new equipment in the plant.

Designers were influenced by the existing hospital when approaching the design of the tower. Since this building will be an addition to the current patient tower, the mechanical systems were designed to maintain the appropriate air pressure relationships with the existing tower systems. To ease connections between the new and old buildings, the architect kept a tight floor to floor height which influences the design of the mechanical distribution systems. It should be noted that no design strategies were based upon rebates or tax relief.

Due to the nature of the patient tower, a great deal of the thermal and energy loads can be attributed to the lighting and hospital equipment in operation. Both of these are fairly constant as the hospital is a 24 hour operation. The loads that can be seen as variable are due to infiltration, solar gain, conditioning of ventilation air and the mechanical equipment.

The outside air fraction for the systems in the South Patient Tower well exceeds the required percentage by ASHRAE 62.1. The design is maintained at 40% outside air, with the hopes of improved air quality with increased air changes. The minimum ventilation rates used by the design engineers exceeds what is recommended in both ASHRAE 62.1 and ASHRAE 170, which helps to show a concern for proper quality of air in the tower.

Loads due to solar gains were design considerations for the South Patient Tower due to the fenestration being located largely on the southern facing facades of the building. A design goal of the tower was to provide adequate day lighting to help the healing process in each of the patient rooms. Also large expanses of glass exist around the two-storied atrium entry lobby on the South and Southwest sides of the building, which contribute to the cooling load. To provide heating in the winter months due to the large fenestration, designers placed reheat coils on perimeter zones as well as fin-tube radiators in the lobby area.

Operation of the mechanical equipment contributes the most to the overall energy consumption of the South Patient Tower. This can be partly attributed to the oversized equipment selections; however this oversizing was done with good intent to help maintain redundancy, reliability, and indoor air quality rather than efficiency. The approach the designers took is understandable due to the goal of a world-class healing and recovery facility.

4.3 Design Conditions

The INOVA South Patient Tower is located in Falls Church, VA. To estimate the weather data, values were taken from ASHRAE Fundamentals 2009 for Washington, D.C. Reagan Airport. A brief summary of the data inputs for the TRACE weather data can be seen below in ***Table 1***.

Table 1: Weather Conditions

Washington, D.C. Reagan Airport	
Latitude	38.87N
Longitude	77.03W
Heating DB (99.6%)	16.3 F
Cooling DB (0.4%)	94.3 F
Cooling WB (0.4%)	76.0 F

The thermostat set points do not vary throughout the hospital. The thermostats are located in the room and the drift points were not specified, rather assumed in previous analyses. ***Table 2*** below summarizes the set points for heating and cooling for the South Patient Tower as determined by the mechanical designer.

Table 2: Summary of Thermostat Settings

South Patient Tower Temperature Set Points	
Cooling Dry Bulb	72 F
Heating Dry Bulb	72 F
Relative Humidity	50 %
Cooling Drift Point	81 F
Heating Drift Point	64 F

4.4 Ventilation Requirements

After analyzing the ventilation system of the INOVA South Patient Tower, it has been determined that not all spaces meet the minimum ventilation requirements set by ASHRAE 62.1. The spaces that do not meet the minimum ventilation are storage areas, janitor closets, electrical closets, and equipment rooms. Typically these spaces are not supplied with air, but rather have air transferred from adjoining spaces. Due to this they are not provided with any supply air in the current design.

The South Patient Tower is mainly supplied by AHU-1, 2, 3, and 4, which are coupled together to help serve the loads of the spaces. The maximum Z_p value for the zones served by these air-handlers was found to be 0.99 in the basement. There were other spaces, however over the 0.55 limit of Table 6-3 so even if this zone was not included, the method provided in Appendix A would still need to be exercised. After following the method outlined, it was found that the E_v for AHU-1, 2, 3 and 4 would be 0.77. The uncorrected outdoor airflow for each of these air-handlers was calculated as 9,600 CFM and taking into account the 0.77 efficiency, the adjusted outdoor airflow intake for each was found to be

12,468 CFM. The kitchen is served exclusively by AHU-6. The maximum Z_p value found for the zones that AHU-6 serves was 0.33. From Table 6-3, the efficiency value (E_v) was found to be 0.8. The uncorrected outdoor airflow for AHU-6 was calculated as 2,270 CFM and when the efficiency is taken into account, the adjusted outdoor intake airflow was calculated as 2,838 CFM.

AHU-1, 2, 3, and 4 each are designed to handle a supply of 50,000 CFM with a designed outdoor airflow of 20,000 CFM. The adjusted outdoor airflow minimum of 12,468 CFM is below the design and shows that these air-handlers exceed the standard and thus comply. AHU-6 was selected to handle a supply of 13,000 CFM with an outdoor airflow of 5,000 CFM. The adjusted outdoor airflow minimum of 2,838 CFM is below the design, so AHU-6 complies with Section 6. When combined in viewing the whole building, the designed airflow was found to be 223,000 CFM with a design outdoor airflow of 95,000 CFM. Calculating the minimum outdoor airflow for the building as a whole, it was found that 62,708 CFM was required. This is well below the design value and thus the systems comply with ASHRAE 62.1 Section 6. ***Table 3*** provides a summary of the design supply and outdoor airflow, efficiency, and comparison to the calculated minimums.

Table 3: **Summary Chart of Compliance with ASHRAE 62.1 Section 6**

Unit	Area(s) Served	Supply Airflow	Outdoor Airflow	Uncorrected OA	System Efficiency	Minimum OA	Comply Y/N?
AHU-1	Tower	50,000	20,000	9,600	0.77	12,468	Y
AHU-2	Tower	50,000	20,000	9,600	0.77	12,468	Y
AHU-3	Tower	50,000	20,000	9,600	0.77	12,468	Y
AHU-4	Tower	50,000	20,000	9,600	0.77	12,468	Y
AHU-5	Hood MAU	10,000	10,000	-	-	10,000	Y
AHU-6	Kitchen	13,000	5,000	2,270	0.80	2,838	Y
TOTALS		**223,000**	**95,000**			**62,708**	**Y**

It can be seen that the designer upsized the equipment for the South Patient Tower. They met the minimum required ventilation airflows and, in fact, exceeded them for the systems. This can be attributed to designer's factors of safety in the calculations, as well as the requirement for there to be redundancy in the hospital so that it may operate 24 hours a day. They also designed in excess of the outdoor airflow required to provide the best possible quality of air for the patients that will be occupying the bed tower.

*All supporting calculations can be found in Technical Report 1: Appendix B.

4.5 ASHRAE Standard 90.1 Conclusions

To determine compliance with ASHRAE Standard 90.1, the prescriptive path method was used for all sections. After evaluating all sections of the standard the South Patient Tower was determined as compliant with a few minor exceptions. The fan power was not entirely compliant with the air-handler fans not meeting the minimum standard. Also the pump motor efficiencies did not show compliance with the minimum required efficiencies.

The fans for the air-handlers did not meet the required performance determined in the standard. This can be attributed to the oversizing of the units to help provide redundancy to maintain operation 100% of the time. In the hospital, providing ventilation and supply air to the patient rooms is critical and if one air-handler is taken off-line, the others must be able to help provide their share of that missing load. To do this the air-handlers are coupled together and slightly oversized. Although not compliant with Standard 90.1, this oversize was done with good intentions to maintain the design intent.

Pump motor power was also not compliant with ASHRAE Standard 90.1. None of the pumps reached the required minimum efficiency of the standard. The pumps are required to provide redundancy and help share parts of the load when a pump is off-line. This redundancy and need for continuous service attributes to the oversizing of pumps and the resulting low efficiency values.

The South Patient Tower was designed with ASHRAE Standard 90.1 in mind and the results show that the design was compliant. The fan and pump non-compliances can be seen as a design intent to maintain continuous operation of the building. Due to variable frequency drives being put into place on both, the design may show compliance when the building is in operation.

4.6 Mechanical Equipment Summary

The primary heating, air-conditioning, and ventilation for the South Patient Tower is done through a constant air volume system with four (4) 50,000 CFM air-handlers located on the fifth floor mechanical space. These units are coupled together in a loop system to serve all areas of the tower excluding the kitchen and the electrical and IT rooms which are served by separate air handlers or fan coil units. Natural redundancy is built into the system through the coupled system which allows every air-handler to provide air to all diffusers in the tower. Cooling is provided by connection to the existing campus loop for the hospital. The chilled water enters in the basement and is delivered by a riser to the 5th floor mechanical space.

Rooftop air-handlers (AHU-5 and AHU-6) provide the necessary heating, air-conditioning and ventilation for the kitchen in the South Patient Tower. AHU-5 is a 100% outdoor air make-up unit serving the kitchen hoods only. AHU-6 provides the necessary supply and ventilation air for the kitchen. Each is served from the campus loop cooling system and heating hot water system for cooling and heating purposes. Both units are located on the low podium roof (second floor roof).

On the heating side, the building is served from the campus steam loop. Located in the basement are three (3) 715 GPM steam to hot water heat exchangers, which provide the heating hot water for the air-handlers and reheat coils in the tower. The hot water system is transported through the building by three (3) 715 GPM pumps that supply 60 feet of head. These pumps are served with variable frequency drives (VFDs) and can adjust to the appropriate need for heating called for by the system. Additional recirculating pumps are provided for necessary distribution to the reheat coils on each floor. ***Tables 4-8*** provide a breakdown of the mechanical equipment used in the South Patient Tower.

Table 4: Air Handling Unit Schedule

Unit	Service	Supply CFM	Cooling		Heating	
			EAT (DB in F)	LAT (DB in F)	EAT (F)	LAT (F)
AHU-1	Tower	50,000	83.3	50	0	45
AHU-2	Tower	50,000	83.3	50	0	45
AHU-3	Tower	50,000	83.3	50	0	45
AHU-4	Tower	50,000	83.3	50	0	45
AHU-5	Hood-MAU	10,000	95	68.2	0	73.6
AHU-6	Kitchen	13,000	83.3	52.8	45	61.7

Table 5: Air Handling Supply Fan Data

Unit	Service	Supply CFM	Minimum OA CFM	HP	RPM
AHU-1	Tower	50,000	20,000	125	1750
AHU-2	Tower	50,000	20,000	125	1750
AHU-3	Tower	50,000	20,000	125	1750
AHU-4	Tower	50,000	20,000	125	1750
AHU-5	Hood-MAU	10,000	10,000	15	1750
AHU-6	Kitchen	13,000	5,000	25	1750

Table 6: Return and Exhaust Fan Schedule

Designation	Service	CFM	SP INCH WG	HP
RF-1	Return Plenum	30,000	6.0	50
RF-2	Return Plenum	30,000	6.0	50
RF-3	Return Plenum	30,000	6.0	50
RF-4	Return Plenum	30,000	6.0	50
RF-5	Return Plenum	30,000	6.0	50
RF-6	Return Plenum	30,000	6.0	50
RF-6a	Return (AHU-6)	8,000	2.0	7.5
KEF-1	Kitchen Exhaust	6,800	1.75	5
KEF-2	Kitchen Exhaust	2,700	1.25	2
EF-1	Toilet Exhaust	6,300	0.75	5
EF-2	Toilet Exhaust	6,300	0.75	5
EF-3	Toilet Exhaust	3,150	0.9	2
EF-4	Toilet Exhaust	3,150	0.9	2
EF-5	Toilet Exhaust	1,500	0.95	1
EF-6	Trash/Lin Exhaust	890	0.75	0.25
GEF-1	General Exhaust	4,500	-	5
TB-1	General Exhaust	12,600	3.25	15

Table 7: Steam/Heating Water Converter Schedule

Designation	GPM	EWT (F)	LWT (F)	Passes
HX-1	715	160	190	2
HX-2	715	160	190	2
HX-3	715	160	190	2

Table 8: Pump Schedule

Designation	Service	GPM	Head (ft wg)	HP
HWP-1	Heating Water	715	60	15
HWP-2	Heating Water	715	60	15
HWP-3	Heating Water	715	60	15
DWBP-1	Dom. Water Booster Pump (BSMT-4th)	330	196	30
DWBP-2	Dom. Water Booster Pump (BSMT-4th)	330	196	30
DWBP-3	Dom. Water Booster Pump (BSMT-4th)	330	196	30
DWBP-4	Dom. Water Booster Pump (5th-11th)	220	196	25
DWBP-5	Dom. Water Booster Pump (5th-11th)	220	196	25
DWBP-6	Dom. Water Booster Pump (5th-11th)	220	196	25
HWRP-1	Hot Water Recirc. Pump (BSMT-4th)	30	90	3
HWRP-2	Hot Water Recirc. Pump (BSMT-4th)	30	90	3
HWRP-3	Hot Water Recirc. Pump (BSMT-4th)	30	90	3
HWRP-4	Hot Water Recirc. Pump (5th-11th)	30	90	3
HWRP-5	Hot Water Recirc. Pump (5th-11th)	30	90	3
HWRP-6	Hot Water Recirc. Pump (5th-11th)	30	90	3
HWRP-7	Hot Water Recirc. Pump (5th-11th)	30	90	3
CRP-1	Coil Recirc. Pump (AHU-1)	162	20	2
CRP-2	Coil Recirc. Pump (AHU-2)	162	20	2
CRP-3	Coil Recirc. Pump (AHU-3)	162	20	2
CRP-4	Coil Recirc. Pump (AHU-4)	162	20	2
CRP-5	Coil Recirc. Pump (AHU-5)	54	20	0.75
CRP-6	Coil Recirc. Pump (AHU-6)	16	20	1/12

4.7 Mechanical First Costs

The following is a breakdown of the first costs associated with the mechanical, plumbing and medical gas systems as reported by the contractor. ***Table 9*** provides a detailed summary of the costs associated with various equipment, installation, material and permitting. It can be seen that the HVAC system (excluding Medical Gas and Plumbing) costs **$9,818,635** and has a cost per square foot of about **$42/SF.**

Including the Plumbing and Medical Gas systems that fall under the Mechanical Contract, the total cost is **$14,918,435** with a cost per square foot of **$63.80/SF**

Table 9: Mechanical Cost Breakdown

Item	Cost	Cost/SF
Mechanical Equipment		
AHU-1,2,3,4	$ 894,945.00	$ 3.83
Fan Coil Units (20)	$ 80,000.00	$ 0.34
Terminal Boxes	$ 150,000.00	$ 0.64
Steam Humidifiers	$ 40,000.00	$ 0.17
HEPA Filter	$ 50,000.00	$ 0.21
Steam Condensate Pumps	$ 14,000.00	$ 0.06
Misc. Heaters	$ 30,000.00	$ 0.13
Fans/Air Curtain	$ 8,000.00	$ 0.03
Steam Specialties	$ 100,000.00	$ 0.43
Variable Frequency Drives	$ 100,000.00	$ 0.43
Med Gas Equipment	$ 397,000.00	$ 1.70
TOTAL	*$ 1,863,945.00*	*$ 7.97*
Plumbing Equipment		
Domestic Water Heaters	$ 215,000.00	$ 0.92
Domestic Booster Pumps	$ 85,000.00	$ 0.36
Pumps, HX, EX Tank	$ 68,000.00	$ 0.29
TOTAL	*$ 368,000.00*	*$ 1.57*
Miscellaneous Material		
Mechanical	$ 4,120,653.00	$ 17.62
Plumbing	$ 1,271,500.00	$ 5.44
Med Gas	$ 570,000.00	$ 2.44
TOTAL	*$ 5,962,153.00*	*$ 25.50*
Labor Summary		
Mechanical	$ 4,231,037.00	$ 18.10
Plumbing	$ 867,500.00	$ 3.71
Med Gas	$ 794,000.00	$ 3.40
TOTAL	*$ 5,892,537.00*	*$ 25.20*
Project Deliverables/Permits	$ 831,800.00	$ 3.56
GRAND TOTAL	**$ 14,918,435.00**	**$ 63.80**

4.8 Lost Usable Space

A summary of the lost usable space due to the mechanical system in the South Patient Tower can be seen in ***Table 10*** below. A majority of the floors only lose space due to shaft penetrations in the northern and south central area of the floor. The basement has 2,013 SF of lost area due to a smaller mechanical room being located here. The fifth floor is the mechanical floor which serves in place of a rooftop mechanical penthouse, thus the entire floor is taken by mechanical space. Finally, the number of shafts increases starting at the third floor due to the exhaust shafts for the bathrooms in the patient rooms.

Table 10: Lost Usable Space

Floor	Area (SF)
Basement	2,013
Ground	332
First	360
Second	332
Third	416
Fourth	416
Fifth	15,057
Sixth	421
Seventh	421
Eighth	421
Ninth	421
Tenth	421
Eleventh	421
TOTAL	**21,452**

4.9 Air Side Operation

The main four air-handlers that supply the tower with heating, ventilation and air conditioning (AHU-1, 2, 3, 4) are all independent units which are headered together to handle the entire load of the South Patient Tower. All of the units are the same size and have independent supply fans, outdoor air dampers and return dampers. Along with these devices, each air-handler is equipped with a pre-heat coil, cooling coil, low pressure steam humidifiers, pre- and final filters, and separate controls. Variable frequency drives (VFDs) control each of the supply fans to help meet the various loading conditions of the tower and are modulated with static pressure sensors at the outlet of each air handling unit. The return fans are grouped together in a common return air plenum for the whole system. These fans are operated with VFDs to help maintain a constant pressure differential with the supply air. They are designed to modulate with the supply fans as needed to maintain the differential at various loads.

The supply air temperature for each unit is controlled by a temperature sensor located at the outlet of the supply fan and modulates the outdoor air damper, return air damper, pre-heat coil and cooling coil all in sequence. The initial set point for cooling mode is a supply temperature of 55 F and the humidity sensors will control temperature if the relative humidity rises above 60%. Control will be returned to the temperature sensor when relative humidity reaches 55%. During the heating mode, a steam humidifier will be controlled by a relative humidity sensor in the return air in an effort to maintain a minimum relative humidity in the space of 35%. ***Figure 1*** and ***Figure 2*** show schematics of the system in further detail.

AHU-5 is energized when a kitchen hood is activated to provide air for exhausting the grease hoods. The supply fan is located in the unit and controlled by a VFD to meet the various loads of different hoods being engaged at different times. Supply air temperature is maintained by a temperature sensor located at the outlet of the supply fan and modulates the heating/cooling coils to provide appropriate temperatures.

AHU-6 provides heating, ventilation and air conditioning for the kitchen space to meet the loads associated with the space excluding the exhaust hoods. The control is very similar to AHU-1, 2, 3, and 4 except on the return side. The return fan is located within the unit and controlled in conjunction with the supply fan on a VFD. The supply air set point for cooling is 55 F with no specifications on the relative humidity set point.

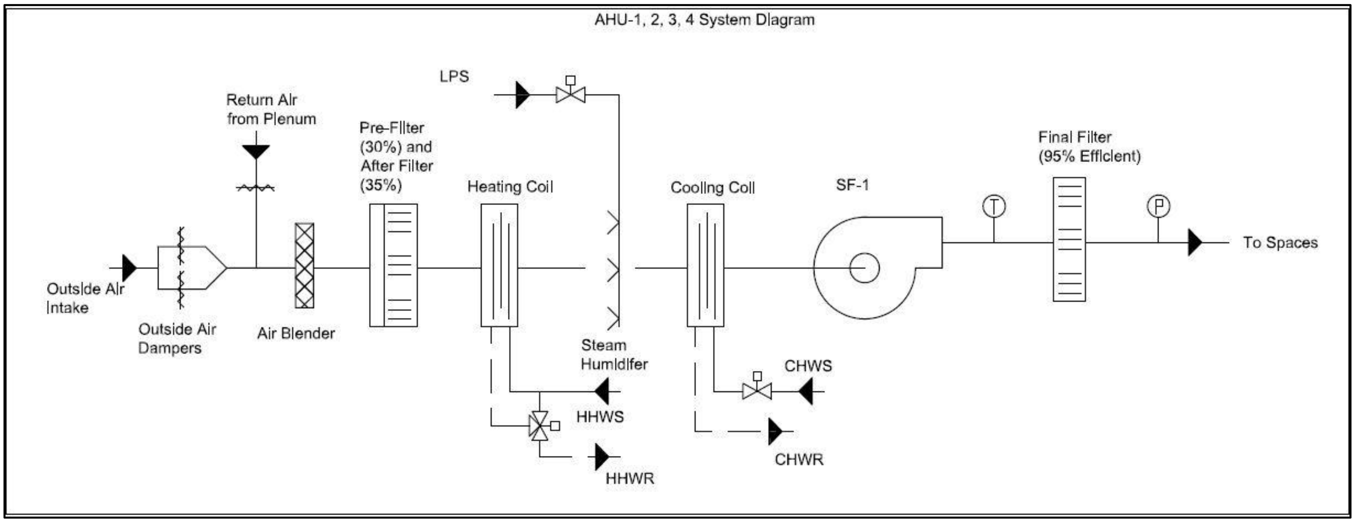


Figure 1: Air Handler Diagram

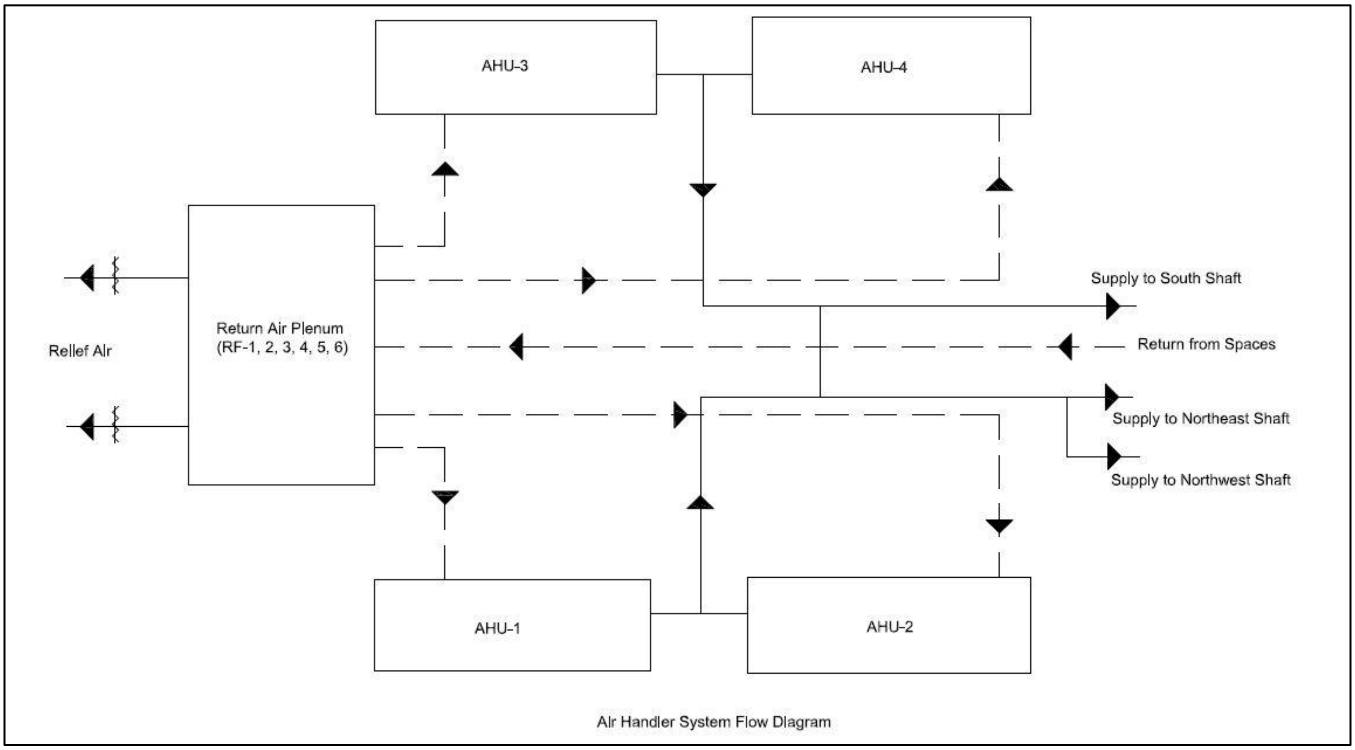


Figure 2: Air-Handling System Diagram

4.10 Water Side Operations

4.10.1 Chilled Water

The building is served from the central utility plant and enters the tower in the basement utility tunnel. It is distributed to the cooling coils for the air-handling units located on the fifth floor and no booster pumps are used in the process. Flow through the coils is controlled via an automatic control value that correlates to the leaving air temperature from the coil and adjusted when needed. After flowing though the coils, the chilled water returns to the central plant to be cooled once again.

4.10.2 Heating Hot Water

The heating hot water is created via a steam to water heat exchanger served by the campus steam loop. After flowing through the heat exchanger, the water then flows through an air separator and expansion tank before reaching the distribution pumps. The heating hot water system is distributed using three (3) pumps controlled with variable frequency drives. The VFDs are regulated by the differential pressure measures taken from the system on the highest floor, and adjust as necessary. Temperature is controlled by temperature sensors on the hot water supply side of the heat exchanger to maintain a constant heating temperature of 190 F. The hot water is distributed from the pumps to the air-handlers on the fifth floor and the multiple reheat coils on each floor. After flowing through the coils it is returned to the heat exchangers in the basement for processing. ***Figure 3*** below shows a schematic of the system.

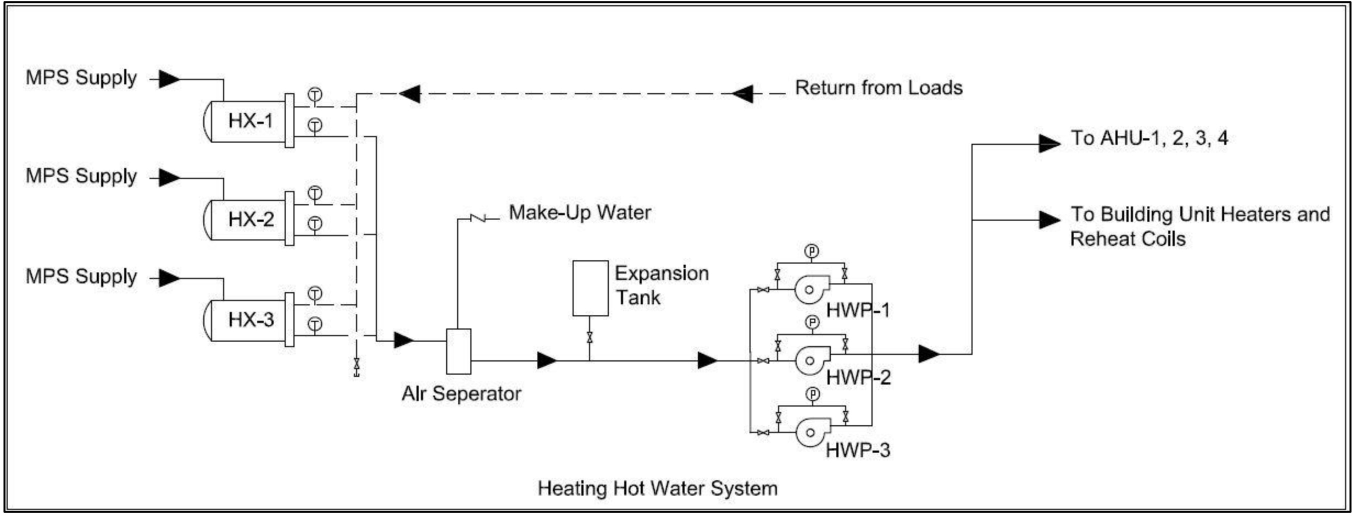


Figure 3: Heating Hot Water Flow Diagram

4.11 LEED Analysis

The South Patient Tower was evaluated under LEED-NC v2.2 system, with a goal of obtaining LEED Silver. The following is a summary of the points pertaining to the mechanical systems. These are the points that the designers strived to obtain while creating the South Patient Tower's mechanical systems. If they have been obtained at this point in the construction it has been noted. Other points were obtained or are pending for the project. For further information on the impact of the mechanical systems on the LEED score, refer to ***Appendix A.***

5.0 Existing Building Performance

5.1 Thermal Loads

The energy analyses presented in this report are results of running the building model in Trane TRACE 700 software. In order to better analysis the building as a whole, a number of assumptions were made for the various room types. Most of the occupancy and airflow data was pulled directly from the original basis of design, while lighting was pulled from ASHRAE Fundamentals 2009 and miscellaneous loads were estimated from prior hospital design experience.

Templates were created for each of the various space types. Internal load assumptions were taken from the basis of design and typical lighting levels noted in ASHRAE Standard 90.1-2007 were used for the space. Miscellaneous loads were estimated from types of equipment that would be in the space for template purposes. The actual miscellaneous loads assumed in the designers hand calculation were then entered to the respective rooms for a more extensive study. A summary of the lighting and miscellaneous loads used in the templates can be seen in ***Table 11***, while the typical occupancy for a space can be seen in ***Table 12***.

Table 11: Assumed Lighting and Miscellaneous Loads

Template Name	LPD (W/SF)	Misc. (W/SF)
Active Storage	0.9	0
Corridor	1.0	0
Lobby	1.3	0
Electrical/Mechanical	1.5	1.5
Inactive Storage	0.3	0
Hospital Lounge	0.8	0.5
Office	1.1	0.5
Restroom	0.9	0
Kitchen	1.2	5.0
Café	2.1	1.0
Locker Room	0.6	0
Patient Room	0.7	2.0
Nurses' Station	1.0	0.5
Conference Room	1.3	1.0
Exam/Treatment	1.5	3.0

5.1.1 Airflows

Assumptions for airflows to the various spaces were determined from the designer's original basis of design and typical ASHRAE Standard 170 air change rates for hospital spaces. The infiltration was selected as a pressurized, average construction of 0.3 air changes per hour for patient and exam rooms, and a neutral, average construction of 0.6 air changes per hour for all other spaces. A summary of the typical values used can be seen in ***Table 12*** below. For detailed information on individual airflow templates, refer to *Technical Report 2: Appendix B*.

Table 12: Basis of Design Values by Space Type

Minimum Ventilation Rates			
Program Occupancy	Design Values		Default Values
	Outdoor Air Rate CFM/person	Space Outdoor Air Rate CFM/SF	Occupancy Density No./1000 SF
Patient Rooms	25	0.25	10
Conference/Meeting	5	0.06	50
Corridors	-	0.06	-
Storage Rooms	-	0.12	-
Reception Areas	5	0.06	30
Main Entry Lobbies	5	0.06	10

5.1.2 Thermostat

The values for the thermostat templates were taken from the designer's basis of design documentation and do not vary throughout the hospital. The thermostats are located in the room and the drift points were not specified, rather assumed for this template. **Table 13** below summarizes the set points for heating and cooling for the South Patient Tower.

Table 13: Summary of Thermostat Settings

South Patient Tower Temperature Set Points	
Cooling Dry Bulb	72 F
Heating Dry Bulb	72 F
Relative Humidity	50 %
Cooling Drift Point	81 F
Heating Drift Point	64 F

5.1.3 Construction

The construction information for this template was taken directly from design documents for the South Patient Tower. ***Table 14*** below summarizes the U-values for the various elements of construction. The windows and curtain walls were assumed to be the same, as they were specified by the designer to be very close in U-value and shading coefficients. Also seen below, ***Table 15*** shows the wall heights for the South Patient Tower. It consists of eleven and a half (11.5) foot floor-to-floor height with a three (3) foot plenum, giving a typical ceiling height throughout of eight and a half (8.5) feet.

Table 14: Construction U-values

South Patient Tower Construction Values		
Element	**Construction**	**U-Value (BTU/hr-ft^2-F)**
Slab	8" HW Concrete	0.49
Roof	6" LW Concrete, 6" Ins.	0.024
Wall	Steel Framed Wall, 3" Ins.	0.043
Window	Low-e Double Pane (SC = 0.36)	0.29

Table 15: Wall Height

Wall Heights	
Walls	11.5 ft
Floor-to-Floor	8.5 ft
Plenum	3 ft

5.1.4 Model Zone Breakdown

In order to accurately model the effects of the solar path and exterior conditions on the building loads, zones were created with a typical pattern on every floor. The building is oriented directly with the cardinal directions, and the zone names follow the direction for naming purposes. All the exterior rooms on the upper floors were patient rooms while on the lower floors; these exterior spaces were primarily entrance lobby and shell space for the future addition to the East. The zones were also grouped in a way that similar space types were accounted for in that zone, examples being the patient rooms being grouped together. Special zones were created for the rooms on the Southwest and Southeast corners since they have windows on two exterior walls and would see a different gain. For basic zoning breakdowns see ***Figure 4*** below.

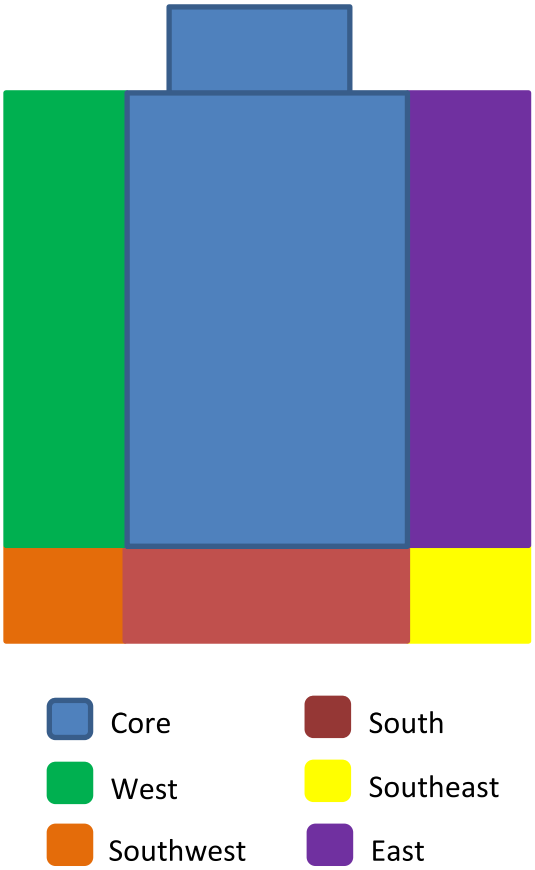


Figure 4: Breakdown of Typical Zoning per Floor

5.1.5 Systems

The systems in the South Patient Tower consist of multiple air handlers ducted together to create one (1) supply system for the hospital as a whole. A separate air-handler supplies the kitchen and food preparation area. Information for both of these systems was taken from design documents and created in TRACE. The zones were then placed under the appropriate system for the analysis.

5.1.6 Load Model Results and Comparisons

The designers did not perform a software based load analysis for this building. All loads were calculated by hand without the use of a program using guidelines suggested in ASHRAE Load Calculation methods. The following presents a comparison of the designers hand calculation and TRACE model results.

5.1.6.1 Supply Air and Ventilation Comparison

The ventilation rate provided in the documentation was 184,553 cubic feet per minute with 40% outdoor air and a CFM/SF value of 0.95. The TRACE model results in a lower total supply and ventilation rate, with a lower percentage of outdoor air. Due to the weather data being the same as what the designer specified in their basis of design, and ventilation being from this documentation also, this can be attributed to inaccurate internal load assumptions in the miscellaneous loads. ***Table 16*** below shows a comparison of the design air-handler and the results of the TRACE model analysis.

Table 16: System Ventilation Comparison

	Design Values	TRACE Values	% Difference
Area (SF)	195,163	193,145	-1 %
Total Supply (CFM)	184,553	159,222	-14 %
Outdoor Air (CFM)	73,741	57,320	-22 %
% Outdoor Air	40 %	36 %	10 %
CFM/SF	0.95	0.82	-14 %

5.1.6.2 Cooling Plant Comparison

Since there was no designer record of plant loads for this building, the results from the TRACE model have been compared to typical cooling load values from the ASHRAE Pocket Guide-2005 Cooling Load Check Figures table. Since the South Patient Tower is primarily patient rooms, the value for a Hospital Patient Room was used from this table. The range in the ASHRAE Pocket Guide-2005 is 275 SF/ton for the lowest to 165 SF/tons for the highest. ***Table 17*** below shows the comparison between the model results and the typical values for this type of building.

Table 17: Cooling SF/ton Comparison

	ASHRAE Typical (Lo)	TRACE Value	% Difference
SF/ton	275	262.6	4.5 %

The value is slightly higher than the lowest suggested value in the ASHRAE Pocket Guide-2005 but this can be partly attributed to inaccuracies in the miscellaneous loads on the spaces since the lighting and occupancy were taken directly from design documentation.

5.2 Energy Consumption Summary

After developing a Trane TRACE model to calculate the various loads on the South Patient Tower, the software was used to determine the buildings total energy consumption. The following section will breakdown the energy usage and associated costs that were determined through the analysis. Although the building is connected to a campus loop, the portion used from that plant was modeled for use in this consumption summary.

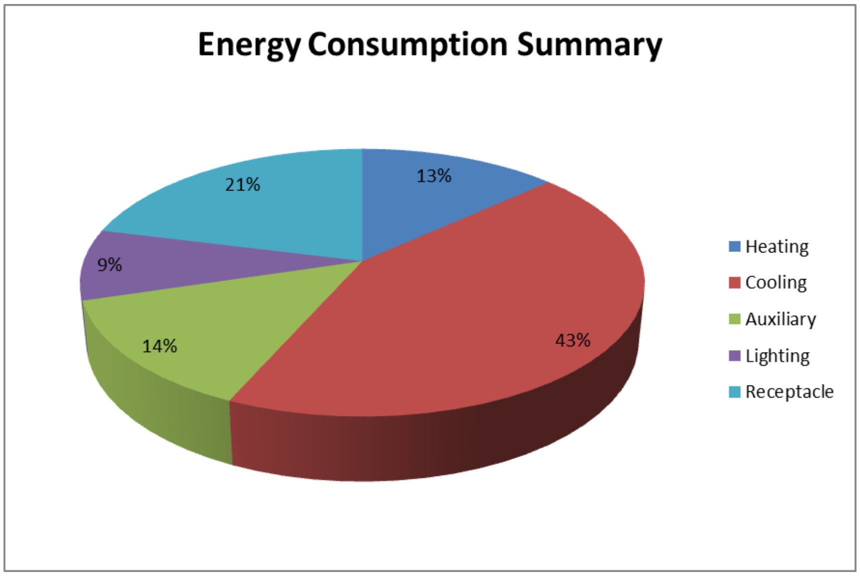


Figure 5: Energy Consumption Summary

As shown previously, ***Figure 5*** breaks down the various consumers of energy in the South Patient Tower. It can be seen that cooling dominates the energy consumption as there are many loads within the hospital that are operating continuously and create heat load. Lighting also seems higher than expected but since the building is under continuous operation, this percentage seems creditable. ***Table 18*** shows the Cost/SF of the equipment and includes the water consumption, while ***Figure 6*** shows the monthly utility costs from the analysis. The total Cost/SF for the building seems lower than it should be indicating the inaccurate miscellaneous equipment levels that were previously assumed.

Table 18: Equipment Cost Summary (Includes Water Consumption)

	Energy Usage (kBTU/yr)	Cost ($/yr)	Cost/SF ($/SF)
Heating	5,511,100	$ 62,827	$ 0.31
Cooling	18,051,030	$ 252,714	$ 1.25
Lighting	3,561,155	$ 83,497	$ 0.41
Supply Fans	4,341,903	$ 101,803	$ 0.50
Misc. Loads	10,116,199	$ 237,191	$ 1.17
Totals	**41,581,387**	**$ 738,032**	**$ 3.65**

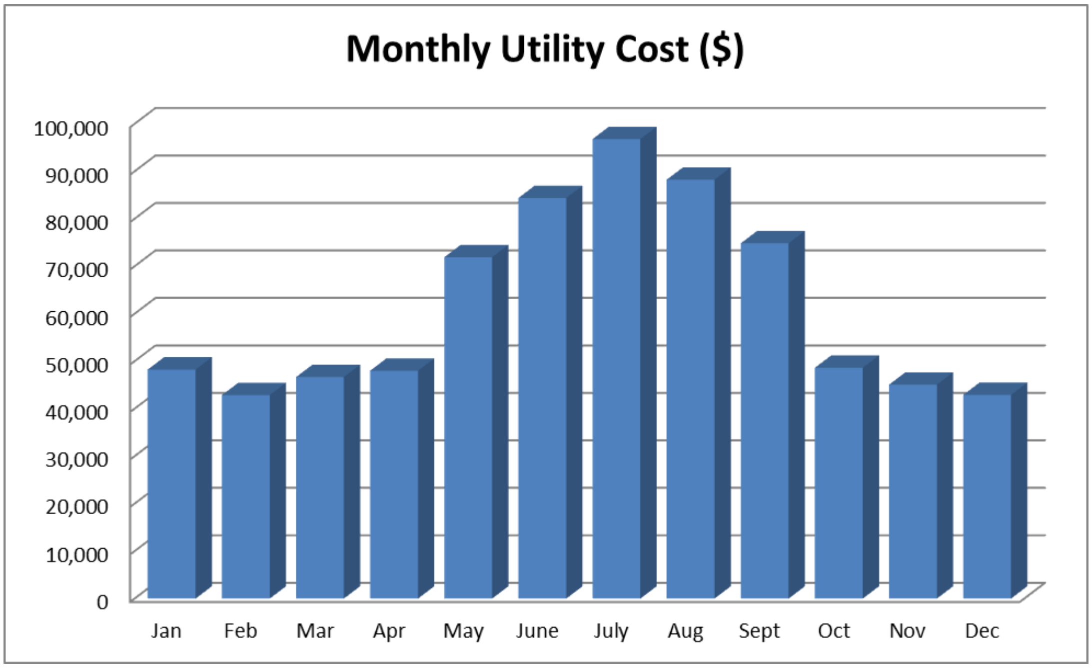


Figure 6: Monthly Utility Costs

An energy analysis was not performed by the designers of the South Patient Tower, thus this data could not be obtained. Energy modeling adds costs to a project and an overall model is expected to be completed when the addition Women's Clinic is added as part of the next phase of construction for LEED purposes. Also the owner was not willing to release utility data. Due to this there is no way to compare the monthly costs to the TRACE results, and the default utility rates were used.

5.3 Emissions

The emissions for the South Patient Data were determined from the Regional Grid Emission Factors using the state of Virginia as reference for values. ***Table 19*** that follows shows the amount of total pollutants using the reference values of pound of pollutant per kWh of electricity. Although there is no on-site combustion in the building itself, the portion of the heating load from the central plant boilers was accounted for in this emissions report.

Table 19: Emission Factors for Virginia

	Electricity	Pre/On-Site Combution (Natural Gas)	
Pollutant	lb/yr	Lb/yr	Total
CO_2	11,154,799	1,363,487	**12,518,286**
CH_4	24,418	7,210	**31,628**
N_2O	263	28	**291**
NO_x	20,405	1,300	**21,705**
SO_x	58,291	12,457	**70,748**
CO	5,809	1,091	**6,900**
TNMOC	494	63	**557**
Lead	1	0	**1**
Mercury	0	0	**0**
PM10	630	94	**724**
Solid Waste	1,394,350	16,329	**1,410,679**

6.0 Proposed Redesign Overview

6.1 Introduction

As previously determined the South Patient Tower currently is made up of a constant volume air system and supplied from a district cooling and steam plant for cooling and heating needs. The following includes alternative designs to limit or eliminate the use of the district utilities of steam and chilled water.

6.2 Chilled Water Plant Design

The district chilled water and steam plant of the INOVA Fairfax Hospital is reaching its design capacity with the addition of the South Patient Tower. To help solve this issue, a centralized cooling plant is being proposed to serve only the South Patient Tower loads. An investigation will be made into the design of a plant which will include; the type of chiller (absorption vs. electric compressor) and the pumping arrangement (primary-secondary vs. variable primary flow). This investigation will be done using an economic analysis along with showing energy usage and emission differences between the system designs, ultimately using these factors to determine the best option for further study.

The existence of high pressure steam supply to the building, the use of absorption chillers may prove to be the more efficient option limiting the use of electricity by the device. However, the cost of the steam generation may prove to be higher than that of purchasing electricity and the electric compression chiller may be the best choice.

Once the most optimal system arrangement is selected, a further investigation into energy savings will be investigated. This will serve as both a technical study and an education study into chilled water plant design.

6.3 Heat Recovery Chiller

The first proposed investigation into additional energy saving techniques includes the implementation of a heat recovery chiller for the South Patient Tower plant. The heat recovery chiller will help supplement the creation of hot water from the steam to hot water heat exchangers, thus limiting the amount of steam required for heating. Heat recovery chillers can produce 170 F water, which is sufficient to supply the buildings heating hot water needs. By adding the heat recovery chilled and limiting the need for steam from the district plant, cost savings are expected to overcome the additional first costs associated with the device.

6.4 Condensate Recovery

In an effort to conserve the usage of water by the cooling towers associated with the new chilled water plant design, a condensate recovery system is being proposed. Condensate from the cooling coils will be collected and pumped back to help feed the cooling tower make-up water. Cooling towers use make-up water during operation due to losses from evaporation and drift. If the condensate can help make up just a small portion if not more of the make-up water significant water consumption savings can be seen. The cost of this system is relatively low and is expected to pay back quickly with the water savings.

6.5 Breadth Topics

6.5.1 Structural

The South Patient Tower's mechanical space is placed on the fifth floor of the building to help conserve space on the roof for a helipad. To help conserve this necessary roof space, it is being proposed to place the new chilled water plant in this mechanical space on the fifth floor. This will create various new structural loads that need to be adjusted. An investigation into the structural concrete redesign is being proposed to mesh with the newly placed chilled water plant by recalculating the loads on the structural members.

6.5.2 Electrical

With the increased large equipment being added with the new chilled water plant redesign, the electrical load will be affected. To investigate the changes, a study will be done into the feeder sizes of the electrical system and resizing will occur for the new loads. The feeders will be resized from the fifth floor back to the building's main switchgear and a sizing calculation will be done on all equipment that supplies this branch of the electrical system.

6.6 MAE Course Relation

A major portion of the system redesign will be related to the AE 557, Centralized Cooling Production and Distribution Systems subject matter. The course centers on the comparison between various cooling plant equipment and the primary/secondary pumping and variable primary flow arrangements, as well as discussing the benefits and downfalls of each system. AE 558, Central Heating Systems, shows the approach to determining life-cycle cost which will be useful in comparing alternatives in this report.

7.0 Mechanical Depth Study

7.1 Purpose

The purpose of this Mechanical Depth study is to perform a chiller plant optimization study. As aforementioned, the INOVA South Patient Tower currently is supplied from a remote district style central plant. During previous studies on the building and system, it was determined that having a dedicated central chilled water plant could show energy savings, reduced emissions, and a lower life cycle cost when compared to the current design.

The primary goal of this study is to evaluate multiple design alternatives for the South Patient Tower in order to quantitatively prove which selection is more cost-effective, and by correlation energy efficient. Both first and operating costs will be calculated for use in a thirty (30) year life cycle cost analysis. The system type and arrangement selection will be chosen for further investigation involving other energy saving strategies such as heat-recovery and condensate recovery.

Along with a life cycle cost analysis, emissions will be estimated from typical rates for the Eastern Interconnect Grid. To validate the life cycle cost analysis, a sensitivity analysis was performed using a Monte Carlo statistical simulation with a normal and uniform distribution on costs, and escalation and discount rates. The base case system was modeled as purchased district chilled water and purchased district steam.

7.2 Depth 1: Chilled Water Plant Redesign

7.2.1 Scope of Work

The South Patient Tower at INOVA Fairfax has a dedicated mechanical floor (5th floor) that houses the air-handling units, domestic water heaters and other smaller mechanical equipment. This depth study will focus on placing a new chilled water plant in the open area on this mechanical floor. The area is shown below in ***Figure 7.*** This area of the mechanical floor will be further analyzed in a structural breadth study for verification of proper support. The size is adequate enough to place the necessary equipment involved in this plant.

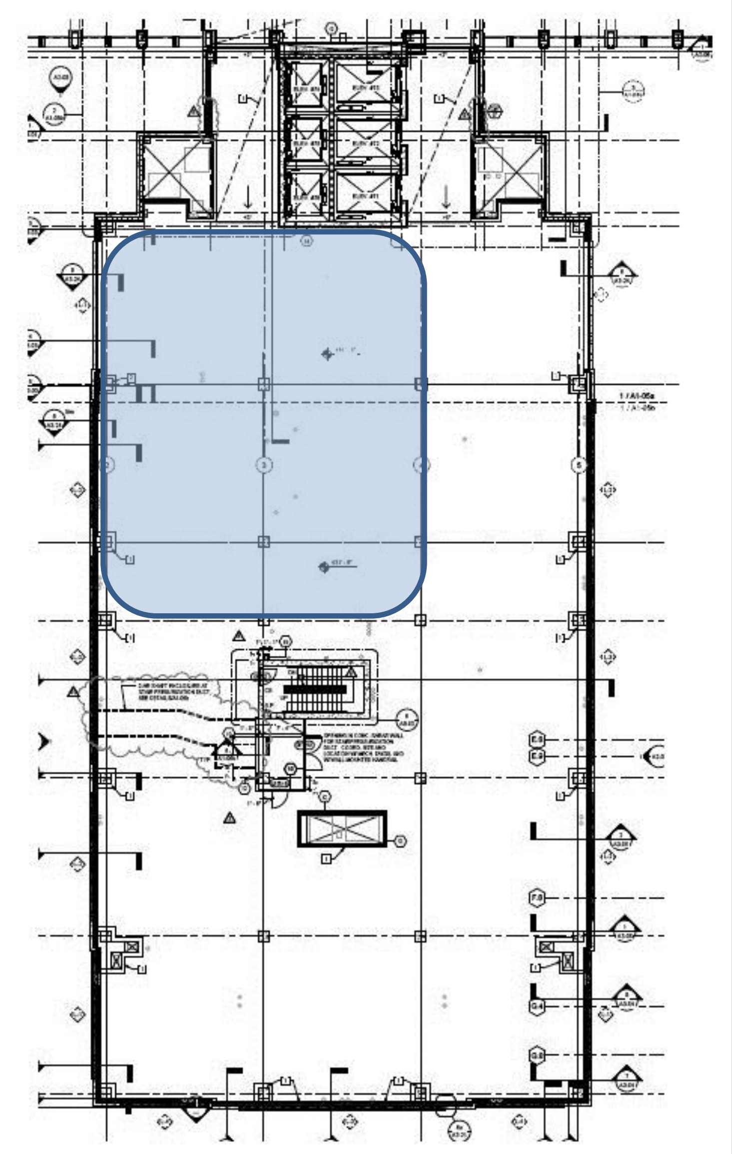


Figure 7: **Chilled Water Plant Location (5th Floor)**

7.2.2 Alternatives Considered

Alternative 1: Purchased Chilled Water and Purchased Steam (BASELINE)

The existing system in place for the South Patient Tower is supplied chilled water and steam from the INOVA Fairfax Hospital central utility plant. To accurately reflect the energy usage and costs of the current system, a Trane TRACE model was created with purchased utilities. The current system uses the district steam in heat exchangers to create the heating hot water and domestic hot water along with providing dehumidification at the air-handlers.

Alternative 1 was included in the analysis not only as a baseline but as a viable alternative for consideration since district plants tend to be very efficient ways to run buildings on a campus like INOVA Fairfax Hospital.

Alternative 2: Primary/Secondary with Centrifugal Chillers

For this alternative, the purchased chilled water was replaced with on-site electric chillers. The plant piping arrangement was chosen as the basic arrangement of primary/secondary. In a primary/secondary system the flow through the chillers remains constant while the flow delivered to the loads can vary as necessary. A bypass is included to maintain the necessary constant flow loop in the plant.

In order to accurately model this plant, pump selections were made for both the primary and secondary pumps as well as the condenser pumps. Full redundancy was achieved with an N+1 strategy on both the chillers and pumps. The chillers will operate on a rotation so they will each receive as equal loading as can be achieved. The pumps will operate similarly, with rotations to ensure equal loading and run-time. The N+1 pumps and chiller was not included in the modeling of the plant but were included in the cost calculations. ***Figure 8 and 9*** that follow show diagrams of the chilled water and condenser water sides of the plant. Flow rates are listed with 570 GPM being provided through each chiller and entering and leaving chilled water temperatures of 58 F and 42 F respectively. The condenser water arrangement is the same for both this alternative and alternative 3. It contains two (2) cooling towers and a flow rate of 1,140 GPM through each condenser with entering and leaving condenser water temperatures of 85 F and 94 F respectively. ***Table 20*** and ***Table 21*** below provide the schedule of chillers and pumps selected for the Primary/Secondary Centrifugal Chiller alternative.

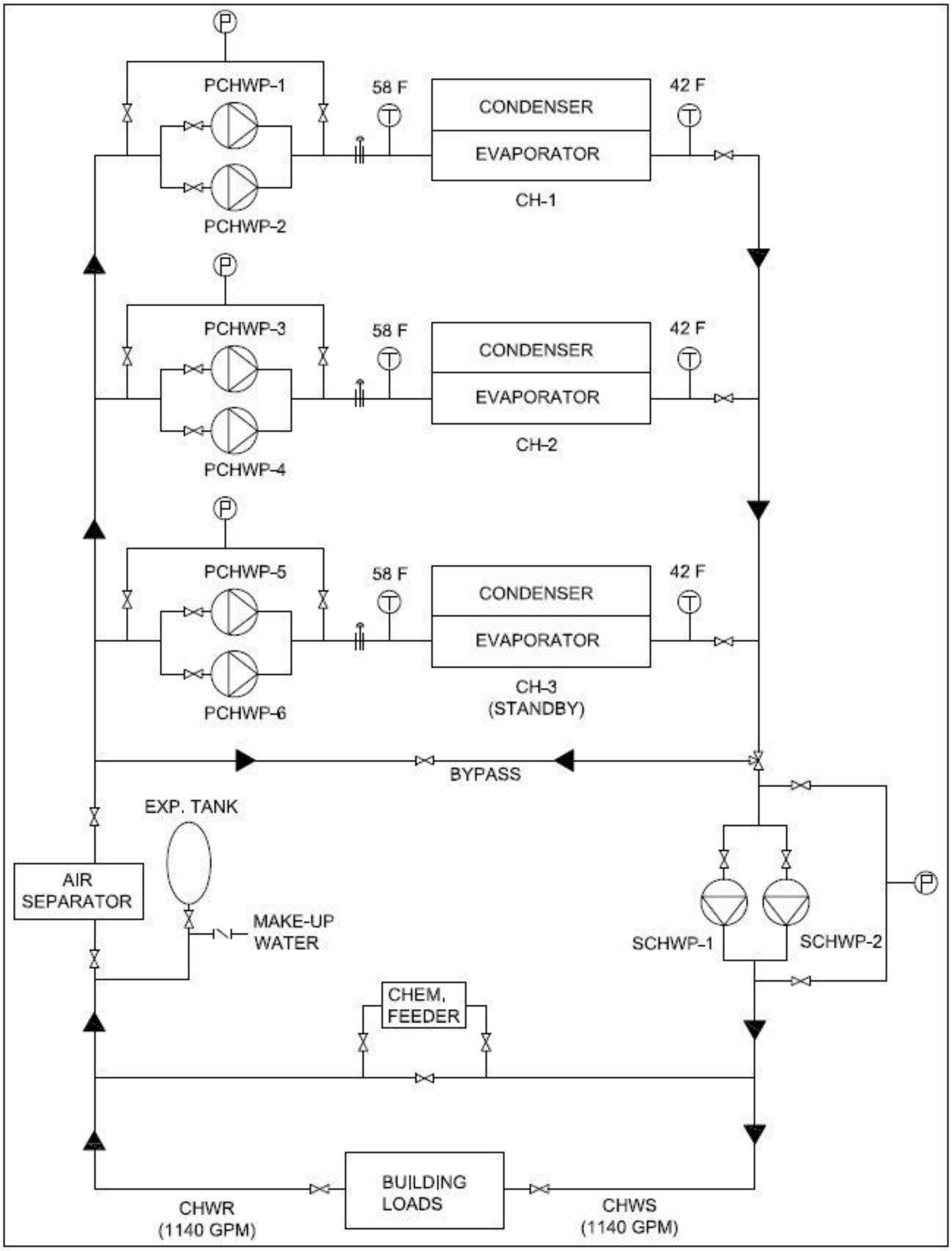


Figure 8: Primary/Secondary Chilled Water System (Centrifugal Chillers)

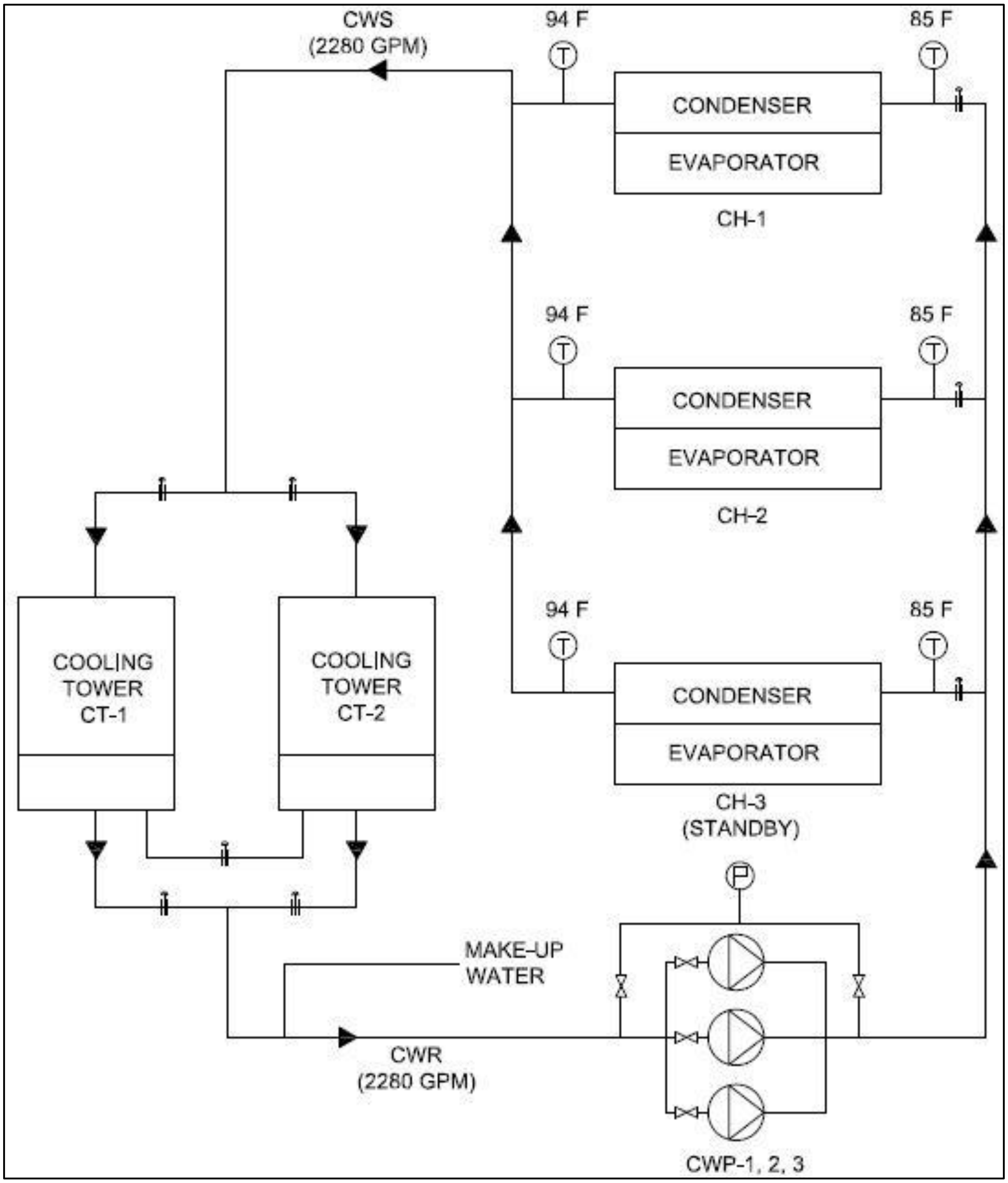


Figure 9: Condenser Water System (Centrifugal Chillers)

Table 20: Pumping Selections for Primary/Secondary

	Capacity (GPM)	Head (ft)	Efficiency (%)	RPM	HP
PCHWP-1	570	30	80	1150	7.5
PCHWP-2	570	30	80	1150	7.5
PCHWP-3	570	30	80	1150	7.5
PCHWP-4	570	30	80	1150	7.5
PCHWP-5	570	30	80	1150	7.5
PCHWP-6	570	30	80	1150	7.5
SCHWP-1	1140	40	82	1150	15
SCHWP-2	1140	40	82	1150	15
CWP-1	1140	40	82	1150	15
CWP-2	1140	40	82	1150	15
CWP-3	1140	40	82	1150	15

Table 21: Chiller Selections for Primary/Secondary and VPF (Centrifugal)

	Chiller Type	Capacity (tons)	EIR (kW/ton)	Evaporator				Condenser			
				Capacity (GPM)	EWT (F)	LWT (F)	Pressure Drop (ft)	Capacity (GPM)	EWT (F)	LWT (F)	Pressure Drop (ft)
CH-1	Centrifugal	380	0.579	570	58	42	10.1	1140	85	94	4.24
CH-2	Centrifugal	380	0.579	570	58	42	10.1	1140	85	94	4.24
CH-3	Centrifugal	380	0.579	570	58	42	10.1	1140	85	94	4.24

Alternative 3: Variable Primary Flow with Centrifugal Chillers

The purchased water was replaced with an on-site variable primary flow centrifugal chiller plant for this alternative. In a variable primary flow plant arrangement, the flow is variable through the chillers with no need for a secondary distribution pump. The bypass is also replaced with a low-flow bypass. Since the flow varies through the plant, variable speed pumps can be used in place of the constant speed.

The chiller selections for this alternative were kept the same as those in Alternative 2 and can be seen in ***Table 21*** above. The pumps were reselected for this alternative only on the chilled water side. They were given the N+1 arrangement as in the Primary/Secondary alternative. ***Figure 10*** below shows the layout of the chilled water system for the variable primary flow alternative. As previously stated the chilled water temperatures were made constant across all the alternatives as is seen. The condenser side does not change for this alternative and is the same as in alternative 2. ***Table 22*** as follows shows the selection of the variable primary pumps used in this analysis.

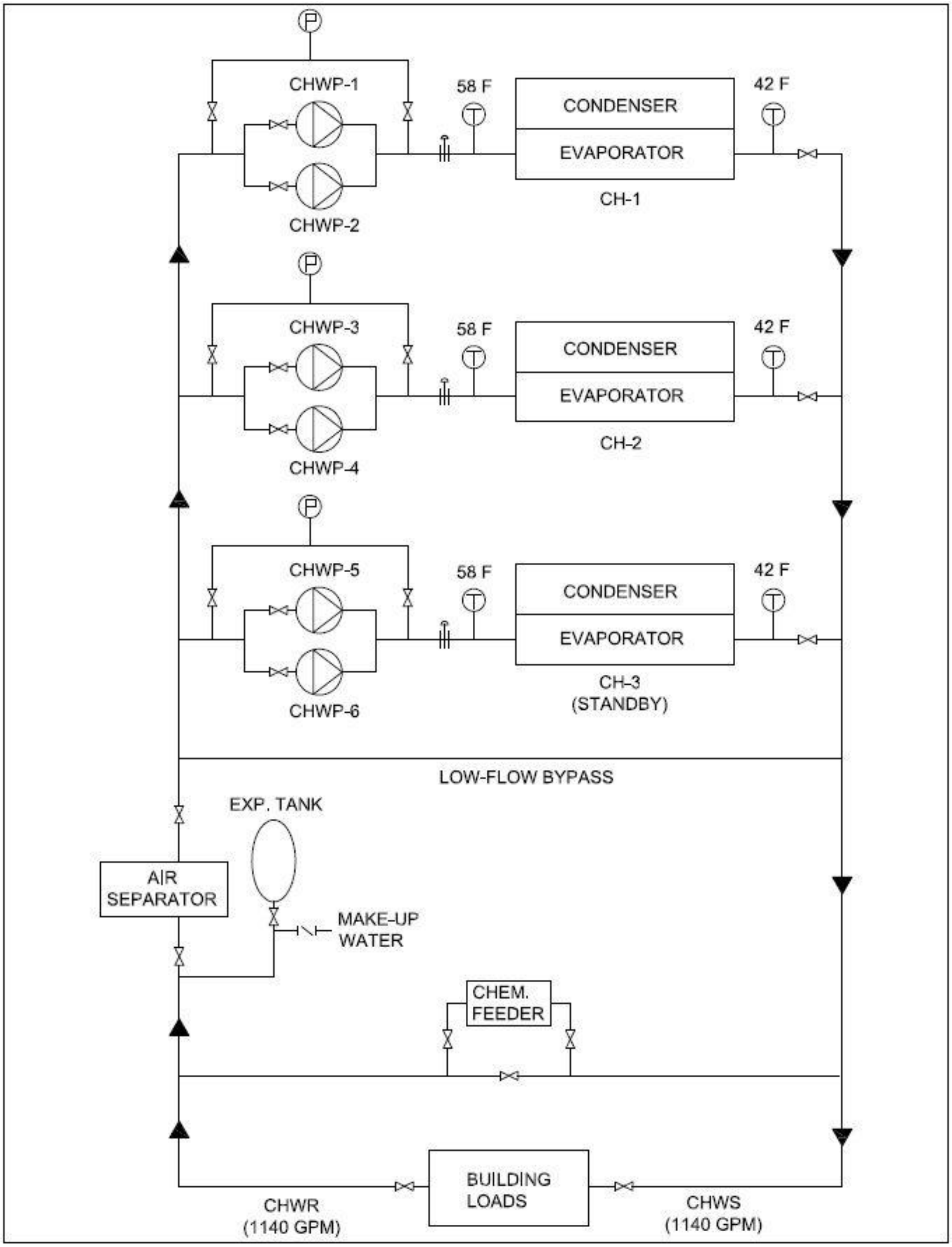


Figure 10: Variable Primary Flow Chilled Water System (Centrifugal Chiller)

Table 22: Variable Primary Flow Pump Selections

	Capacity (GPM)	Head (ft)	Efficiency (%)	RPM	HP
CHWP-1	570	70	81	1150	15
CHWP-2	570	70	81	1150	15
CHWP-3	570	70	81	1150	15
CHWP-4	570	70	81	1150	15
CHWP-5	570	70	81	1150	15
CHWP-6	570	70	81	1150	15

Alternative 4: Primary/Secondary with Absorption Chillers

For Alternative 4, the purchased chilled water of the baseline alternative was replaced with on-site absorption chilling. With district steam already being supplied to the building, the absorption chillers can use 150 psig steam to power their “thermal compressor” generator to provide the necessary cooling required by the South Patient Tower.

The primary and secondary pumps were modeled the same as in Alternative 2 due to no change in the necessary evaporator flow rates. The condenser pumps and cooling towers were modeled differently due to the increased flow rates of the condenser water necessary for absorption chilling. ***Figure 11*** and ***Figure 12*** show the layout of the primary/secondary chilled water and condenser water systems including the absorption chillers. The condenser side will be the same layout for this alternative and Alternative 5. Temperatures of the chilled water and condenser water remain the same as the previous alternatives. The chilled water flow rate remains the same as in previous alternatives with the condenser water flow rate increasing to 1,710 GPM through each condenser. ***Table 23*** shows the updated condenser water pump selections for both absorption chilling alternatives, while ***Table 24*** shows the chiller selection details. The primary and secondary pumps are the same as those in Alternative 2. The steam system changes slightly with the addition of absorption chillers. The redesigned steam schematic can be seen in ***Figure 13***.

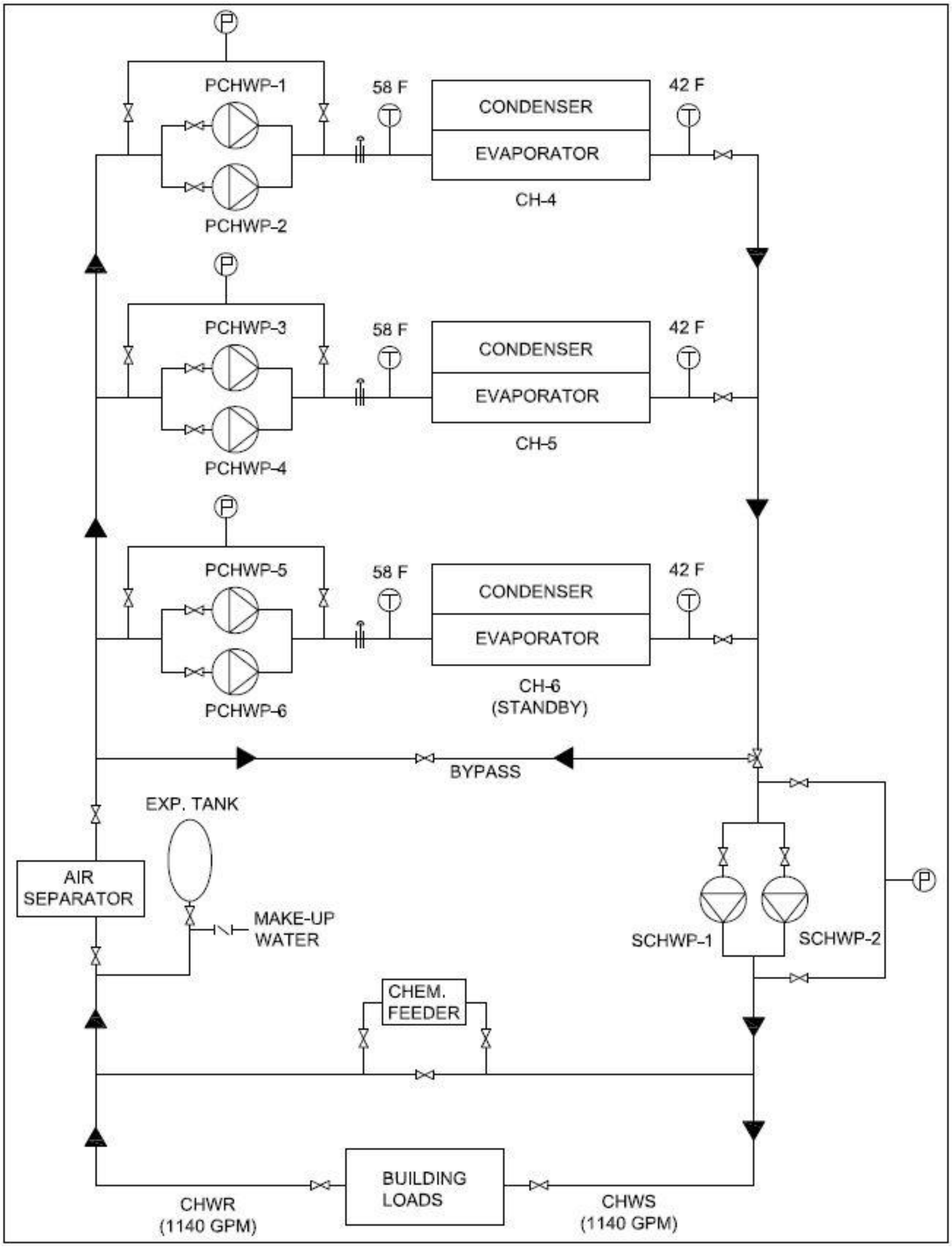


Figure 11: Primary/Secondary Chilled Water System (Absorption Chillers)

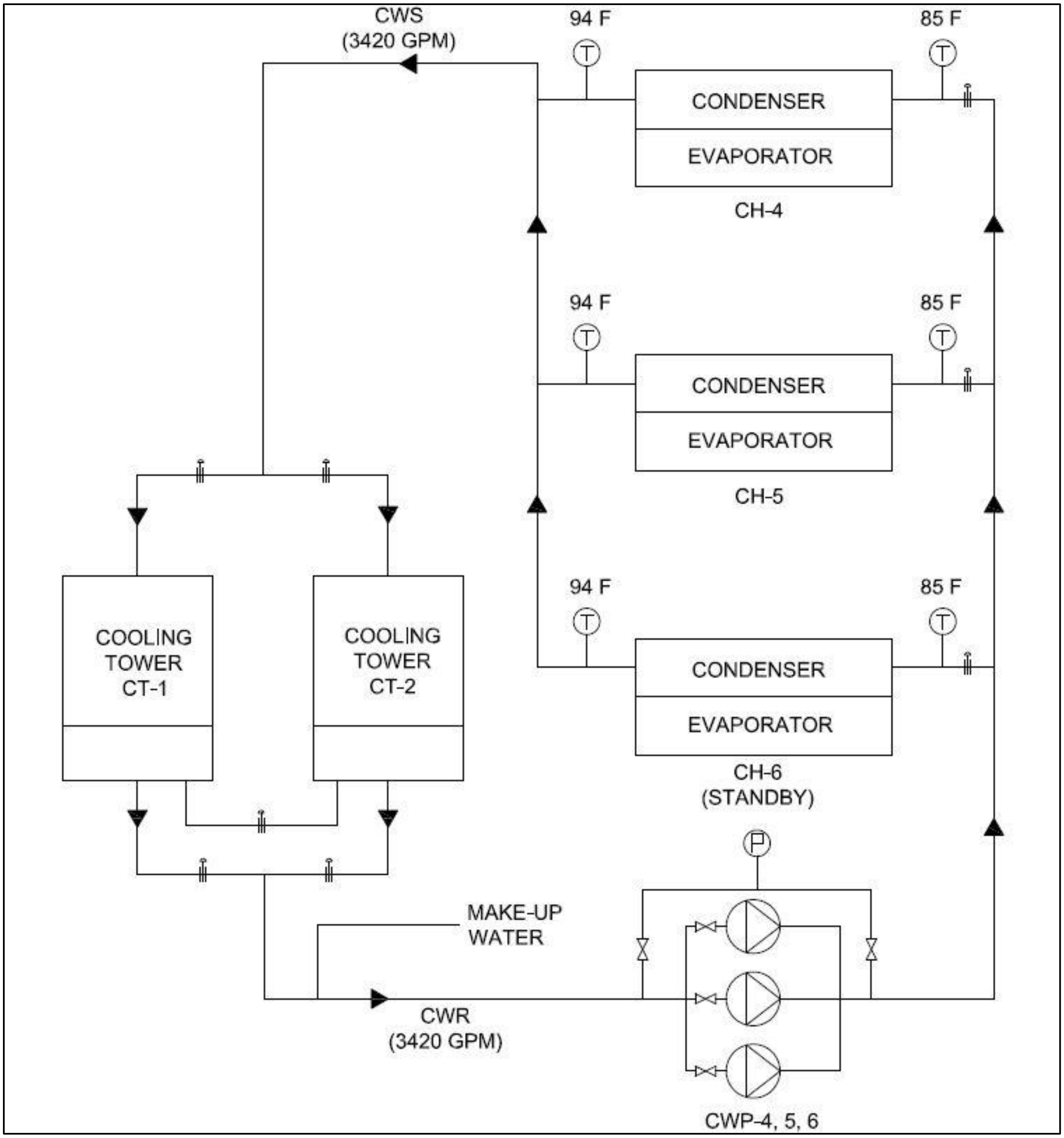


Figure 12: Condenser Water System for Primary/Secondary and VPF (Absorption Chillers)

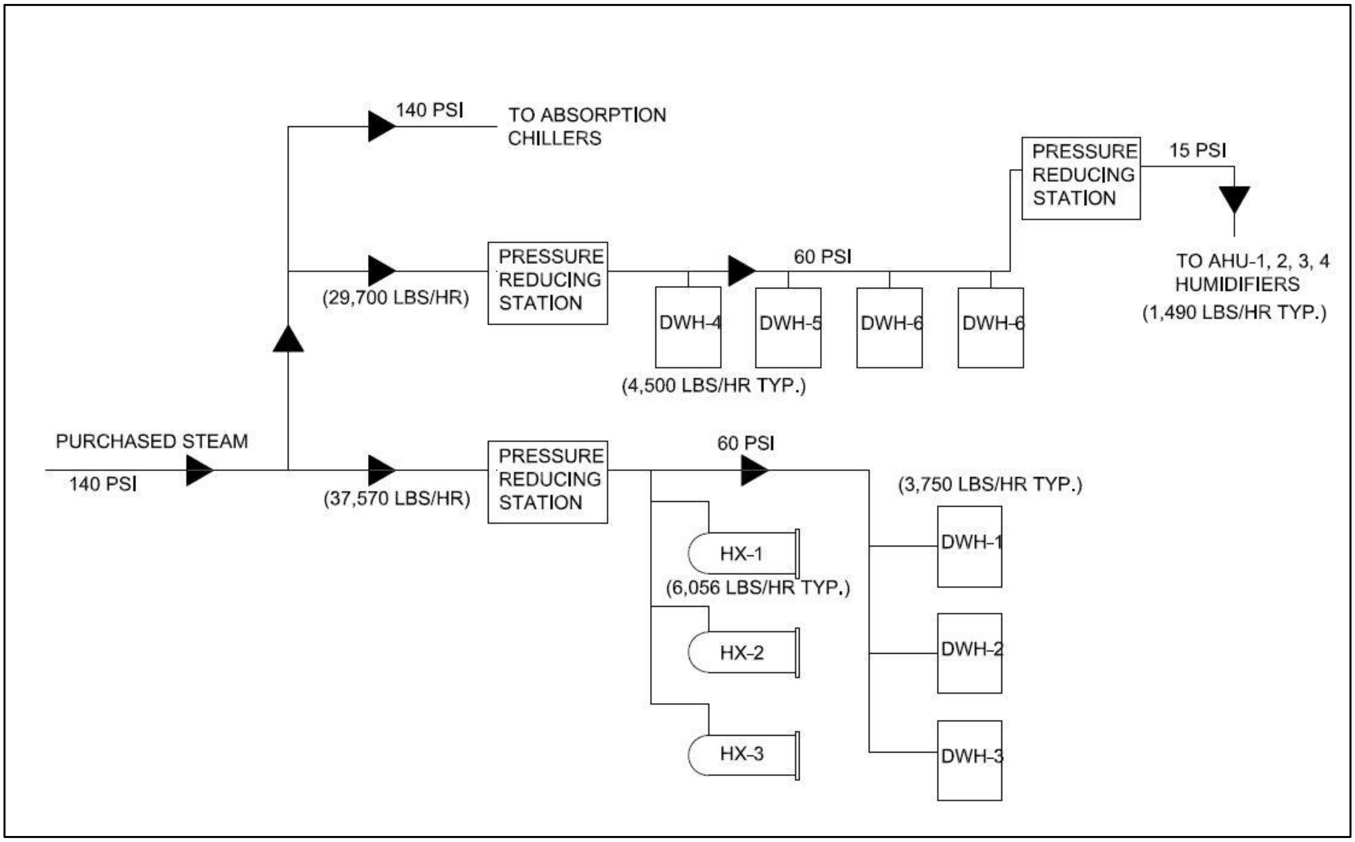


Figure 13: Steam System with Addition of Absorption Chillers

Table 23: Absorption Chillers Condenser Water Pump Selection

	Capacity (GPM)	Head (ft)	Efficiency (%)	RPM	HP
CWP-4	1710	50	80	1150	30
CWP-5	1710	50	80	1150	30
CWP-6	1710	50	80	1150	30

Table 24: Absorption Chiller Selection

	Chiller Type	Capacity (tons)	COP	Evaporator				Condenser			
				Capacity (GPM)	EWT (F)	LWT (F)	Pressure Drop (ft)	Capacity (GPM)	EWT (F)	LWT (F)	Pressure Drop (ft)
CH-4	Absorption	380	1.12	570	58	42	24.4	1710	85	94	17.7
CH-5	Absorption	380	1.12	570	58	42	24.4	1710	85	94	17.7
CH-6	Absorption	380	1.12	570	58	42	24.4	1710	85	94	17.7

Alternative 5: Variable Primary Flow with Absorption Chillers

For the final alternative studied, the purchased chilled water was replaced with a variable primary flow arrangement of absorption chillers. The purchased district steam is used as in Alternative 4 as the input power source for the generator in the "thermal compressor." The arrangement of the plant is identical to that of Alternative 3 with primary pumps that serve the whole system and no secondary arrangement.

Pump selections remained the same as Alternative 3 on the primary chilled water system. Condenser water pumps were selected as the same pumps represented in Alternative 4. The chiller selections are the same as in Alternative 4 since the pumping arrangement had little to no effect on the equipment chosen. ***Figure 14*** below shows the new variable primary flow plant arrangement when the absorption chillers are included. As stated in the previous alternatives, the chilled water entering and leaving temperatures remained constant through the analysis at 58 F and 42 F respectively. The condenser water temperatures also remained the same at 85 F and 94 F. The cooling towers are different from the centrifugal arrangements due to the increased condenser water flow that absorption chillers require and were modeled as such.

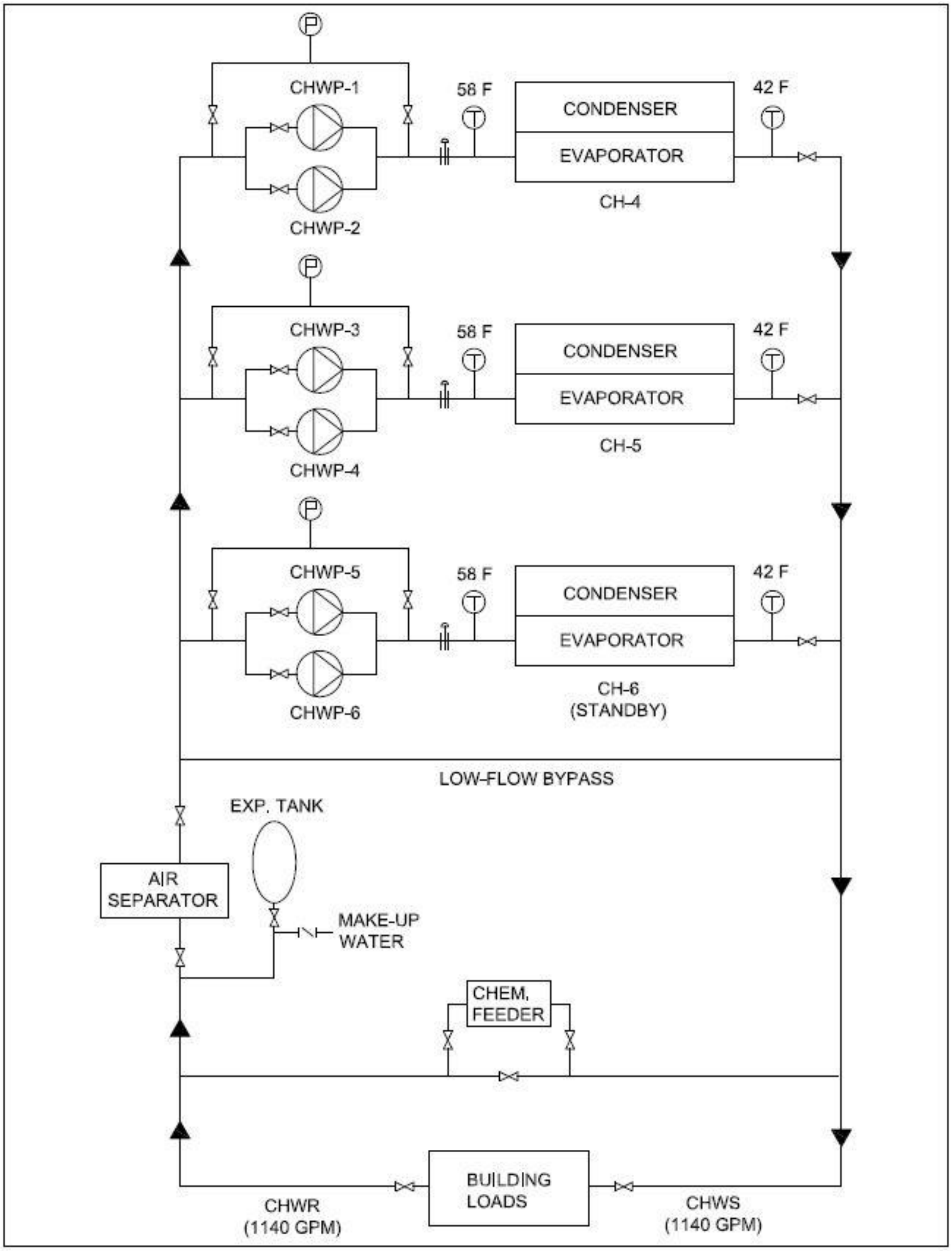


Figure 14: **Variable Primary Flow Chilled Water System (Absorption Chillers)**

7.2.3 Methods of Analysis

To accurately compare the life cycle costs of each alternative considered, the first costs and operating costs had to be determined for input into the calculations. The following sections will describe how those costs were determined and how the analysis was run for comparison of the alternatives.

First Costs

The first costs, or capital costs, of the systems had to be determined in order to do the initial comparison and for a life cycle cost analysis. For the alternatives considered in this report the capital costs include the following equipment: chillers, cooling towers, primary pumping/piping, secondary pumping/piping and condenser pumps/piping. The costs associated with all pieces of equipment were estimated using R.S. Means Mechanical Cost Data 2010 except for the chillers which were obtained from Trane. A summary of the costs used can be seen in ***Table 25*** below. Alternative 1 was considered to have no capital cost since it is purchased chilled water and steam and includes no equipment necessary for comparison with the other alternatives. A summary of the capital costs associated with each alternative can be seen in ***Table 26*** below.

Table 25: Unit Costs of Equipment

Equipment	Unit Cost
Pump (7.5 HP)	$ 4,070 / pump
Pump (15 HP)	$ 4,810 / pump
Pump (30 HP)	$ 8,440 / pump
Cooling Towers – Induced (Axial)	$ 38,220 / tower
Centrifugal Chillers	$ 350 / ton
Absorption Chillers	$ 550 / ton
Schedule 40 Piping (8”)	$ 203.15 / LF
Insulation	$ 25.33 / LF

Table 26: Mechanical Capital Cost Summary

	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
Chillers	$ 0	$ 399,000	$ 399,000	$ 627,000	$ 627,000
Cooling Towers	$ 0	$ 76,440	$ 76,440	$ 76,440	$ 76,440
Primary Pumping+Piping	$ 0	$ 74,686	$ 157,705	$ 74,686	$ 157,705
Secondary Pumping+Piping	$ 0	$ 113,578	$ 0	$ 113,578	$ 0
Condenser Pumping+Piping	$ 0	$ 143,750	$ 143,750	$ 154,640	$ 154,640
TOTAL	**$ 0**	**$ 807, 454**	**$ 773,894**	**$ 1,046,344**	**$ 1,012,784**

It can be seen that the lowest first cost is the existing system because the building owner would have to make zero investment. The next lowest first cost is the Variable Primary Flow with Centrifugal Chillers. In general the centrifugal arrangements cost less than that of the absorption by a significant margin.

Operating Costs

Operating costs consist of two main factors, the utility consumption and the cost for that utility. Since the owner was not willing to release their utility data, the costs had to be estimated in order to perform the alternative comparison presented in this report. For the purposes of this investigation, four utilities were compared. ***Table 27*** summarizes the costs associated with each utility. Electric costs were estimated from typical commercial rates in Northern Virginia at $0.08 / kWh. Steam costs were estimated from the 2003 CBECS report by investigating the total energy produced by steam district plants and the total cost of that steam. The chilled water cost was estimated from another hospital in the Northern Virginia area of approximately the same size. Finally the water rates were found from the Fairfax, VA Water Authority posted rates.

***Table 27:* Utility Cost Summary**

Utility	Cost/Unit
Electricity	$ 0.08 / kWh
Steam	$ 1.14 / therm
Chilled Water	$ 1.40 / therm
Water	$ 2.16 / 1000 gal

The only thing left to determine to get operating costs is the consumption of the various utilities. In order to predict the consumption, since the South Patient Tower is not yet built, a detailed Trane TRACE model was developed.

Energy Consumption

To accurately model the energy consumption of each of the alternatives, the TRACE model created for the load calculations of Technical Report 2 was modified with additional alternatives that referenced the building geometry and systems already in place in the building design. Each of the alternatives had their respective plants modeled with two (2) chillers, chilled water and condenser water pumps for those chillers, and the appropriate heat rejection equipment.

To determine what chillers to model, a manufacturer was contacted with the design conditions of the South Patient Tower. Submittals for the chillers selected can be found in ***Appendix B***. The pump head was determined by a basic pressure drop calculation for the primary, secondary and condenser water pumps. Once the head was determined and the flow rate was known from the chiller submittals, pumps were selected from Bell & Gossett's pump selection curves. The efficiency and HP was determined for input in the energy model.

The resulting energy consumption and make-up water required of each Alternative can be seen in ***Table 28*** and ***Figure 15*** below. For ease of comparison the electricity, steam, chilled water, and make-up water have been compared for each Alternative. The lowest electrical consumer was the baseline but it used more therms of chilled water. Taking this into account, the lowest overall energy consumer was Alternative 3 the Variable Primary Flow with Centrifugal Chillers.

Table 28: **Energy Consumption Comparison**

	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
Electricity (kWh)	5,286,290	6,488,933	6,470,107	5,830,308	5,775,767
Steam (therms)	55,111	55,111	55,111	193,917	193,917
Chilled Water (therms)	180,510	-	-	-	-
Make-Up Water (1000 gal.)	-	5,575	5,575	8,515	8,185

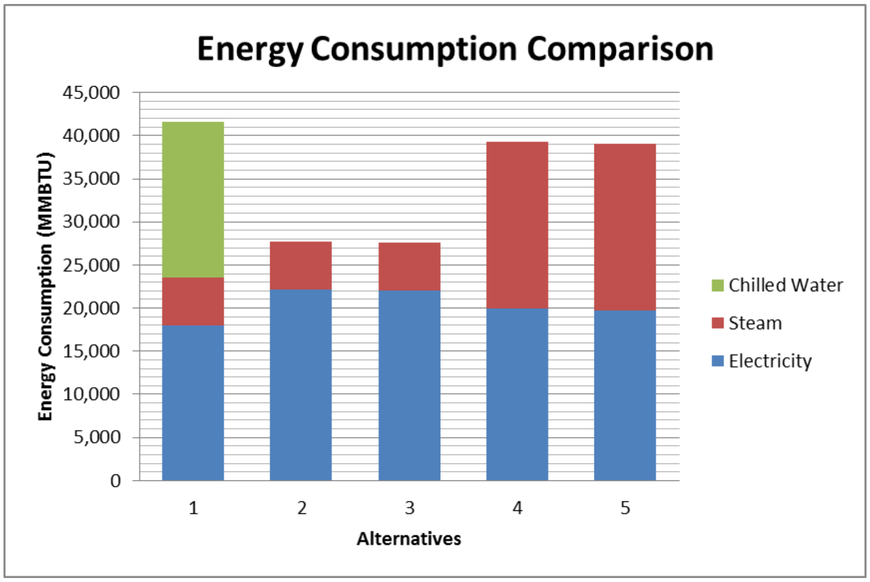


Figure 15: **Energy Consumption Comparison**

Life-Cycle Cost Analysis

After all of the alternatives were modeled with their respective plants in TRACE, the resulting energy consumption was combined with the estimated utility costs for use in a life-cycle cost analysis. To determine which option was the best choice economically for the South Patient Tower, the resulting life-cycle costs were compared and it was determined that the lowest cost would be the resulting choice. For the analysis the life-cycle was determined to be 30 years due to the longevity of hospital use. The method chosen used the escalation rates determined by the NIST Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2011. The escalation rates were determined from the OMB Charts for Commercial buildings in Virginia. To determine the Net-Present Value of the utilities the following equation was utilized:

$$PV = A * \frac{[(1+i)^n - 1]}{[i(1+i)^n]}$$

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

For these analyses the duration was taken as 30 years with a discount rate of 2.3 % as suggested in the NIST Supplement. An annual maintenance cost of $ 3,000 was assumed for all alternatives and was included in the analysis. ***Table 29*** is a summary of the alternatives life-cycle costs. It can be seen from the summary table that although the capital costs of Alternative 1 were the lowest it is the third lowest life-cycle cost. The lowest life-cycle cost was shown to be Alternative 3, which had the second lowest capital cost. It can also be seen that the absorption alternatives were the highest life-cycle costs. Detailed calculations of the life-cycle cost of each alternative can be found in ***Appendix C***.

Table 29: **Life-Cycle Cost Net-Present Value Summary**

	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
Capital Cost	$ 0	$ 807,454	$ 773,894	$ 1,046,344	$ 1,012,784
Maintenance	$ 64,499	$ 64,499	$ 64,499	$ 64,499	$ 64,499
Electricity	$ 9,160,401	$ 11,244,413	$ 11,211,790	$ 10,103,108	$ 10,008,596
Steam	$ 1,454,382	$ 1,454,382	$ 1,454,382	$ 5,117,480	$ 5,117,480
Chilled Water	$ 5,473,975	$ 0	$ 0	$ 0	$ 0
Make-Up Water	$ 0	$ 258,897	$ 258,897	$ 395,427	$ 380,103
Total NPV	**$ 16,153,257**	**$ 13,829,645**	**$ 13,763,462**	**$ 16,726,858**	**$ 16,583,462**
Ranking	3	2	1	5	4

After comparing the life-cycle costs of each of the alternatives, a simple payback for each was calculated using the first year energy cost savings and capital costs. ***Table 30*** provides a summary of the payback calculations for each of the alternatives. It can be seen that both centrifugal arrangements have a reasonable payback of around five (5) years while the absorption arrangements seen higher paybacks upwards of 32 years. The discounted payback provides a more realistic look at payback periods taking into account the discount rate and a non-uniform annual savings. The centrifugal arrangements remain reasonable while the absorption option paybacks become much higher. The analysis could not be done for more than 30 years but the payback was still not reached at that point.

Table 30: **Simple Payback Summary**

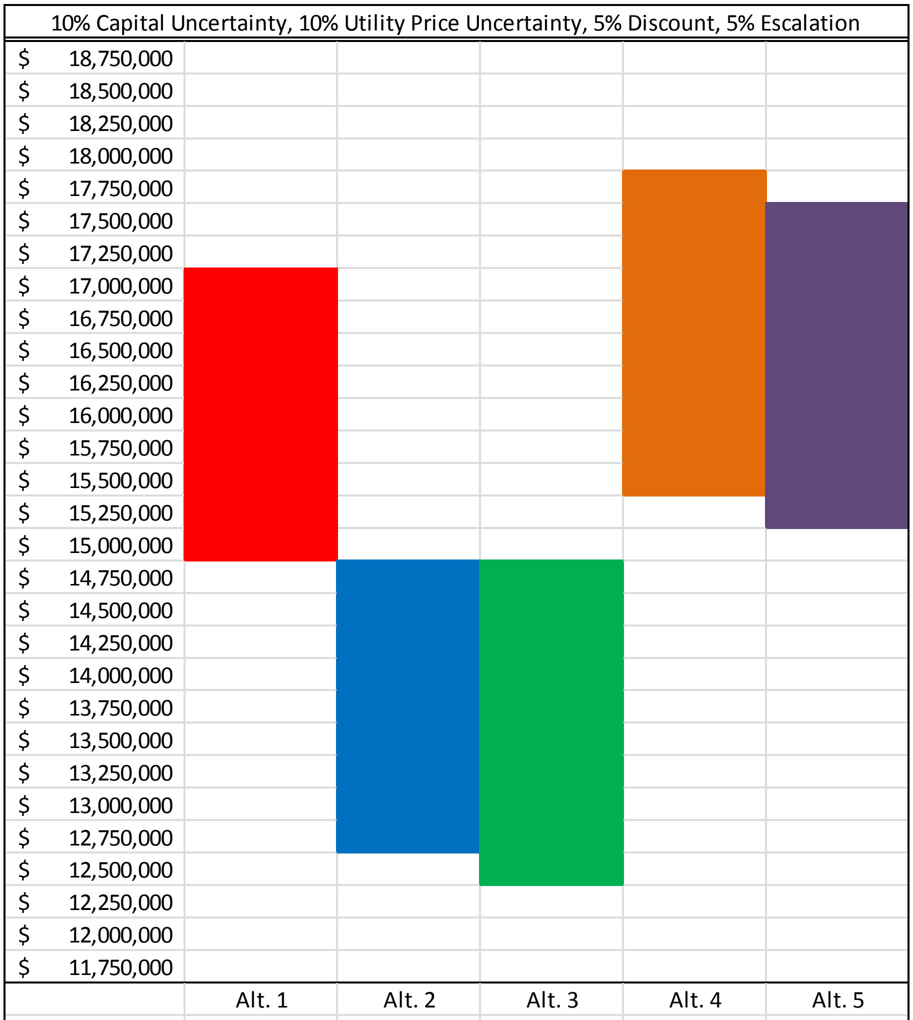
	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
Capital Cost	$ 0	$ 807,454	$ 773,894	$ 1,046,344	$ 1,012,784
Electricity	$ 422,903	$ 519,115	$ 517,609	$ 466,425	$ 462,061
Steam	$ 62,827	$ 62,827	$ 62,827	$ 221,065	$ 221,065
Chilled Water	$ 252,714	$ 0	$ 0	$ 0	$ 0
Make-Up Water	$ 0	$ 12,042	$ 12,042	$ 18,392	$ 17,680
Utility Sum	$ 738,444	$ 593,984	$ 592,478	$ 705,882	$ 700,806
Difference	$ 0	$ 144,460	$ 145,966	$ 32,562	$ 37,638
Simple Payback	**BASELINE**	**5.6 yrs.**	**5.3 yrs.**	**32.1 yrs.**	**26.9 yrs.**
Discounted Payback	**BASELINE**	**7.0 yrs.**	**6.0 yrs.**	**30+ yrs.**	**30+ yrs.**

Sensitivity Analysis

To validate the results of the life-cycle cost analysis with possible changes in utility costs, capital costs and the discount rate, a sensitivity analysis was performed using a Monte Carlo simulation. The study was performed with both a uniform distribution and a normal distribution on each variable. It was run twice for each distribution with varying standard deviations. ***Table 31*** below shows the standard deviation percentages used for each variable of interest in both simulations. Results were determined with a 90% confidence interval and plotted to catch any overlapping areas between alternatives. ***Figures 16-19*** show the results of each simulation of the analysis.

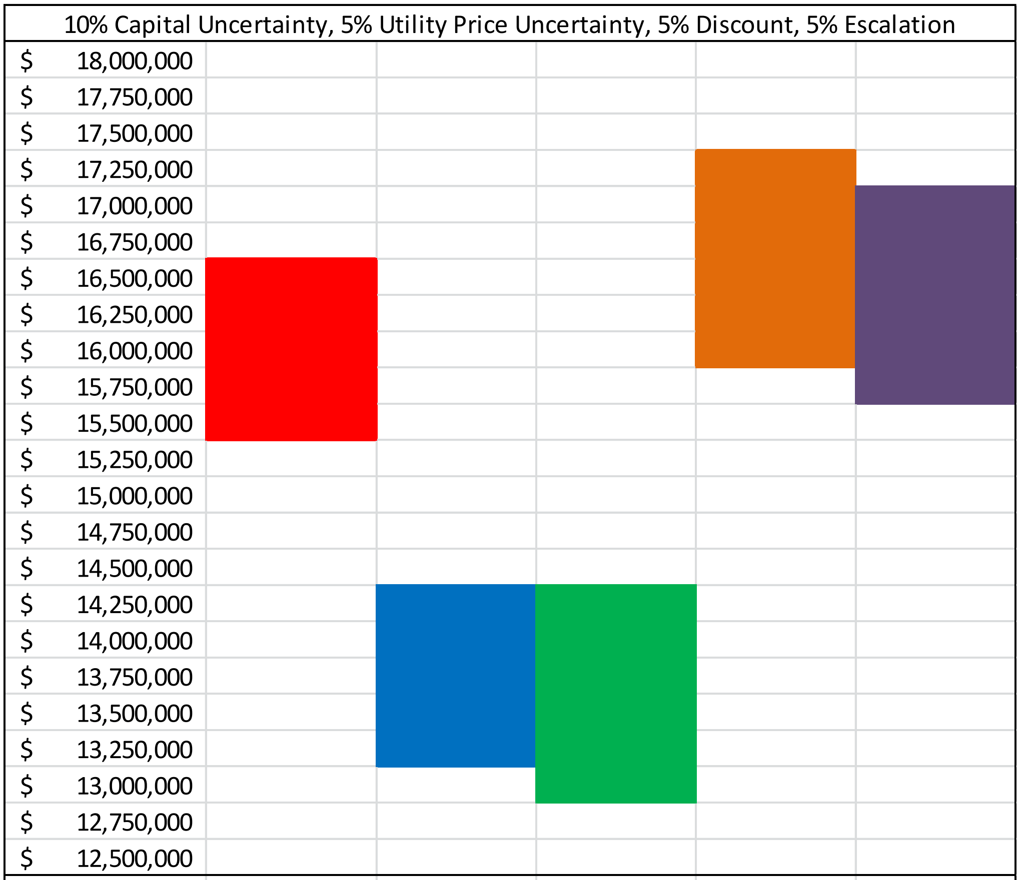
Table 31: **Assumed Standard Deviations (Normal and Uniform)**

	Simulation 1	Simulation 2
Capital Cost	10 %	10 %
Utility Prices	10 %	5 %
Discount Rate	5 %	5 %
Escalation Rates	5 %	5 %



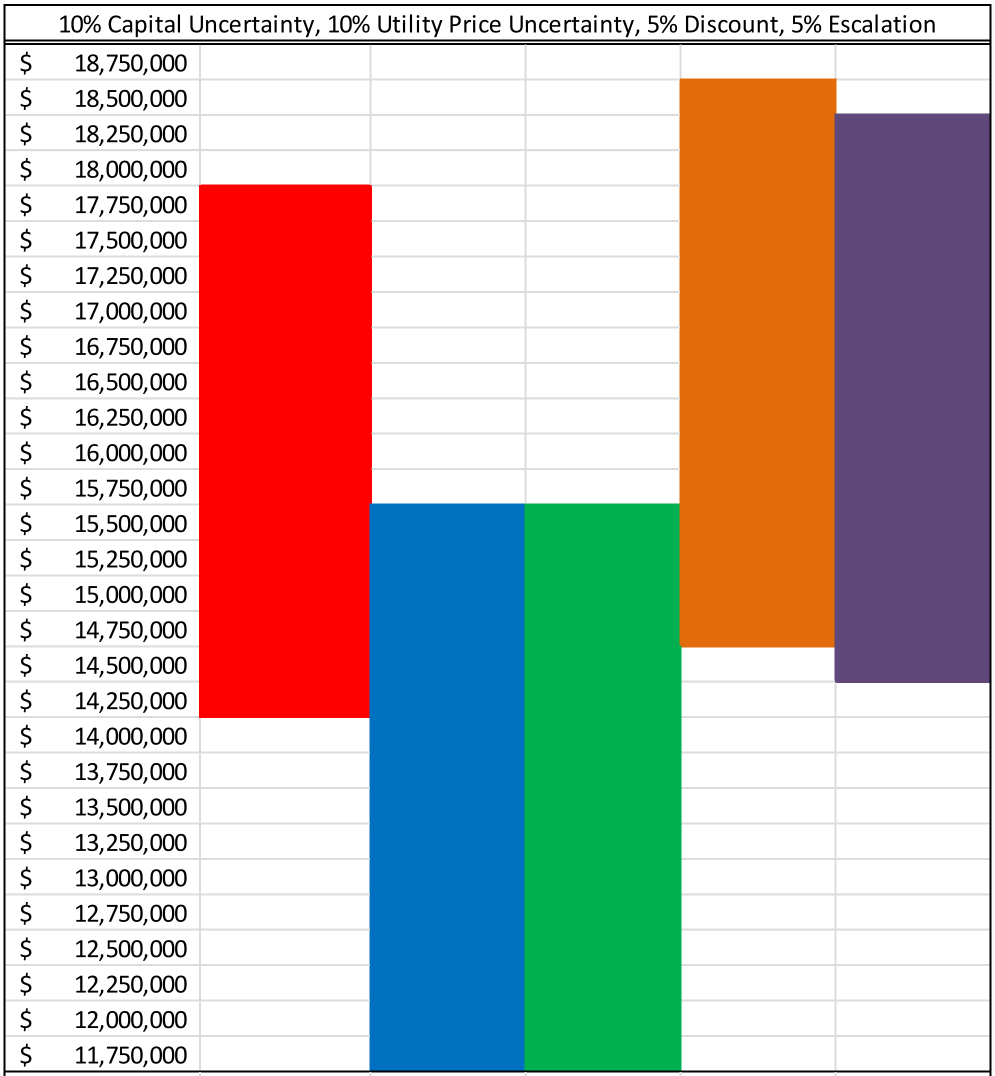
	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
Low	$ 15,103,000	$ 12,782,000	$ 12,728,000	$ 15,631,000	$ 15,495,000
Mean	$ 16,154,184	$ 13,830,493	$ 13,768,082	$ 16,727,778	$ 16,588,395
High	$ 17,201,000	$ 14,889,000	$ 14,813,000	$ 17,835,000	$ 17,679,000

***Figure 16:* Uniform Distribution Simulation 1 90% Confidence Intervals**



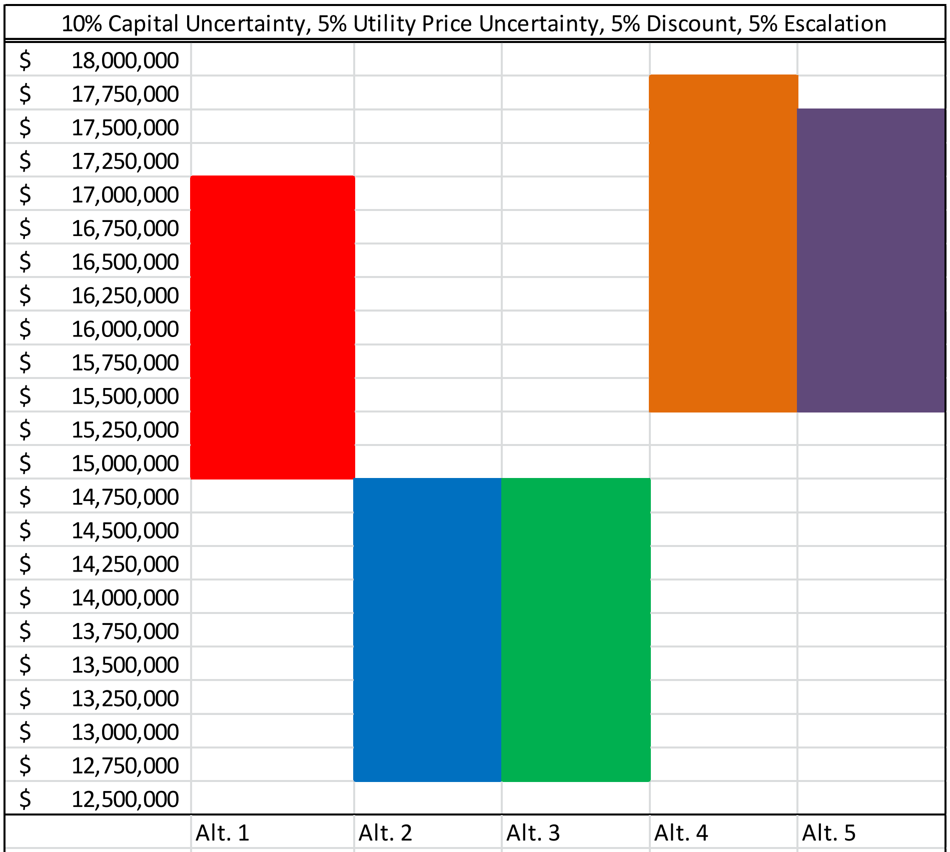
	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
Low	$ 15,585,000	$ 13,257,000	$ 13,203,000	$ 16,126,000	$ 15,991,000
Mean	$ 16,154,221	$ 13,830,404	$ 13,768,144	$ 16,727,804	$ 16,588,362
High	$ 16,735,000	$ 14,402,000	$ 14,331,000	$ 17,324,000	$ 17,174,000

Figure 17: **Uniform Distribution Simulation 2 90% Confidence Intervals**



	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
Low	$ 14,320,000	$ 11,940,000	$ 11,880,000	$ 14,790,000	$ 14,670,000
Mean	$ 16,156,153	$ 13,831,526	$ 13,769,701	$ 16,730,167	$ 16,589,993
High	$ 17,960,000	$ 15,730,000	$ 15,690,000	$ 18,690,000	$ 18,490,000

***Figure 18*: Normal Distribution Simulation 1 90% Confidence Intervals**



	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
Low	$ 15,156,000	$ 12,815,000	$ 12,752,000	$ 15,694,000	$ 15,559,000
Mean	$ 16,156,241	$ 13,832,125	$ 13,769,813	$ 16,729,821	$ 16,590,196
High	$ 17,186,000	$ 14,858,000	$ 14,777,000	$ 17,794,000	$ 17,640,000

Figure 19: **Normal Distribution Simulation 2 90% Confidence Intervals**

It can be seen with 90% confidence in all simulations that Alternative 2 and 3, the centrifugal chiller arrangements, are the best options to choose overall. When you look at the exact numbers Alternative 3 provides the lowest life-cycle cost interval.

Emissions

To estimate the reduction in emissions between the alternatives, the energy consumed was converted to primary energy consumed. The emission factors were found in the NREL publication “Source Energy and Emission Factors for Energy Use in Buildings.” This source uses the on-site kWh of electricity but the chilled water and steam consumption needed to be converted to electricity and natural gas respectively.

In order to estimate the electricity associated with the purchased chilled water and the natural gas associated with the purchased steam, the Federal Greenhouse Gas Accounting and Reporting Guidance Support Document from the G.S.A. was consulted. To determine the electricity needed for production of the necessary chilled water for the South Patient Tower, the total annual ton-hrs were found from the TRACE load calculations and converted to MMBTUs. After this was determined, a transmission loss factor of 1.11 was multiplied and the overall number was divided by a recommended COP of 4.2.

The steam was converted to MCF of natural gas by applying a boiler efficiency of 80%, a production efficiency of 75 %, and a transmission loss of the delivery of 10 %. All of these efficiencies and losses were suggested by the referenced G.S.A. document.

After all of the primary energy was determined, the emission factors were applied for electricity production in the Eastern Interconnect Grid, and for pre-combustion and on-site combustion emissions for natural gas. To determine total emissions all the utilities for each alternative were combined. ***Table 32*** below shows the summary of total emissions in pound of pollutant of each option. ***Figure 20 and 21*** provide visual representations of CO_{2e}, CO_2 and other major pollutants for each of the alternatives.

Table 32: **Total Emissions Summary**

Pollutant (lbs.)	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
CO_{2e}	13,373,996	12,829,769	12,797,012	15,560,048	15,465,146
CO_2	12,518,286	12,005,337	11,974,462	14,359,355	14,269,908
CH_4	31,628	30,506	30,438	46,302	46,106
N_2O	291	279	278	324	322
NO_x	21,705	20,767	20,711	22,066	21,902
SO_x	70,748	68,068	67,906	93,799	93,332
CO	6,900	6,633	6,616	8,818	8,771
TNMOC	557	534	533	645	641
Lead	1	1	1	1	1
Mercury	0	0	0	0	0
PM10	724	695	693	871	866
Solid Waste	1,410,679	1,346,560	1,342,701	1,252,670	1,241,489

It can be seen in comparing the CO_2 equivalents of each case that Alternative 3 has the lowest overall emissions when compared to the other alternatives. These emissions trend with the life-cycle costs and energy use results that the centrifugal options help reduce emissions from the existing design while the absorption chillers tend to create more emissions.

Although emissions are not the major determining factor in the central plant redesign, it was important to see how the design alternatives would affect the emissions associated with the South Patient Tower.

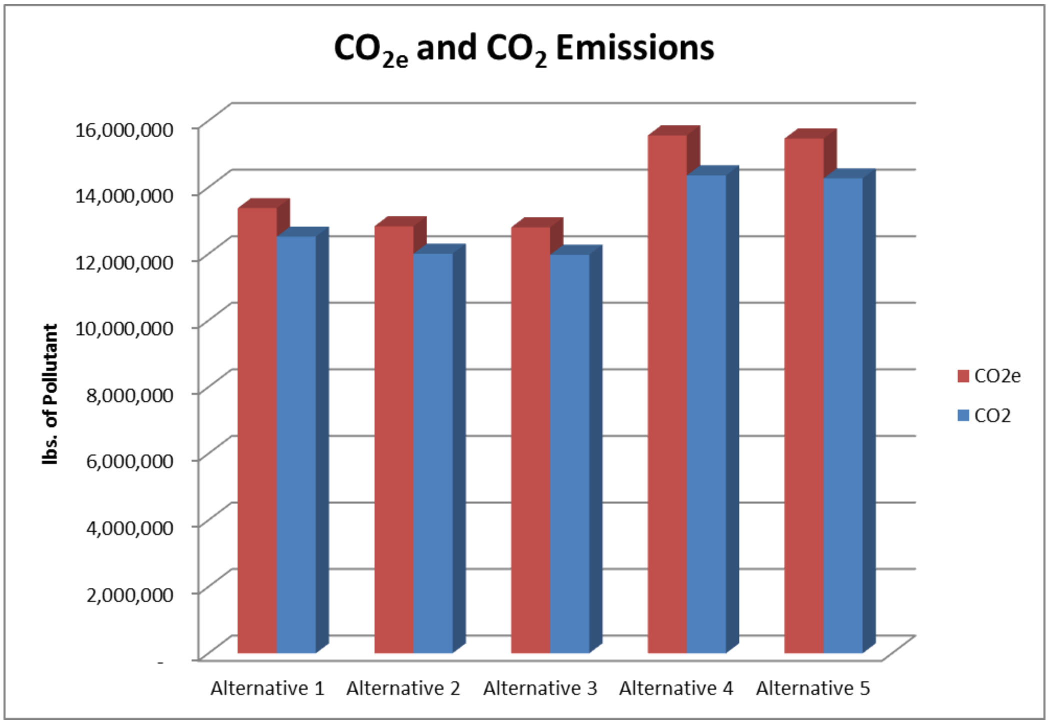


Figure 20: CO_2 Equivalent and CO_2 Emissions

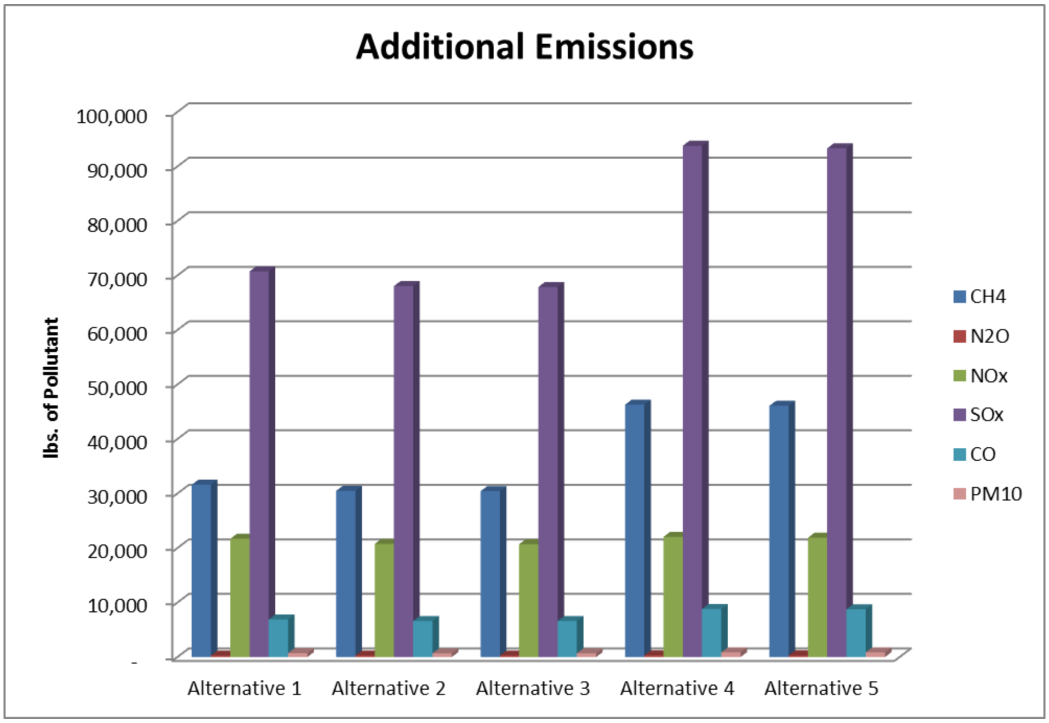


Figure 21: Addition Pollutant Emissions

7.2.4 Conclusions

For the South Patient Tower, the design alternative using Variable Primary Flow with Centrifugal Chillers (Alternative 3) proved to be the most cost-effective option. Its 30 year life-cycle cost of $13,763,462 only saved $66,000 compared to the Primary/Secondary Centrifugal option but saved $2.4 million compared to the existing design. This alternative proved the best option throughout the plant design studies. Alternative 3 provided the shortest simple pay-back with 5.3 years compared with the existing design. It also showed the greatest reduction in overall emissions when compared to the existing design alternative.

The basis of the next two depth topics involving central plant energy optimization will be the Variable Primary Flow with Centrifugal Chillers design alternative.

7.3 Depth 2: Dedicated Heat Recovery Chiller

7.3.1 Scope of Work

For this optimization study of a central plant, a dedicated heat recovery chiller was added to the best alternative from Depth 1, the Variable Primary Flow with Centrifugal Chillers plant. With the addition of a heat recovery chiller, the domestic water load can be completely replaced by the recovered heat and the heating hot water need will be reduced due to preheating on the return. A heat recovery chiller will produce 170 F hot water during operation which will drop the ΔT seen by the steam to hot water heat exchanger from 40 F to 20 F reducing the amount of steam necessary for heating.

7.3.2 Design Process

A heat recovery chiller is placed on the chilled water loop in parallel with the other chillers in the plant to help produce some cooling while rejecting the heat to the hot water system. For the South Patient Tower, the heat recovery chiller will reject heat to the domestic hot water heaters first and any excess will help reduce the amount of energy required to heat the heating hot water system by pre-heating the return water. ***Figure 22*** below shows how the heat recovery chiller (HRC) will be integrated into the chilled water loop and heating hot water system.

To design the heat recovery chiller for the South Patient Tower, a Multi-Stack unit was investigated. With this type of chiller, you can add modules in certain ton increments to improve the effects of heat recovery. Due to the size of the loads on this building, two module sizes were investigated for further study. The modules chosen were the 25 ton and 32 ton units. ***Table 33*** shows the operating conditions for each of the modules chosen.

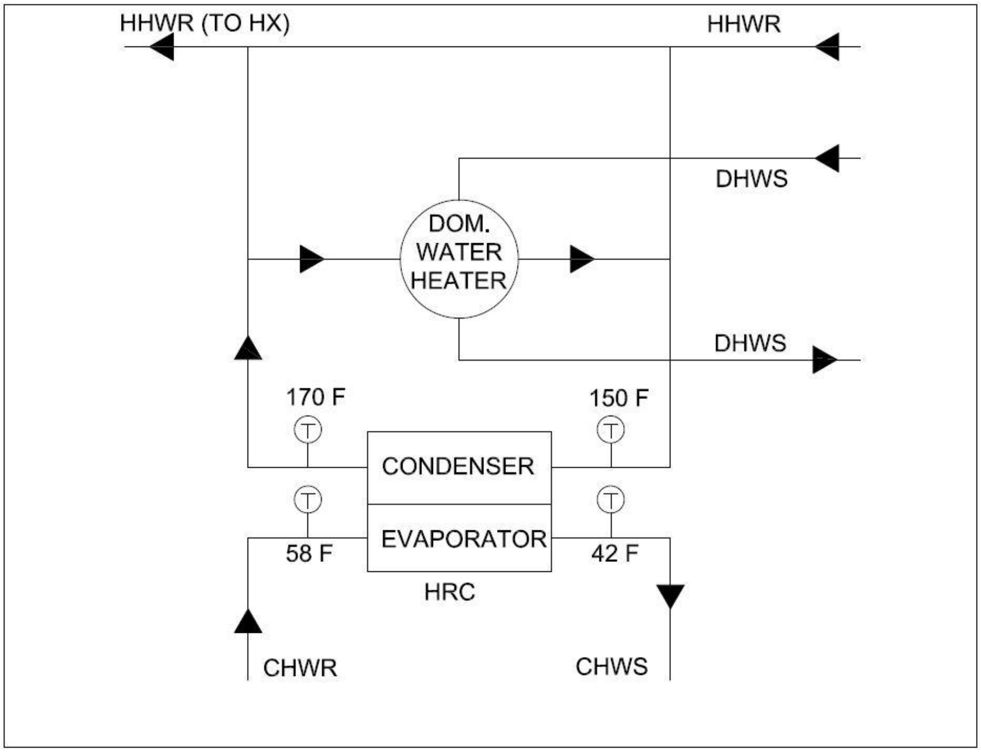


Figure 22: **Heat Recovery Chiller System Integration**

Table 33: **Heat Recovery Chiller Operating Conditions**

Module	Chilled Water		Heat Rejection		Cooling	Heating
	EWT (F)	LWT (F)	EWT (F)	LWT (F)	EER	COP
25 ton	58	42	150	170	3.7	2.1
32 ton	58	42	150	170	3.8	2.1

Once the heat recovery chillers were modeled in TRACE, they were added to the central plant configuration and sequenced to start first. A heat recovery operating schedule was made to optimize the recovery capability in the heating months and by-pass the chiller in the cooling months. An energy analysis was run for different multiples of the module size to see the impact on the energy consumption.

Once energy consumption data was found, a new life-cycle cost analysis was done for each of the modeled combinations. ***Table 34*** below shows the cost estimate for the heat recovery chillers as a $/ton. This cost was applied to all ton options considered. To decide which size heat recovery unit would provide the most benefit for the South Patient Tower's new central plant, the 25 ton increment modules and the 32 ton increment modules were compared separately. ***Figure 23 and 24*** below show the results of these comparisons with total annual energy consumed in MMBTU and 30 year life-cycle cost.

Table 34: **Heat Recovery Chiller Cost**

	Cost / Unit
Heat Recovery Chiller	$ 600 / ton

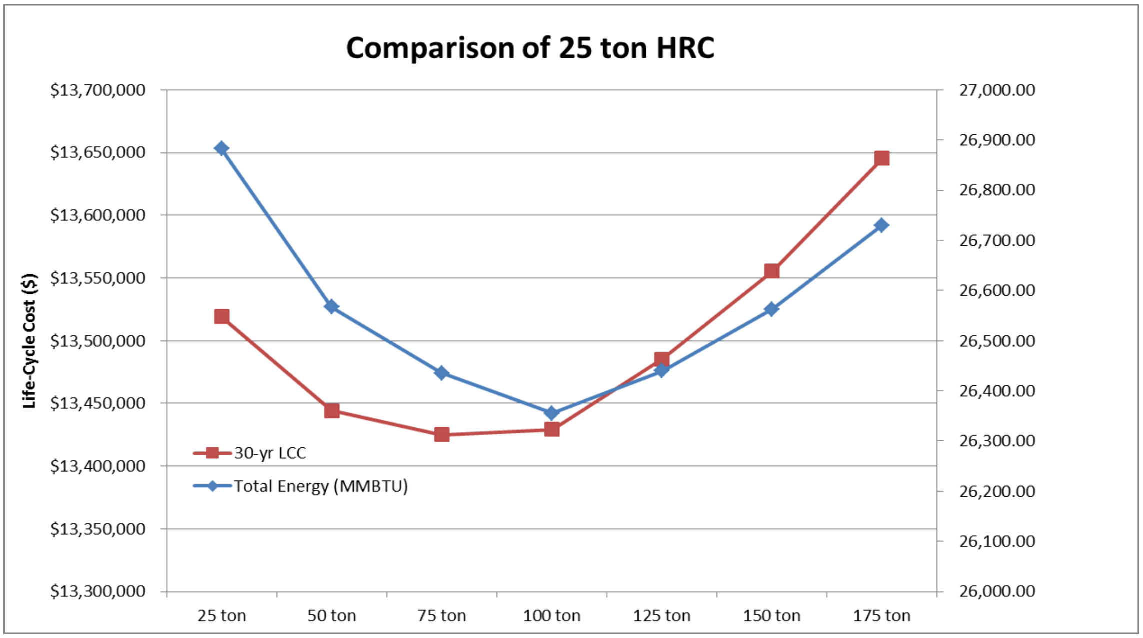


Figure 23: **Comparison of 25 ton Increment Heat Recovery Chillers**

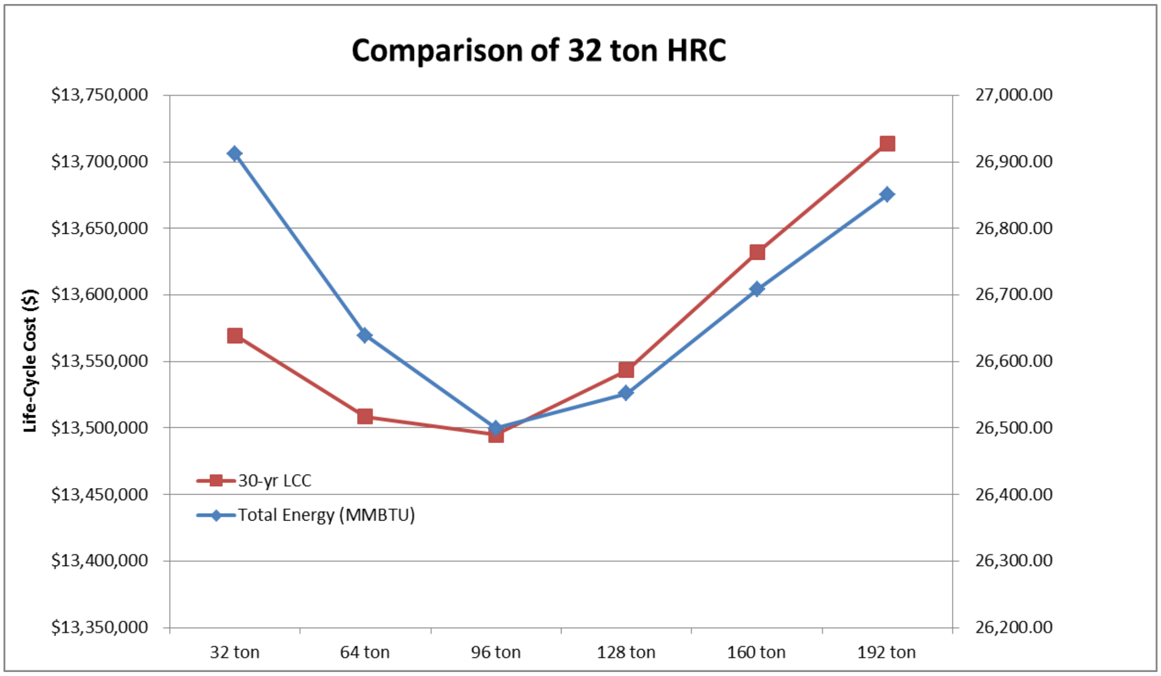


***Figure 24*:** **Comparison of 32 ton Increment Heat Recovery Chillers**

The options that provided the most benefit in energy savings were chosen when the minimum energy consumed was found on each of the graphs. The 30 year life-cycle cost followed the energy trend so the lowest consumer of energy was also the lowest life-cycle cost option. The options selected for additional comparison were the 96 ton and 100 ton heat recovery chiller. ***Figure 25 and 26*** show the comparison of 30 year life-cycle cost and total annual energy between the two options.

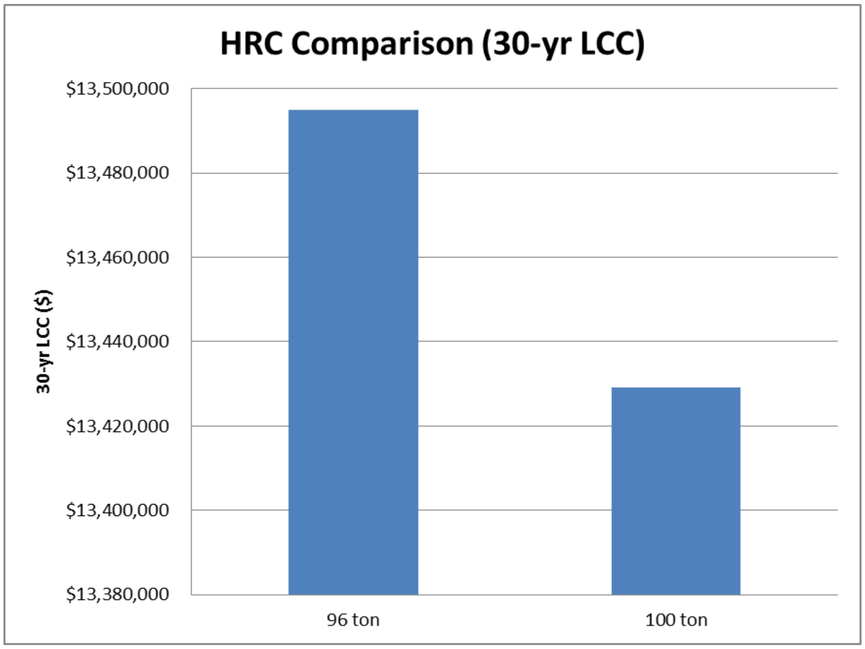


Figure 25: 30 year Life-Cycle Cost Comparison

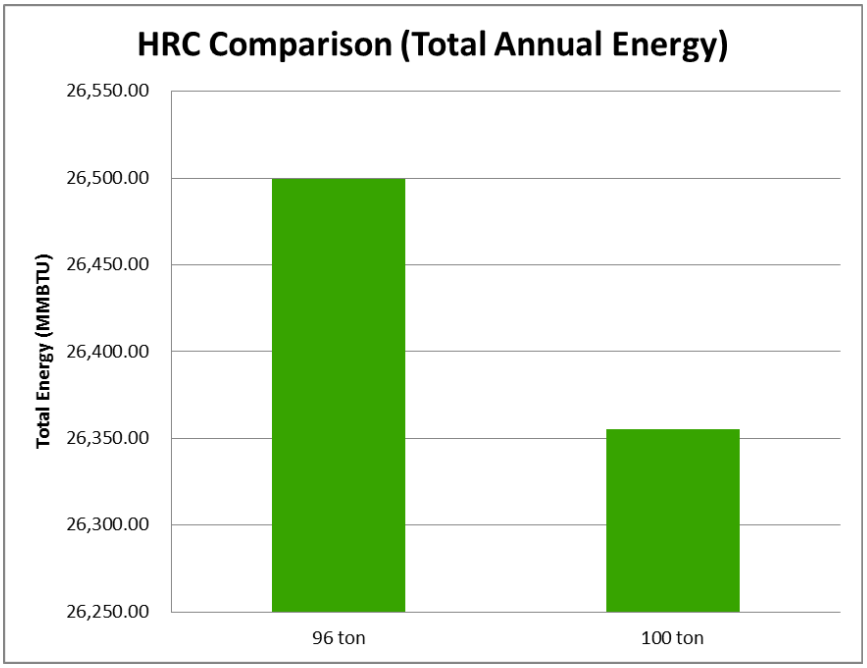


Figure 26: **Total Annual Energy Comparison**

The 100 ton heat recovery chiller shows a 30 year life-cycle cost decrease along with an annual total energy decrease. Although these aren't large differences, the energy savings helps justify the additional cost of the heat recovery chiller.

Both options also can be seen to provide the necessary domestic hot water load of the South Patient Tower during operation. The additional recovered energy can be used to help offset the steam necessary to provide the heating hot water to the building. Both the 96 ton and 100 ton heat recovery chillers provide approximately 16-17% of the heating hot water load required for the building.

7.3.3 Conclusions

Heat recovery chillers help reduce both cost and energy by rejecting the condenser heat to preheating the hot water. Through this analysis it was determined that the most cost effective and energy efficient option was to add 100 tons of heat recovery to the Variable Primary Flow Centrifugal Chiller central plant design.

When comparing the new chilled water plant and including the addition of the heat recovery chiller, the simple payback of the new design actually slightly decreased from 5.3 to 5.2 years, while the discounted payback remained around 6 years. The heat recovery also added an additional $330,000 in 30 year life-cycle cost reduction, or a total of $2.7 million reduction from the existing design.

Due to the decreased life-cycle cost and simple payback, it is recommended to include a 100 ton heat recovery chiller in the Variable Primary Flow with Centrifugal Chillers design. This optimization study proved to be helpful in providing energy savings and cost savings to the South Patient Tower.

7.4 Depth 3: Air Handler Condensate Recovery

7.4.1 Scope of Work

For this optimization study, an air handler condensate recovery system was added to the best selection from Depth 1 and Depth 2. Air handlers produce condensate while cooling the supply air due to the dew point being reached. This condensate traditionally is drained away from the unit and offsite to limit the chances of contaminant growth. The water is typically very pure water and thus makes for a good supplement for the cooling tower make-up water. This study will focus on determining the amount of condensate that can be recovered and the effects on the life-cycle cost of the plant designed so far in Depth 1 and 2.

7.4.2 Method of Analysis

Condensate is created from a cooling coil due to the differential humidity ratio of the entering air and leaving air, as well as the amount of air passing over the coil. The amount of condensate can be determined with the following equation:

$$Condensate\left(\frac{lbs.}{hr}\right) = CFM * \rho_{air} * 60\frac{min}{hr} * \Delta w$$

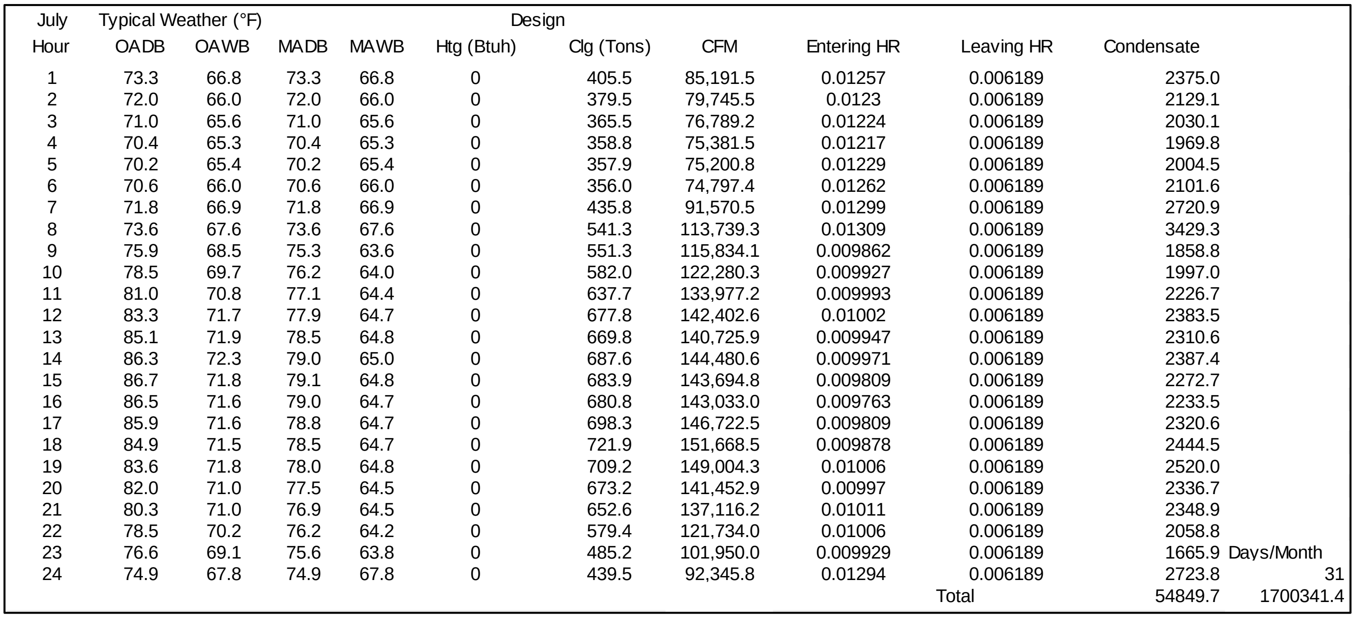
Where:
CFM = Airflow over the cooling coil
ρ_{air} = density of air
Δw = difference of humidity ratios across the cooling coil

Due to the airflow variation throughout the year the monthly load profile was needed. The TRACE model of the South Patient Tower was referenced and the load profile was found for a typical day in each month. From this report a simple ratio was set up to determine the airflow at part load since the full load airflow and full load tonnage was known.

This report also had the TMY weather averages for every hour of a typical day in each month. This outdoor air condition (Dry-Bulb and Wet-Bulb Temperatures) were combined with the return air conditions to determine the mixed air conditions that the coil would see for each hour. Due to the South Patient Tower system having an economizer, the mixed air conditions were only found if the outdoor air conditions were above the return air dry-bulb of 73.1 F or wet-bulb temperatures of 61.3 F.

After the mixed air, or coil entering air, condition was found, Engineering Equation Solver (EES) software was utilized to determine the humidity ratio for each hourly condition. EES was also used to determine the humidity ratio of the leaving coil air condition of 49.6 F (DB) and 49.5 F (WB). Once these ratios were determined, an Excel spreadsheet was used to determine the condensation amount for each hour of the typical day in each month. These amounts were determined and a daily total was found for each month. This was multiplied by the amount of days in that month to determine the monthly totals and summed for the annual total. ***Figure 27*** below shows an example of the spreadsheet calculation for the month of July. All of the monthly calculations can be found in ***Appendix D***.

Table 35 below shows the monthly summary of recovered condensate determined by the analysis. It is clear that in the heavy cooling season more condensate can be recovered, but is surprising that even a little can be recovered in the winter months.



July	Typical Weather (°F)					Design					
Hour	OADB	OAWB	MADB	MAWB	Htg (Btuh)	Clg (Tons)	CFM	Entering HR	Leaving HR	Condensate	
1	73.3	66.8	73.3	66.8	0	405.5	85,191.5	0.01257	0.006189	2375.0	
2	72.0	66.0	72.0	66.0	0	379.5	79,745.5	0.0123	0.006189	2129.1	
3	71.0	65.6	71.0	65.6	0	365.5	76,789.2	0.01224	0.006189	2030.1	
4	70.4	65.3	70.4	65.3	0	358.8	75,381.5	0.01217	0.006189	1969.8	
5	70.2	65.4	70.2	65.4	0	357.9	75,200.8	0.01229	0.006189	2004.5	
6	70.6	66.0	70.6	66.0	0	356.0	74,797.4	0.01262	0.006189	2101.6	
7	71.8	66.9	71.8	66.9	0	435.8	91,570.5	0.01299	0.006189	2720.9	
8	73.6	67.6	73.6	67.6	0	541.3	113,739.3	0.01309	0.006189	3429.3	
9	75.9	68.5	75.3	63.6	0	551.3	115,834.1	0.009862	0.006189	1858.8	
10	78.5	69.7	76.2	64.0	0	582.0	122,280.3	0.009927	0.006189	1997.0	
11	81.0	70.8	77.1	64.4	0	637.7	133,977.2	0.009993	0.006189	2226.7	
12	83.3	71.7	77.9	64.7	0	677.8	142,402.6	0.01002	0.006189	2383.5	
13	85.1	71.9	78.5	64.8	0	669.8	140,725.9	0.009947	0.006189	2310.6	
14	86.3	72.3	79.0	65.0	0	687.6	144,480.6	0.009971	0.006189	2387.4	
15	86.7	71.8	79.1	64.8	0	683.9	143,694.8	0.009809	0.006189	2272.7	
16	86.5	71.6	79.0	64.7	0	680.8	143,033.0	0.009763	0.006189	2233.5	
17	85.9	71.6	78.8	64.7	0	698.3	146,722.5	0.009809	0.006189	2320.6	
18	84.9	71.5	78.5	64.7	0	721.9	151,668.5	0.009878	0.006189	2444.5	
19	83.6	71.8	78.0	64.8	0	709.2	149,004.3	0.01006	0.006189	2520.0	
20	82.0	71.0	77.5	64.5	0	673.2	141,452.9	0.00997	0.006189	2336.7	
21	80.3	71.0	76.9	64.5	0	652.6	137,116.2	0.01011	0.006189	2348.9	
22	78.5	70.2	76.2	64.2	0	579.4	121,734.0	0.01006	0.006189	2058.8	
23	76.6	69.1	75.6	63.8	0	485.2	101,950.0	0.009929	0.006189	1665.9	Days/Month
24	74.9	67.8	74.9	67.8	0	439.5	92,345.8	0.01294	0.006189	2723.8	31
									Total	54849.7	1700341.4

Figure 27: Monthly Condensate Recovery (lbs.) Calculation (July)

Table 35: **Amount of Recovered Condensate Per Month**

	January	February	March	April	May	June
Condensate (1000 gal.)	1.1	0.8	8.6	7.5	53.9	128.0
	July	**August**	**September**	**October**	**November**	**December**
Condensate (1000 gal.)	203.9	161.1	86.4	4.7	6.8	1.8

After this calculation was performed, the results were compared to those determined by the TRACE model. The results were surprisingly close to that estimated by the model and can be seen graphically in ***Figure 28*** below. This figure shows the monthly amount of recovered condensate of both the calculation and the TRACE model. Although the distribution was slightly different, the total amount was of just slightly. ***Figure 29*** shows the annual total calculated compared to the annual total from the TRACE model. It can be seen that the results are very close and off by just 0.08%.

The annual total of recovered condensate was used in the life-cycle comparison to the plant designed to this point. It was determined to offset the make-up water needed in the design by 14% which correlated to a 14% cost savings on the water. ***Table 36*** shows the resulting amount and cost of make-up water from the analysis.

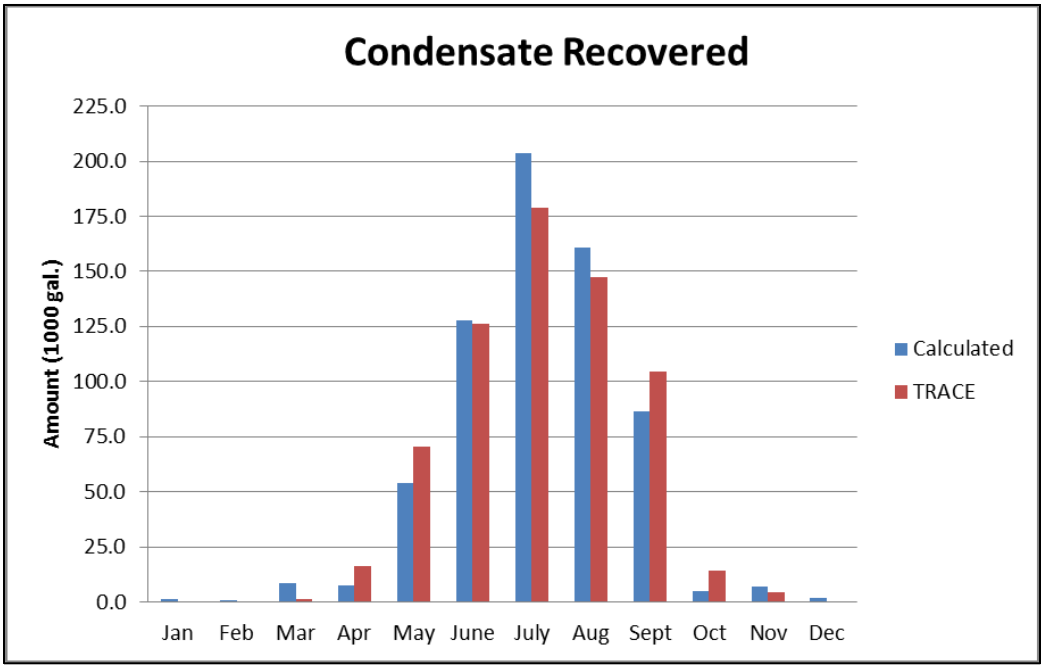


Figure 28: **Comparison of Condensate Recovered**

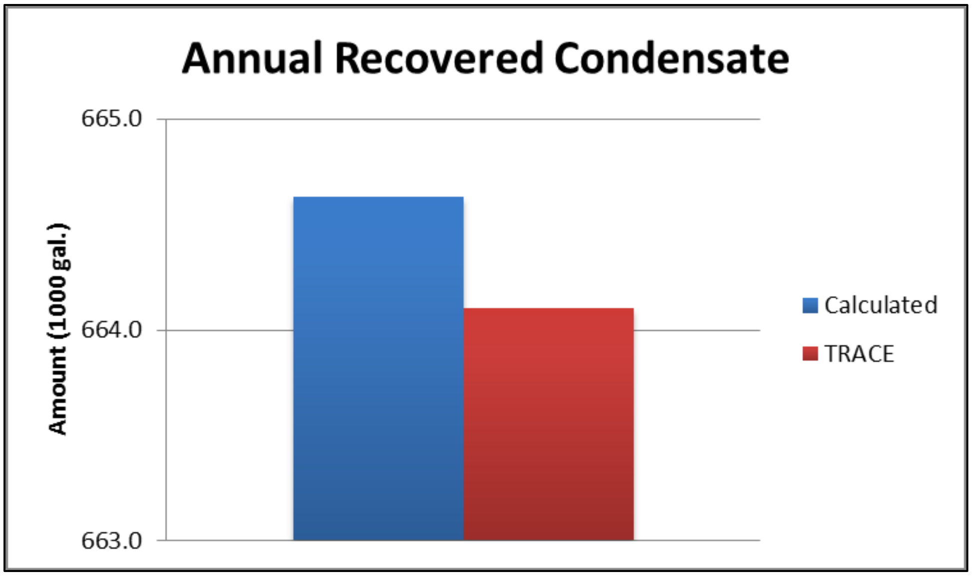


Figure 29: **Comparison of Annual Recovered Condensate**

Table 36: **Make-Up Water Annual Savings**

	Amount (1000 gal.)	Annual Cost
Water (Make-Up)	4,891	$ 10,565
Reduced Make-Up	4,226	$ 9,129
Savings	14 %	14 %

7.4.3 Conclusions

By recovering the air handler cooling coil condensate, a building can reduce the need for make-up water for use in the cooling tower. The condensate from the coil is in some cases much cleaner than that of the city water and would need less chemical treatment. The system can be run during all months of the year and the water can be stored if necessary for use later in the cooling season.

When comparing the chilled water plant with the inclusion of a condensate recovery system to the chilled water plant design in Depth 1 and 2, the capital costs go up by 1 % due to the necessary equipment for this system, the electricity consumption increases due to the new pumping energy by a negligible amount and the overall simple payback of the system remains unchanged from that of Depth 2 at 5.1 years. There are savings seen in the water consumption of the calculated 664,600 gallons per year.

The life-cycle cost analysis proves beneficial to reducing the net present value of the system and increasing the savings for the owner. The condensate recovery system saves an additional $5,000 when added to the plant with the heat recovery chiller. Due to the annual savings and overall lower life-cycle cost, a condensate recovery system is recommended. Also with the addition of this system the payback period remains the same so inclusion of this system seems like a good option for the South Patient Tower.

7.5 Mechanical Depth Conclusions

From this in-depth study of a chilled water plant redesign and optimization, the recommendations on the basis of life-cycle cost, energy savings and emissions are as follows: a Variable Primary Flow Centrifugal Chiller plant arrangement with a 100 ton heat recovery chiller and an air handler cooling coil condensate recovery system.

With regards to life-cycle cost all the options selected have been compared in ***Table 37*** below to show the most economical selection. It can be seen that the existing design of purchased chilled water remains the least economical option with the highest 30 year life-cycle cost. It also can be seen that the optimized plant with heat and condensate recovery is the most economical option. When compared to the baseline, the optimized plant with heat and condensate recovery saves $2,729,372 over a 30-year life-cycle to the owners of the South Patient Tower.

***Table 37:* 30-year Life-Cycle Cost Summary for Depth Conclusions**

	As Designed	VPF w/ Cent. Chillers	VPF w/ 100 ton HRC	VPF w/ HRC and Condensate Recovery
Capital Cost	$ -	$ 773,894	$ 833,894	$ 844,984
Maintenance	$ 64,499	$ 64,499	$ 64,499	$ 64,499
Electricity	$ 9,160,401	$ 11,211,790	$ 11,133,842	$ 11,160,788
Steam	$ 1,454,382	$ 1,454,382	$ 1,169,739	$ 1,169,739
Chilled Water	$ 5,473,975	$ -	$ -	$ -
Make-Up Water	$ -	$ 258,897	$ 227,133	$ 183,875
Total	$ 16,153,257	$ 13,763,462	$ 13,429,107	$ 13,423,885
Ranking	4	3	2	1

Emissions were also considered when determining the best selection of plant and optimization. When the CO_2 equivalent levels were compared to the existing design, the Variable Primary Flow plant reduced emissions by 4.3 % while adding heat recovery added an additional reduction of about 3 % to show a total reduction of 7.2%. Adding the condensate recovery system added slightly higher emissions due to the increase in electricity consumption. With both optimization strategies in place, the new design totaled a reduction in emissions of 6.95%. ***Figures 30 and 31*** below show the reduction in emissions as optimization is added to the plant as compared to the existing design.

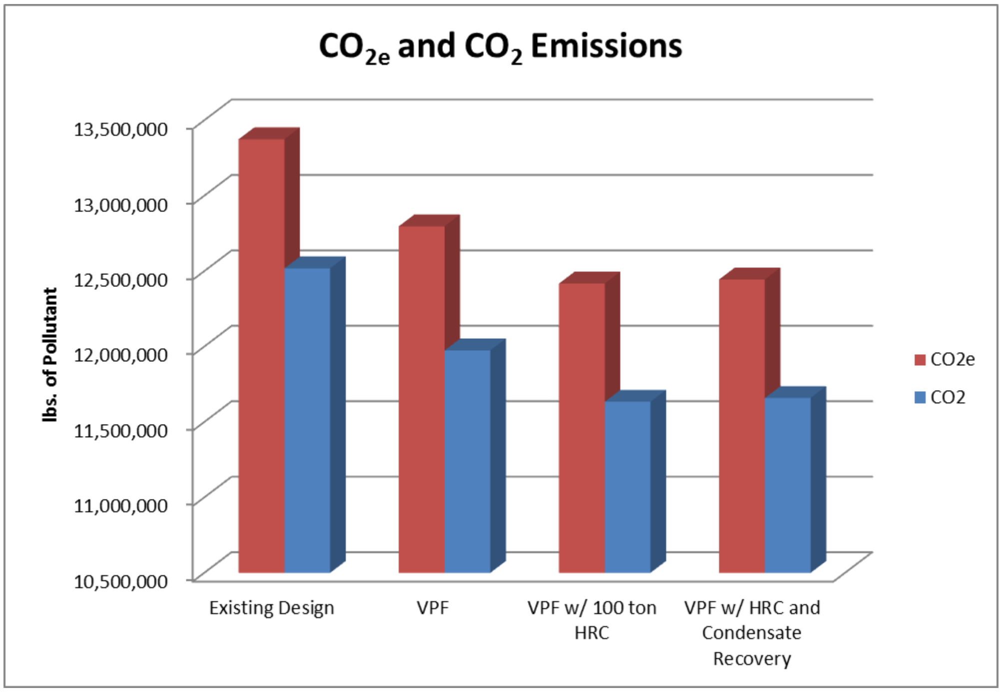


***Figure 30:* CO_{2e} and CO_2 Comparison of Redesign to Existing**

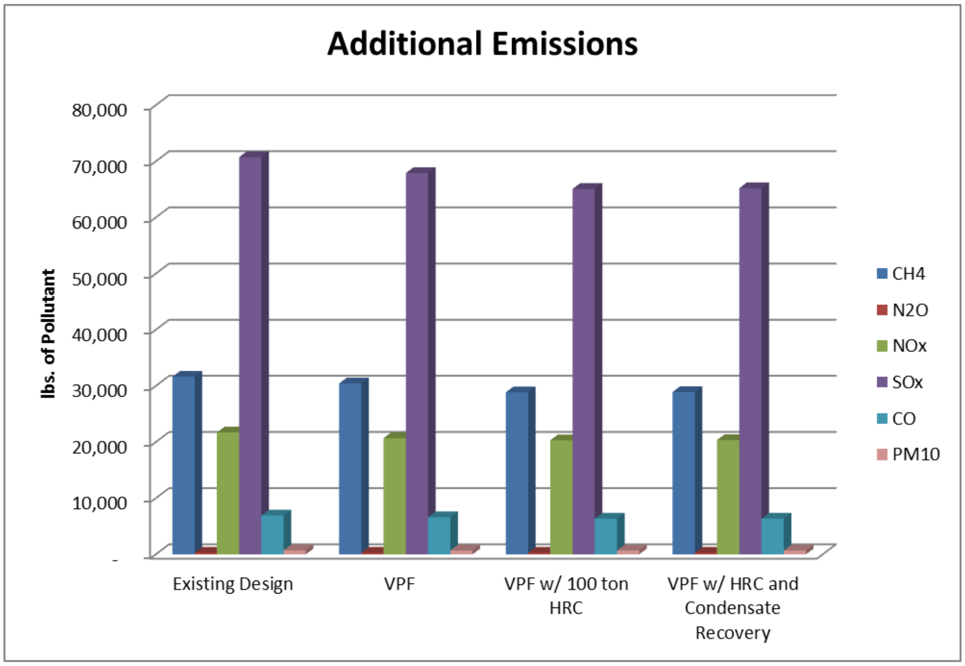


Figure 31: **Additional Emission Comparison of Redesign to Existing**

Due to the results from the 30-year life-cycle cost and emissions calculations the most economical and recommended option would be the Variable Primary Flow plant with Centrifugal Chillers, a 100 ton Heat Recover Chiller, and Condensate Recovery. It provides the best alternative when optimized and reduces the cost and emissions seen by the South Patient Tower and its owners. With a simple payback of the combined system being 5.1 years, the system will pay for itself in no time considering the estimated life time of the South Patient Tower to be 30+ years.

8.0 Electrical Breadth Study

8.1 Introduction

An electrical breadth topic was investigated to determine the impact of the new chilled water plant on the electrical distribution system. Due to the equipment being a new addition, all the power distribution equipment that serves the 5th floor will need to be analyzed. Over current protection, feeder sizes and panel board /switchboard sizes will be sized and added to the current design. The equipment serving this addition will be check and resized if necessary.

8.2 Electrical Load Calculations

8.2.1 Equipment Electrical Loads

All the equipment being added in the chilled water plant design is being considered for this breadth study. The horsepower of each motor needed to be determined in order to properly calculate the electrical loads on the system. Both submittals on the chillers and cooling towers, and horsepower specified for the motors in the Mechanical Depth were used in this study.

8.2.2 Full Load Current

Since the motor sizes were known for the new equipment, the NEC 2008 Table 430.250 was utilized in order to determine the full-load current (FLA) of each piece of equipment. A copy of this table has been included in ***Appendix E***. The result FLA of each piece of equipment can be seen in ***Table 38*** below.

8.2.3 Connected Load

To determine the overall connected load, the FLA was used along with the Voltage and power factors to find the KVA and KW of each piece of equipment. The following equations were used to determine the KVA and KW shown in ***Table 38***.

KVA = (Volts x Full-Load Amps x 1.73)/1000

KW = KVA x PF

The power factors were provided or assumed to determine the proper KW. The following power factors were used in this calculation:

Motors < 5 HP : **PF = 0.85**
Motors > 5 HP : **PF = 0.90**
Chillers (Both Centrifugal and HRC): **PF = 0.88**

8.2.4 Over Current Protection Device (Circuit Breaker)

Once the FLA was found for each piece of equipment, the proper over current protection device needed to be sized. Common circuit breaker sizes are found in the NEC 2008 Article 240.6, which a copy of can be found in ***Appendix E***. The sizes shown in ***Table 38*** below have been determined from the following equation:

Circuit Breaker Size < 2.5 x Full-Load Amps

8.2.5 Branch Circuit Feeder Sizing

In order to properly size the branch circuit feeder wires attached to each piece of equipment, the NEC 2008 Table 310.16 was used. It was assumed that the feeder wires would be Type THW, Copper wire at 75 C. The sizes selected are show below in ***Table 38.*** To determine the appropriate size the following equation was used when sizing:

Wire Size > 1.25 x FLA

8.2.6 Ground Wire Sizing

The ground wire shown along with the branch circuit feeder sizes was determined by utilizing the NEC 2008 Table 250.122. The circuit breaker size was used to select the appropriate grounding wire size for each feeder. The resulting sizes are shown next to the feeder sizes in ***Table 38*** below.

8.2.7 Conduit Sizing

To determine the conduit size needed, the NEC 2008 Table C.1 (EMT) was consulted. The main feeder wire size was considered and the conduit that allowed for four (4) wires of that size was selected. The selected sizes of conduit can be seen in ***Table 38*** below.

8.2.8 Motor Starter Sizing

Motors starters were selected from the full-load amperes associated with the pump and fan motors. The selections were chosen from the NEMA Motor Starter Guidelines, a copy of which is shown in ***Appendix E.*** The resulting selections are noted in ***Table 38*** below.

Table 38: **Electrical Load Calculation Summary**

Equipment	HP	FLA	Volts	KVA	PF	KW	OCP	Wire Size	Conduit Size	Motor Starter
CHWP-1	15	21	480	17.4	0.9	15.7	50	(3) #10 - (1) #10 G.	3/4"	1
CHWP-2	15	21	480	17.4	0.9	15.7	50	(3) #10 - (1) #10 G.	3/4"	1
CHWP-3	15	21	480	17.4	0.9	15.7	50	(3) #10 - (1) #10 G.	3/4"	1
CHWP-4	15	21	480	17.4	0.9	15.7	50	(3) #10 - (1) #10 G.	3/4"	1
CHWP-5	15	21	480	17.4	0.9	15.7	50	(3) #10 - (1) #10 G.	3/4"	1
CHWP-6	15	21	480	17.4	0.9	15.7	50	(3) #10 - (1) #10 G.	3/4"	1
CWP-1	15	21	480	17.4	0.9	15.7	50	(3) #10 - (1) #10 G.	3/4"	1
CWP-2	15	21	480	17.4	0.9	15.7	50	(3) #10 - (1) #10 G.	3/4"	1
CWP-3	15	21	480	17.4	0.9	15.7	50	(3) #10 - (1) #10 G.	3/4"	1
CH-1	-	294	480	244.1	0.88	214.8	600	(3) 500 kcmil - (1) #1 G.	3"	N/A
CH-2	-	294	480	244.1	0.88	214.8	600	(3) 500 kcmil - (1) #1 G.	3"	N/A
CH-3	-	294	480	244.1	0.88	214.8	600	(3) 500 kcmil - (1) #1 G.	3"	N/A
HRC-1	-	184	480	152.8	0.8	122.2	450	(3) 4/0 - (1) #4 G.	2-1/2"	N/A
CT-1	10	14	480	11.6	0.9	10.5	30	(3) #12 - (1) #10 G.	1/2"	0
CT-2	10	14	480	11.6	0.9	10.5	30	(3) #12 - (1) #10 G.	1/2"	0
CRP-1	3	4.8	480	4.0	0.85	3.4	15	(3) #14 - (1) #14 G.	1/2"	00

8.3 Panelboard Schedules

After all of the electrical loads were found and the feeders were sized, a panelboard and switchboard were selected to handle the additional load to the 5th floor due to the current switchboard not having enough excess capacity. The pump motors were placed on a new 225A panel while the chillers and cooling towers were placed directly on the new 1600A switchboard. The 225A panel also fed into the 1600A switchboard as it had enough capacity to handle this additional load.

The feeders were sized for both the panel and switchboard and are noted on the schedules themselves found in ***Appendix E***. From the switchboard, the feeder will be directed back to the South Patient Tower's main switchboard in the basement. This switchboard did not need resized due to the excess capacity already built in for expansion. The one-line diagram for this arrangement can be found in ***Appendix E.***

8.4 Electrical System Costs and Conclusions

In order to see the cost effects of adding the new electrical equipment to the South Patient Tower, R.S. Means Electrical Cost Data 2009 was consulted. All the new equipment to be added with the central plant redesign was included in the cost analysis. The summary table of this cost analysis can be seen in ***Table 39*** below.

Through the analysis it was shown that by adding the new electrical equipment necessary for the central plant, a total cost of $73,489 is added to the capital cost of the system. This is a significant addition to the first cost and will be included in a final analysis of life-cycle cost and paybacks that are presented in the Final Conclusions section of this report.

Table 39: **Summary of Additional Cost Due to Electrical System**

Equipment	Unit Cost	Quantity	Subtotal
1600 A Switchboard	$ 3,450 / each	1	$ 3,450
225 A Panelboard	$ 1,090 / each	1	$ 1,090
Motor Starters			
1	$ 513 / each	9	$ 4,617
0	$ 411 / each	2	$ 822
00	$ 312 / each	1	$ 312
Conduit			
½”	$ 1.35 / L.F.	300	$ 405
¾”	$ 2.35 / L.F.	450	$ 1,058
2-1/2”	$ 13.59 / L.F.	150	$ 2,039
3”	$ 16.00 / L.F.	250	$ 4,000
Wire			
#14	$ 39.30 / C.L.F	2.2	$ 86
#12	$ 49.90 / C.L.F	6.6	$ 329
#10	$ 62.50 / C.L.F	22	$ 1,375
#4	$ 177 / C.L.F	1.65	$ 292
#1	$ 307 / C.L.F	1.65	$ 507
4/0	$ 686 / C.L.F	6.05	$ 4,150
400 kcmil	$ 1,191 / C.L.F	3.3	$ 3.930
500 kcmil	$ 1,410 / C.L.F	4.95	$ 6,980
Circuit Breakers			
15 A	$ 45.00 / each	1	$ 45
30 A	$ 90.00 /each	2	$ 180
50 A	$ 150 / each	9	$ 1,350
225 A	$ 1,876 / each	1	$ 1,876
450 A	$ 3,571 / each	1	$ 3,571
600 A	$ 4,625 / each	3	$ 13,875
1600 A	$ 17,150/ each	1	$ 17,150
Total			**$ 73,489**

9.0 Structural Breadth Study

9.1 Introduction

A structural breadth study was performed to determine the effects of the new central plant design on the structural support system implemented on the fifth floor mechanical space. The plant will be located on the four (4) northwest bays of the fifth floor. Each of these bays is 29 feet x 29 feet from column center to column center. The floor is made up of a 10.5" two-way reinforced concrete slab. This study will investigate the reinforcing to be added for the necessary support of the new mechanical equipment.

9.2 Mechanical Equipment Load Calculations

In order to properly account for the additional mechanical equipment loads that are to be added to the design, weights had to be determined either through calculations or from submittal documentation. The chillers, heat recovery chiller and pumps weights were found from documentation of operation weight since this will be the worst case scenario. To determine the plant piping weights a calculation was done assuming the pipes are entirely full of water. The interior area of the pipe was used in a simple volume calculation of one (1) foot of pipe. The pipe was assumed to be Schedule 40 Steel piping and the weight per foot of this type of 8" piping was used. The water and pipe weights were added together to achieve an overall weight per foot. It was assumed that around 300 feet of piping will contribute to the load on the four (4) bays of the fifth floor. The weight per foot value of the piping was multiplied by the total linear feet of piping to find a total piping weight. All the weights were added together to get a total addition weight on the slab. This total weight was divided by the total area that the plant will be assumed to use of the four bays previously described to determine a distributed load for the two-way slab. The weight of the mechanical equipment and the total distributed load can be seen in ***Table 40*** below.

Table 40: **Mechanical Equipment Weights**

Equipment	Amount	Weight/Unit	Total Weight (lbs)
Centrifugal Chillers	3	22,173 lb /each	66,519
Heat Recovery Chiller	4	2,000 lb / 25 ton	8,000
Pumps	9	200 lbs / each	1,800
Piping	300 ft	36.32 lb / ft	10,896
Water	-	19.66 lb / ft	
Steel Pipe (8")	-	16.66 lb / ft	
Total			87,215
Distributed Load	Area =	3,364 ft^2	25.9 lb / ft^2

9.3 Design Process

9.3.1 Introduction

In order to determine the necessary reinforcing for the additional mechanical load, one of the four identical bays will be investigated. The slab is a two-way slab with drop panels, so one direction will be investigated and will determine the reinforcing in the other direction since it will be the same. Once the appropriate reinforcing is determined, area of steel will be used for comparison to the existing reinforcing. If the existing is less than what is necessary, additional reinforcing will be required to handle the load. All detailed calculations can be found in ***Appendix F*****.**

Assumptions/ Design Data for the two-way concrete slab are as follows:

Slab Thickness: 10.5”
Column Size: 24” x 24”
F_y = 60 ksi
F'_c = 4000 psi

Live Load: 150 psf (non-reducible)
Superimposed Dead Load: 20 psf
Slab Self Weight: 131.25 psf
Mechanical Equipment Weight: 25.9 psf

9.3.2 Concrete Slab Deflection Check

To determine the size of the two-way slab with drop panels without accounting for deflections of the fifth floor, the following equation was used from ACI 318-08 Table 9.5:

$$\textit{For Fy = 60,000 psi}: \mathbf{l_n / 36}$$

Where:
l_n = the distance between columns (interior face to interior face)

If the slab thickness is greater than the thickness determined by this equation, then deflections do not need to be checked. The calculation results in a slab thickness of 9”. The fifth floor of the South Patient Tower has a 10.5” slab which well exceeds this minimum suggested by ACI 318-08 so deflections do not need to be checked.

9.3.3 Conditions to Use Direct Design Method

The direct design method is preferred for this analysis, but in order to use this method some conditions must first be satisfied. The following is a list of the conditions and the conditions of the design:

1. 3 Continuous Spans in Each Direction

   The design satisfies this condition.

2. Panel Ratio must be less than or equal to 2.0

   l_2 / l_1 *= 29' / 29' = 1.0 which satisfies this condition.*

3. l_1 is greater than or equal to (2/3) l_2

   29' > (2/3) x 29' = 19' which satisfies this condition.

4. No column is offset more than 10% of the length.

   The design satisfies this condition.

5. W_L is less than or equal to $2W_D$

   150 psf < (131.25+20+25.9) = 354.3 psf which satisfies this condition.

Since all of the conditions are satisfied for the bay that is being investigated, the direct design method can be utilized to determine the necessary reinforcing.

9.3.4 Direct Design Method

The direct design method will help determine the appropriate amount of reinforcing necessary to handle the additional load of the central plant. The length of the column strip and middle strip had to be determined for this calculation. The column strip was found to be 14.5' with ½ the strip being 7.25' while the middle strip was 14.5'. The moment needed to be found for this panel in order to proceed with the calculation. To properly find the moment the Wu had to be determined from the following equation:

$$\mathbf{W_U = (1.2 \times W_D) + (1.6 \times W_L)}$$

Once the load was found, the Moment was determined by applying the following equation:

$$M_O = (W_U \times l_2 \times l_n^2) / 8$$

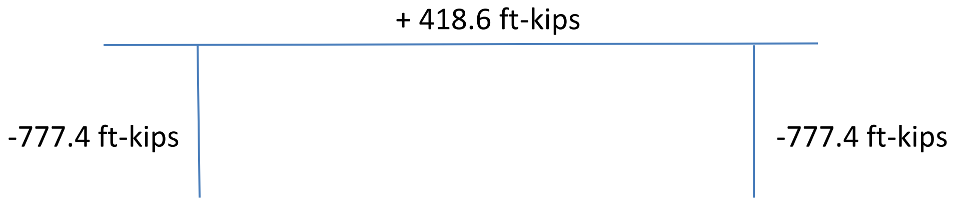
Where:

M_O = the moment in the panel
W_U = the factored distributed load
l_2 = distance between the columns (center to center) perpendicular to the panel
l_n = distance between columns (interior to interior) parallel to the panel

The total moment was determined to be 1,196 ft-kips. This moment needed to be factored for the interior negative moment and the positive factored moment. To determine these values, ACI 318-08 Section 13.6.3.3 was referenced for an exterior edge full restrained case. The factors for the moments were found as follows:

Interior Negative Factored Moment: 0.65 x M_O
Positive Factored Moment: 0.35 x M_O

Once these factors were applied, the moments on the panel were found to be as pictured in the simple diagram below:



This represents the total moments in the panel. To perform the reinforcing study, the moments had to be determined for the column and middle strips. In order to see the distribution of the moments to each of the strips, ACI 318-08 Section 13.6.4 was referenced. Once all the values were applied, it was determined that the distribution would be as follows:

Negative Moment at Interior Support: 75%
Positive Moment of Interior Panel: 60%

The moments were distributed into the column and middle strip as can be seen in ***Table 41*** below. It can be seen that the column strip has more positive and more negative moment than the middle strip.

***Table 41:* Moment Distribution Summary**

Total (ft-kips)	-777.4	+ 418.6	-777.4
Column Strip	-583.1	+ 251.2	-583.1
Middle Strip	-194.3	+ 167.4	-194.3

To determine the number of reinforcing bars necessary to handle the load of the mechanical equipment a #6 bar was assumed. The numbers were then compared to the design reinforcing by area of steel. It was then determined from this area how many bars needed to be added to the current design to adjust for the additional weight. ***Table 42*** below shows the calculation procedure summary for determining the amount of reinforcing necessary assuming a #6 bar.

***Table 42:* Summary of Reinforcing Calculation Values**

Assuming #6 Bars	Middle Strip		Column Strip	
	Neg. Moment	Pos. Moment	Neg. Moment	Pos. Moment
Moment (M_U)	-194.3	+ 167.4	-583.1	+251.2
Width Column Strip	174”	174”	174”	174”
Effective Depth	9.375”	9.375”	14.25”	9.375”
$M_N = M_U / \phi$	-215.94	+186	-647.9	+279.1
$R = (Mn \times 12000) / bd^2$	169.4	145.95	220.04	219
ρ (Table A-3)*	0.0033	0.0033	0.0039	0.0039
$A_s = \rho bd$	5.383 in^2	5.383 in^2	9.67 in^2	6.362 in^2
$A_{smin} = 0.0018bt$	3.289 in^2	3.289 in^2	3.289 in^2	3.289 in^2
N = (larger 7 or 8) / 0.44	13	13	22	15
N_{min} = width / (2t)	9	9	9	9

***Table A-3 found in Wright/MacGregor Text**

9.3.5 Current Design Comparison

In order to determine if the current design is sufficient or needs addition reinforcing, the area of steel was compared with the calculated values. The areas were compared in both the column and middle strips for both the negative and positive moments. The following is a summary of the design and calculated comparison:

Column Strip:

Negative Moment:

Calculated: (22) #6 bars = 9.68 in^2
Design: (16) #8 bars = 12.64 in^2

Positive Moment:

Calculated: (15) #6 bars =	6.6 in^2
Design: (10) #6 bars =	4.4 in^2

Middle Strip:

Negative Moment:

Calculated: (13) #6 bars =	5.72 in^2
Design: (16) #5 bars =	4.96 in^2

Positive Moment:

Calculated: (13) #6 bars =	5.72 in^2
Design: (15) #5 bars =	4.65 in^2

9.3.6 Additional Reinforcing

To determine the amount of bars needed to be added to the existing design, the calculated area of steel was used with the design reinforcing bars so the amount could easily be compared. The amount was determined for one way in one bay so this number needed to be multiplied by 8 to account for the four (4) bays with two directions of strips in each. The following is provides a summary of the addition reinforcing needed in the design.

Column Strip:

Negative Moment:	0 bars (Design is sufficient for additional load)
Positive Moment:	(40) #6 bars

Middle Strip:

Negative Moment:	(24) #5 bars
Positive Moment:	(32) #5 bars

9.4 Additional Reinforcing Costs

To determine the additional cost associated with the reinforcing, R.S. Means 2011 was referenced. The weights of each size of reinforcing had to be found on a lb/ft basis to get an overall total weight. The lengths of the reinforcing were determined from the length of the column and middle strip. The total weight for each size was then found and summed. ***Table 43*** below shows a summary of the weight calculation for the additional reinforcing.

Table 43: **Reinforcing Weight Calculation Summary**

Size	lb/ft	Amount	Length (ft)	Total Weight (lb.)
# 6	1.502	40	14.5	871.2
# 5	1.043	56	14.5	846.9
TOTAL				**1718.1**

From R.S. Means 2011 Data, the Cost for an Elevated Slab Reinforcing #4 to #7 was found to be $0.76 / lb (including labor costs). From this a simple calculation can be done since all the additional reinforcing as follows:

$ 0.76 / lb X 1718.1 lb = $ 1,305.76

9.5 Structural Conclusions

It was determined that additional reinforcing is necessary to handle the new central plant on the fifth floor. Through the direct design method, the area of steel required to handle the new load was found and compared to the area of steel in the current design. Only the column strip negative moment was sufficient to support the new load. The middle strip and the positive moment of the column strip required additional reinforcing in order to support the new load. It was found that a total of **(40) #6 bars and (56) #5 bars** needed to be added to the current design. Total weights were found and an additional cost of **$1,305.76** was necessary and will be added to the overall first cost of the central plant design.

10.0 Summary and Conclusion

10.1 MAE Course Relation Summary

A requirement for the Master of Architectural Engineering is to integrate 500 level classes into studies performed for the senior thesis report. Depth 1, the central cooling plant redesign utilized two courses and all other depth studies involved topics covered in one course. The following is a summary of the specific courses used for analysis and writing of this report.

AE 557 – Centralized Cooling Production and Distribution Systems

AE 557 is a course centered on the various systems and types of equipment that can be found in cooling systems, primarily central plants. A section of this course is devoted to comparing chillers. The chillers that were compared were the types of electric chillers and absorption chillers. This was referenced in the design of a central plant for the South Patient Tower as there was a comparison between Centrifugal Chilling (Electric) and Absorption Chilling. This course also provided a comparison between various pumping arrangements and how they affect the performance of the plant. The depth provided a plant comparison with variable primary flow and primary/secondary pumping arrangements to investigate the energy consumption and life-cycle costs associated with the two styles.

AE 558 – Centralized Heating

AE 558 is a course centered on the various systems and types of equipment that can be found in heating systems, primarily district heating plants. This course also addresses the issues of cost analysis in the form of simple and discounted payback as well as life-cycle costs. This course was referenced throughout the entire report as a verification and comparison tool to help select the most economical options and to determine realistic paybacks on the implementation of the new central plant.

10.2 Conclusion

In conclusion, a centralized cooling plant was designed for use in the South Patient Tower. Alternatives were compared to one another and a baseline of purchased chilled water and purchased steam. The best chiller and pumping arrangement option was selected and two other studies were done to decrease the amount of purchased steam and purchased make-up water. The variable primary flow plant with centrifugal chillers was selected and saved **$ 2,389,795** when compared to the purchased baseline over the 30-yr life-cycle. This option also had the shortest payback period of **5.3 years** for simple payback and **6.0 years** for discounted payback.

A heat recovery chiller was added to the plant to help promote a reduction in the purchased steam necessary for the domestic hot water and heating hot water systems. The size of the heat recovery was sized iteratively and the option that achieved the lowest energy usage and cost was selected. A 100 ton heat recovery chiller was selected. This reduced the purchased steam amount by **10,786 therms** annually which equates to **$ 284,643** over the 30-yr analysis.

Finally a condensate recovery system was studied to investigate the reduction in cooling tower make-up water. The system was found to recovery approximately **665 (1000 gallons)** of water annually, which correlates to an annual savings of **$ 3,489.**

When all the design studies are combined and compared to the baseline purchased utilities, the plant saves **$ 2,729,372** over the 30-yr life-cycle analysis. It also has a simple payback of **5.1** years and a discounted payback of **6.0** years.

When designing a new central plant for a building other systems are affected. The systems investigated were the electrical distribution and the structural support system. Through analysis it was found that additional electrical equipment would need added to the design to account for the increased load. The additional electrical components were estimated to add **$ 73,489** to the capital cost of the new design. The structural support system was also investigated to determine if additional reinforcing was necessary in the two-way concrete slab. It was found that additional reinforcing would be necessary at a cost of **$ 1,306** to be added to the capital cost of the new design.

A final 30-yr life-cycle cost analysis was performed with the adjusted new capital cost to get a realistic life-cycle savings and payback period. With all the costs included, the new central plant saved **$ 2,654,577** over the 30-yr life-cycle and had a simple payback of **5.6 years** with a discounted payback of **7.0 years**. These payback periods are very reasonable and this report shows that a dedicated central cooling plant for the South Patient Tower is worth the extra capital cost due to its reduction in energy, emissions and overall life-cycle cost.

References

American Concrete Institute. “Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary.” 2008.

This material code was referenced when redesigning the reinforcing for the concrete slab. Sections and Tables and Charts were utilized to get the correct values for the calculation.

ASHRAE. “ASHRAE Fundamentals 2008.” ASHRAE, Atlanta.

This handbook was referenced throughout this investigation to determine values, check values, and check methods of certain calculations.

Avery, G. “Improving the Efficiency of Chilled Water Plants.” ASHRAE Journal. (May 2001): 14-18.

This article discusses the options for chilled water plant optimization and increasing the efficiency of the plant as a whole. It discusses the various styles of pumping and pros and cons for each. This source provides more information on improving plant design that was useful when designing the chilled water plant.

General Services Agency. “Federal Greenhouse Gas Accounting and Reporting Guidance.” Technical Support Document. October 6, 2010.

This document discusses approaches of estimating the emission rates for purchased chilled water. Emissions of chilled water are related to the electricity required to power the chillers, this document gives default values to use when converting back to the electricity consumed by the chillers in a district plant based on the amount purchased.

Lawrence, T. M. “Predicting Condensate Collection from HVAC Air Handling Units.” ASHRAE Transactions. Volume 116, Part 2.

This article provides a method for estimating the condensate that can be recovered from a cooling coil by implementing psychrometrics. It was useful in determining the amount that is recovered in a year for use in the condensate recovery system design.

McQuinston, Parker, Spitler. “Heating, Ventilating, and Air Conditioning – Analysis and Design.” Wiley and Sons, Inc. 2005.

This book provided useful information when sizing pipe work for the central plant design to utilize in the sizing of the pumps and the other equipment. It also served as a reference for the condensate recovery properties when needed.

National Fire Protection Association. “National Electrical Code Handbook 2008.”

This handbook was consulted throughout the sizing calculations for the new feeders, breakers and conduit. This also helped provide information on the new switchboard and panelboard sizing.

National Institute of Standards and Testing. “Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2011.” Supplement. September 2011.

This supplement was referenced for all of the life-cycle cost analysis. The discount rate and escalation factors provided in this document were utilized and helped more accurately calculate the life-cycle cost of the design alternatives.

National Renewable Energy Laboratory. “Source Energy and Emission Factors for Energy Use in Buildings.” NREL Technical Report. June 2007.

This document was used to determine the emissions for each alternative considered. It provides tables that relate the amount of pollutants to the amount of energy used. Electricity values and Natural Gas values were of interest for this report.

Reed Construction Data. “R.S. Means Electrical Cost Data 2009.” Klingston, MA. 2009.

This reference was used in determining approximate costs for equipment related to the electrical redesign that was necessary for the central plant.

Reed Construction Data. “R.S. Means Facilities Cost Data 2011.” Klingston, MA. 2011.

This reference was used in determining approximate costs for reinforcing related to the structural redesign required from the new central plant being placed on the fifth floor slab.

Reed Construction Data. “R.S. Means Mechanical Cost Data 2010.” Klingston, MA. 2010.

This reference was used in determining approximate costs for equipment related to the mechanical redesign alternatives for use in the life-cycle comparisons.

Rishel, James B. “Reducing Energy Costs with Condensing Boilers & Heat Recovery Chillers.” (March 2007):46-53.

This article describes the implementation of a heat recovery chiller to help serve cooling loads in the winter and heating loads in the summer. It also explains the costs associated with the system and the potential energy savings that can occur.

Taylor, S. “Primary-Only vs. Primary-Secondary Variable Flow Systems.” ASHRAE Journal. (February 2002): 25-29.

This article discusses the pros and cons of primary-only chilled water systems. It includes information about first costs, plant space and pump power consumption as well as chiller staging strategies. This will aid in the design of the new chilled water plant pumping arrangement.

Trane. TRACE 700. Trane, Inc. Piscataway, NJ.

TRACE was essential in determine energy consumption for the loads calculated for the South Patient Tower. It provided useful comparisons of the various plants while also helping provide the information for the iterative calculation involved with sizing the heat recovery chiller.

U.S. Energy Information Administration. “Commercial Buildings Energy Consumption Survey – 2003.” Technical Report. 2003.

This survey was referenced for finding typical costs of purchased utilities. The report provided collected data from commercial buildings across the country and summarized costs and energy consumption.

Wilson, A. “Alternative Water Sources: Supply-Side Solutions for Green Buildings.” Environmental Building News. (May 2008).

This article describes the various recollection methods of storm water, gray water, and condensate and methods of reuse while maintaining quality required in codes and standards. There is a large discussion on the reuse of air-handler cooling coil condensate in cooling towers due to the high quality of the water and low pollutants. This article helped in the investigation of condensate recovery.

Appendix A: LEED Analysis

Energy and Atmosphere

Prerequisite 1: Fundamental Commissioning of Building Energy Systems

Verify that the project's energy-related systems are installed, and calibrated to perform according to the owner's project requirements, basis of design and construction documents. This point is pending on the South Patient Tower until the construction and commissioning is finished but should be achieved upon completion.

Prerequisite 2: Minimum Energy Performance

Establish the minimum level of energy efficiency for the proposed building and systems. The South Patient Tower is designed with ASHRAE 90.1 recommendations for energy usage which makes the design achieve this prerequisite.

Prerequisite 3: Fundamental Refrigerant Management

Reduce ozone depletion by having zero usage of chlorofluorocarbon (CFC) –based refrigerants in the new buildings heating, ventilating, air conditioning and refrigeration systems. The designers have obeyed the requirements for this credit and have achieved this prerequisite.

Credit 1: Optimize Energy Performance

To achieve increasing levels of energy performance above the baseline in the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use. The South Patient Tower designers followed the suggestions of *Option 1 – Whole Building Energy Simulation* and compared to the ASHRAE 90.1 baseline building, the tower achieved a 14% energy reduction and obtained 2 points.

Indoor Environmental Quality

Prerequisite 1: Minimum IAQ Performance

Meet the minimum requirements of Sections 4 through 7 of ASHRAE 62.1-2004, Ventilation for Acceptable Indoor Air Quality. Mechanical ventilation systems shall be designed using the Ventilation Rate Procedure or the applicable local code, whichever is more stringent. The tower complies with the standard and thus receives this prerequisite.

Prerequisite 2: Environmental Tobacco Smoke (ETS) Control

Minimize exposure of building occupants, indoor surfaces, and ventilation air distribution systems to Environmental Tobacco Smoke (ETS). The design achieves this prerequisite by following *Option 1* and prohibiting smoking in the building, and locating any exterior designated smoking area at least 25 feet away from entries, outdoor air intakes and operable windows.

Credit 2: Increased Ventilation

Provide additional outdoor air ventilation to improve indoor air quality for improved occupant comfort, well-being and productivity. Due to the increase in ventilation required by ASHRAE 170 which is above the requirements of ASHRAE 62.1, the South Patient Tower is predicted to obtain 30% more ventilation thus receiving this credit.

Credit 3.1: Construction IAQ Management Plan, During Construction

Reduce indoor air quality problems resulting from the construction/renovation process in order to help sustain the comfort and well-being of construction workers and building occupants. South Patient Tower is implementing the requirements of this credit and the point is pending with high hopes of obtaining it.

Credit 4.1: Low-Emitting Materials, Adhesives and Sealants

Reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants. The designers have taken this into account and the point should be achieved at the completion of construction.

Credit 4.2: Low-Emitting Materials, Paints and Coatings

Reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants with regards to paints and coatings. The designers have taken this into account and the point should be achieved at the completion of construction.

Credit 4.3: Low-Emitting Materials, Flooring Systems

Reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants with regard to the flooring systems especially carpeting. The designers have taken this into account and the point should be achieved at the completion of construction.

Credit 5: Indoor Chemical & Pollutant Source Control

Minimize exposure of building occupants to potentially hazardous particulates and chemical pollutants. The designer has specified filters that are either HEPA or better than MERV 13 for the towers air filtration media, which helps obtain this credit.

Credit 6.2: Controllability of Systems, Thermal Comfort

Provide a high level of thermal comfort system control by individual occupants or by specific groups in multi-occupant spaces to promote productivity, comfort and well-being of building occupants. South Patient Tower employs controls for at least 50% of the building occupants as well as providing comfort system controls for all shared multi-occupant spaces to enable adjustments to suit group needs and preferences, thus obtaining the credit.

Credit 7.1: Thermal Comfort, Design

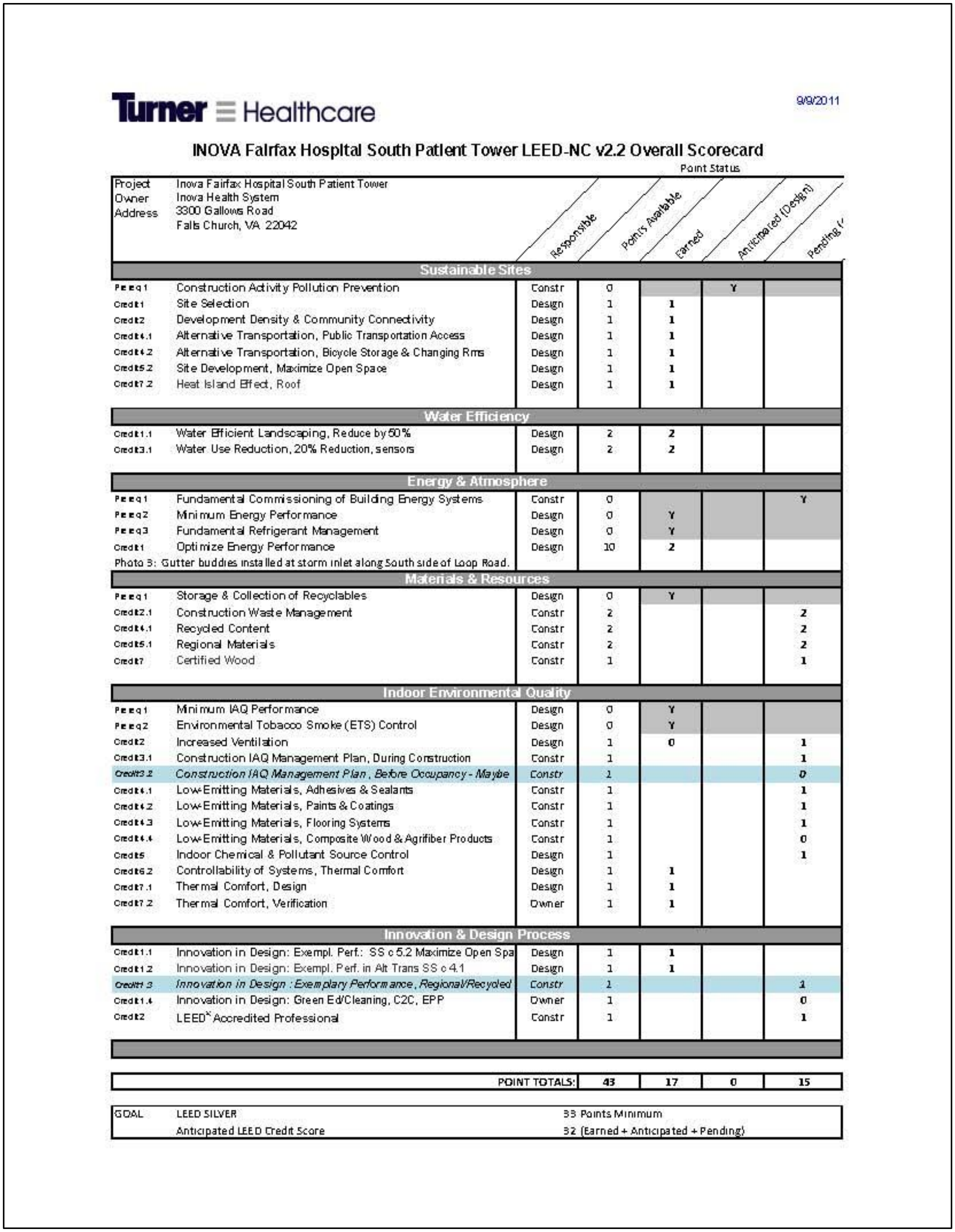
Provide a comfortable thermal environment that supports the productivity and well-being of building occupants. Since the designer followed the guidelines of ASHRAE Standard 55, the South Patient Tower is awarded this point.

Credit 7.2: Thermal Comfort, Verification

Provide for the assessment of building thermal comfort over time. There was an agreement to implement a thermal comfort survey to the building occupants over a period of 6 to 18 months after occupancy, given the project this credit.

All of the previous credit areas are assumed to be attainable by the design of the South Patient Tower. The mechanical system was able to earn five (5) credits with potential for six (6) more making up 11 of the 43 total points in the overall rating. More credits could have been earned with more energy efficient choices to increase the savings from the baseline.

LEED Scorecard



Turner Healthcare

9/9/2011

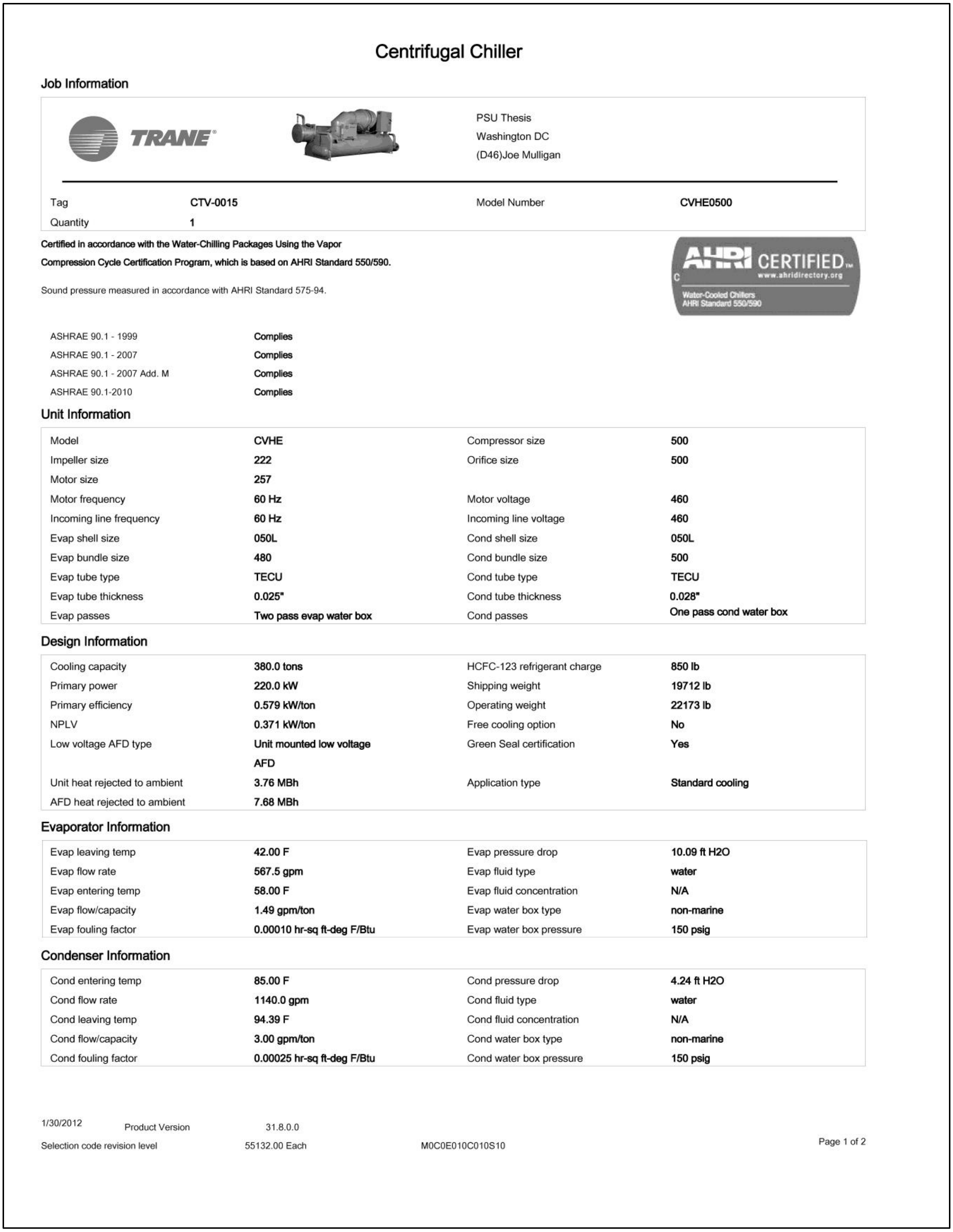
INOVA Fairfax Hospital South Patient Tower LEED-NC v2.2 Overall Scorecard

Project Inova Fairfax Hospital South Patient Tower
Owner Inova Health System
Address 3300 Gallows Road
Falls Church, VA 22042

				Point Status		
		Responsible	Points Available	Earned	Anticipated (Design)	Pending (
	Sustainable Sites					
Prereq 1	Construction Activity Pollution Prevention	Constr	0		Y	
Credit 1	Site Selection	Design	1	1		
Credit 2	Development Density & Community Connectivity	Design	1	1		
Credit 4.1	Alternative Transportation, Public Transportation Access	Design	1	1		
Credit 4.2	Alternative Transportation, Bicycle Storage & Changing Rms	Design	1	1		
Credit 5.2	Site Development, Maximize Open Space	Design	1	1		
Credit 7.2	Heat Island Effect, Roof	Design	1	1		
	Water Efficiency					
Credit 1.1	Water Efficient Landscaping, Reduce by 50%	Design	2	2		
Credit 3.1	Water Use Reduction, 20% Reduction, sensors	Design	2	2		
	Energy & Atmosphere					
Prereq 1	Fundamental Commissioning of Building Energy Systems	Constr	0			Y
Prereq 2	Minimum Energy Performance	Design	0	Y		
Prereq 3	Fundamental Refrigerant Management	Design	0	Y		
Credit 1	Optimize Energy Performance	Design	10	2		
Photo 3: Gutter buddies installed at storm inlet along South side of Loop Road.						
	Materials & Resources					
Prereq 1	Storage & Collection of Recyclables	Design	0	Y		
Credit 2.1	Construction Waste Management	Constr	2			2
Credit 4.1	Recycled Content	Constr	2			2
Credit 5.1	Regional Materials	Constr	2			2
Credit 7	Certified Wood	Constr	1			1
	Indoor Environmental Quality					
Prereq 1	Minimum IAQ Performance	Design	0	Y		
Prereq 2	Environmental Tobacco Smoke (ETS) Control	Design	0	Y		
Credit 2	Increased Ventilation	Design	1	0		1
Credit 3.1	Construction IAQ Management Plan, During Construction	Constr	1			1
Credit 3.2	*Construction IAQ Management Plan, Before Occupancy - Maybe*	*Constr*	*1*			*0*
Credit 4.1	Low-Emitting Materials, Adhesives & Sealants	Constr	1			1
Credit 4.2	Low-Emitting Materials, Paints & Coatings	Constr	1			1
Credit 4.3	Low-Emitting Materials, Flooring Systems	Constr	1			1
Credit 4.4	Low-Emitting Materials, Composite Wood & Agrifiber Products	Constr	1			0
Credit 5	Indoor Chemical & Pollutant Source Control	Design	1			1
Credit 6.2	Controllability of Systems, Thermal Comfort	Design	1	1		
Credit 7.1	Thermal Comfort, Design	Design	1	1		
Credit 7.2	Thermal Comfort, Verification	Owner	1	1		
	Innovation & Design Process					
Credit 1.1	Innovation in Design: Exempl. Perf.: SS c 5.2 Maximize Open Spa	Design	1	1		
Credit 1.2	Innovation in Design: Exempl. Perf. in Alt Trans SS c 4.1	Design	1	1		
Credit 1.3	*Innovation in Design : Exemplary Performance, Regional/Recycled*	*Constr*	*1*			*1*
Credit 1.4	Innovation in Design: Green Ed/Cleaning, C2C, EPP	Owner	1			0
Credit 2	LEED^{x} Accredited Professional	Constr	1			1
		POINT TOTALS:	43	17	0	15

GOAL	LEED SILVER	33 Points Minimum
	Anticipated LEED Credit Score	32 (Earned + Anticipated + Pending)

Appendix B: Submittal Documentation



Centrifugal Chiller

Job Information

PSU Thesis
Washington DC
(D46)Joe Mulligan

Tag	CTV-0015	Model Number	CVHE0500
Quantity	1		

Certified in accordance with the Water-Chilling Packages Using the Vapor Compression Cycle Certification Program, which is based on AHRI Standard 550/590.

Sound pressure measured in accordance with AHRI Standard 575-94.

AHRI CERTIFIED™ www.ahridirectory.org
Water-Cooled Chillers AHRI Standard 550/590

ASHRAE 90.1 - 1999	Complies
ASHRAE 90.1 - 2007	Complies
ASHRAE 90.1 - 2007 Add. M	Complies
ASHRAE 90.1-2010	Complies

Unit Information

Model	CVHE	Compressor size	500
Impeller size	222	Orifice size	500
Motor size	257		
Motor frequency	60 Hz	Motor voltage	460
Incoming line frequency	60 Hz	Incoming line voltage	460
Evap shell size	050L	Cond shell size	050L
Evap bundle size	480	Cond bundle size	500
Evap tube type	TECU	Cond tube type	TECU
Evap tube thickness	0.025"	Cond tube thickness	0.028"
Evap passes	Two pass evap water box	Cond passes	One pass cond water box

Design Information

Cooling capacity	380.0 tons	HCFC-123 refrigerant charge	850 lb
Primary power	220.0 kW	Shipping weight	19712 lb
Primary efficiency	0.579 kW/ton	Operating weight	22173 lb
NPLV	0.371 kW/ton	Free cooling option	No
Low voltage AFD type	Unit mounted low voltage AFD	Green Seal certification	Yes
Unit heat rejected to ambient	3.76 MBh	Application type	Standard cooling
AFD heat rejected to ambient	7.68 MBh		

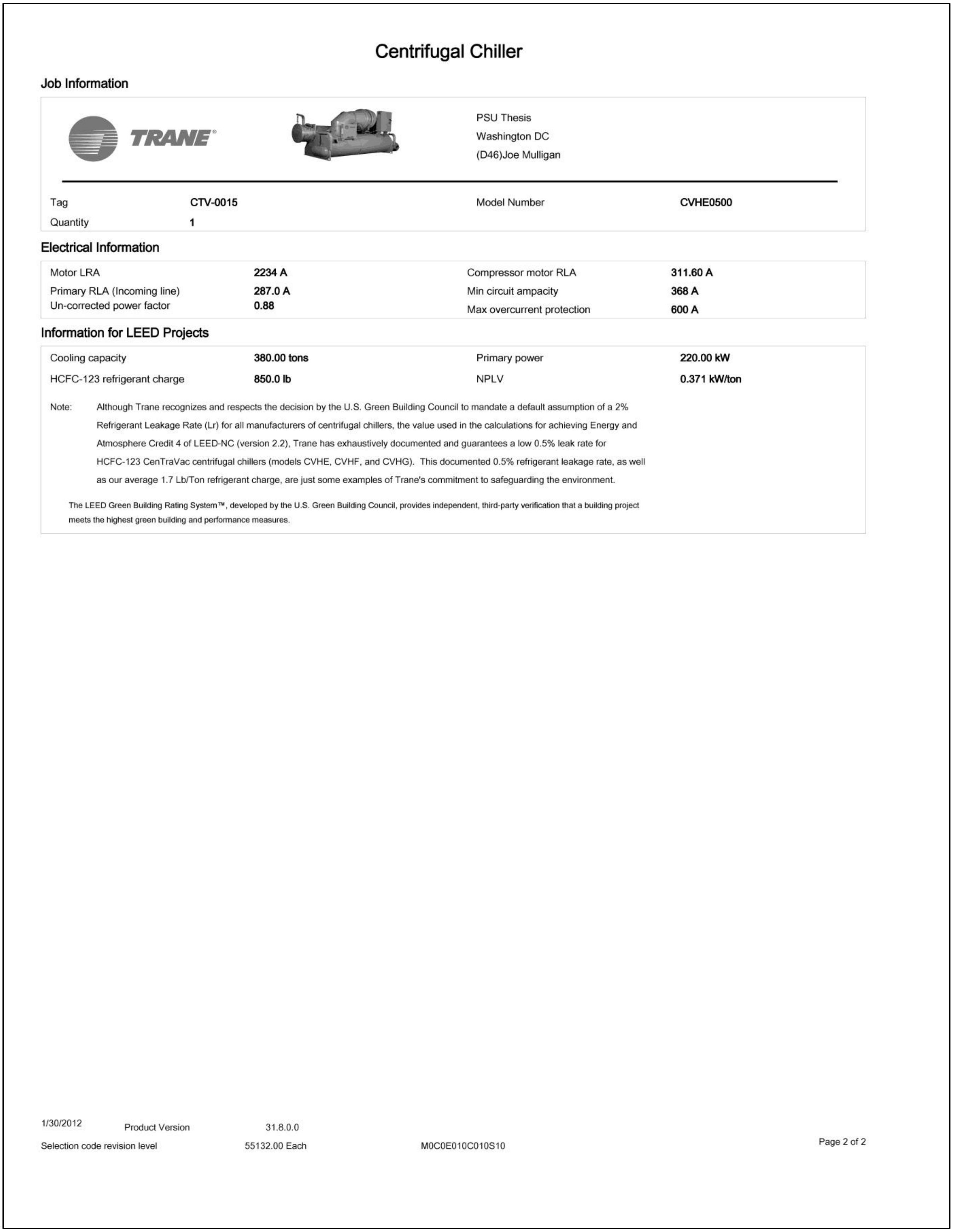
Evaporator Information

Evap leaving temp	42.00 F	Evap pressure drop	10.09 ft H2O
Evap flow rate	567.5 gpm	Evap fluid type	water
Evap entering temp	58.00 F	Evap fluid concentration	N/A
Evap flow/capacity	1.49 gpm/ton	Evap water box type	non-marine
Evap fouling factor	0.00010 hr-sq ft-deg F/Btu	Evap water box pressure	150 psig

Condenser Information

Cond entering temp	85.00 F	Cond pressure drop	4.24 ft H2O
Cond flow rate	1140.0 gpm	Cond fluid type	water
Cond leaving temp	94.39 F	Cond fluid concentration	N/A
Cond flow/capacity	3.00 gpm/ton	Cond water box type	non-marine
Cond fouling factor	0.00025 hr-sq ft-deg F/Btu	Cond water box pressure	150 psig

1/30/2012 Product Version 31.8.0.0
Selection code revision level 55132.00 Each M0C0E010C010S10 Page 1 of 2



Centrifugal Chiller

Job Information

TRANE

PSU Thesis
Washington DC
(D46)Joe Mulligan

Tag	**CTV-0015**	Model Number	**CVHE0500**
Quantity	**1**		

Electrical Information

Motor LRA	**2234 A**	Compressor motor RLA	**311.60 A**
Primary RLA (Incoming line)	**287.0 A**	Min circuit ampacity	**368 A**
Un-corrected power factor	**0.88**	Max overcurrent protection	**600 A**

Information for LEED Projects

Cooling capacity	**380.00 tons**	Primary power	**220.00 kW**
HCFC-123 refrigerant charge	**850.0 lb**	NPLV	**0.371 kW/ton**

Note: Although Trane recognizes and respects the decision by the U.S. Green Building Council to mandate a default assumption of a 2% Refrigerant Leakage Rate (Lr) for all manufacturers of centrifugal chillers, the value used in the calculations for achieving Energy and Atmosphere Credit 4 of LEED-NC (version 2.2), Trane has exhaustively documented and guarantees a low 0.5% leak rate for HCFC-123 CenTraVac centrifugal chillers (models CVHE, CVHF, and CVHG). This documented 0.5% refrigerant leakage rate, as well as our average 1.7 Lb/Ton refrigerant charge, are just some examples of Trane's commitment to safeguarding the environment.

The LEED Green Building Rating System™, developed by the U.S. Green Building Council, provides independent, third-party verification that a building project meets the highest green building and performance measures.

1/30/2012 Product Version 31.8.0.0
Selection code revision level 55132.00 Each M0C0E010C010S10

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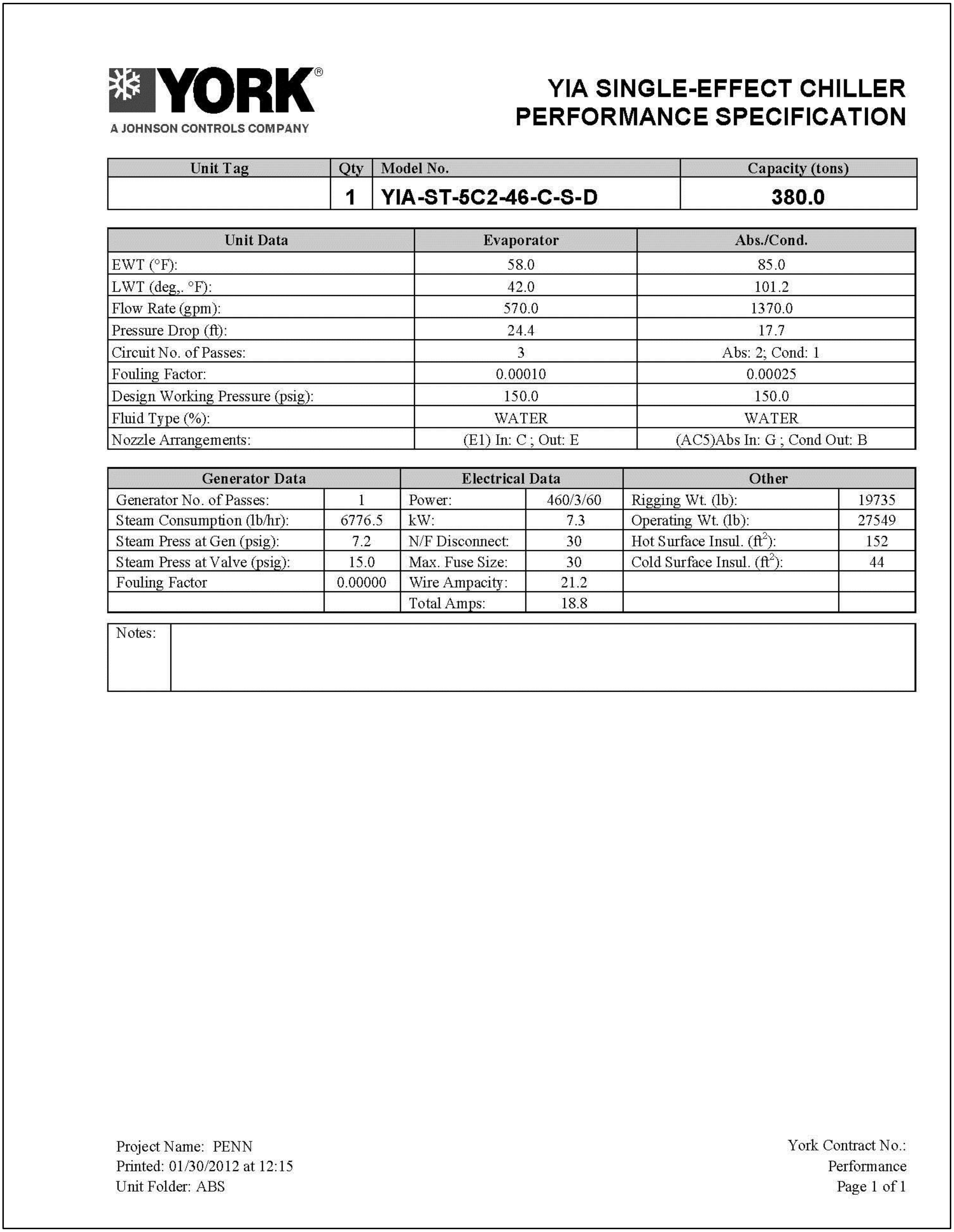


YORK
A JOHNSON CONTROLS COMPANY

YIA SINGLE-EFFECT CHILLER PERFORMANCE SPECIFICATION

Unit Tag	Qty	Model No.	Capacity (tons)
	1	**YIA-ST-5C2-46-C-S-D**	**380.0**

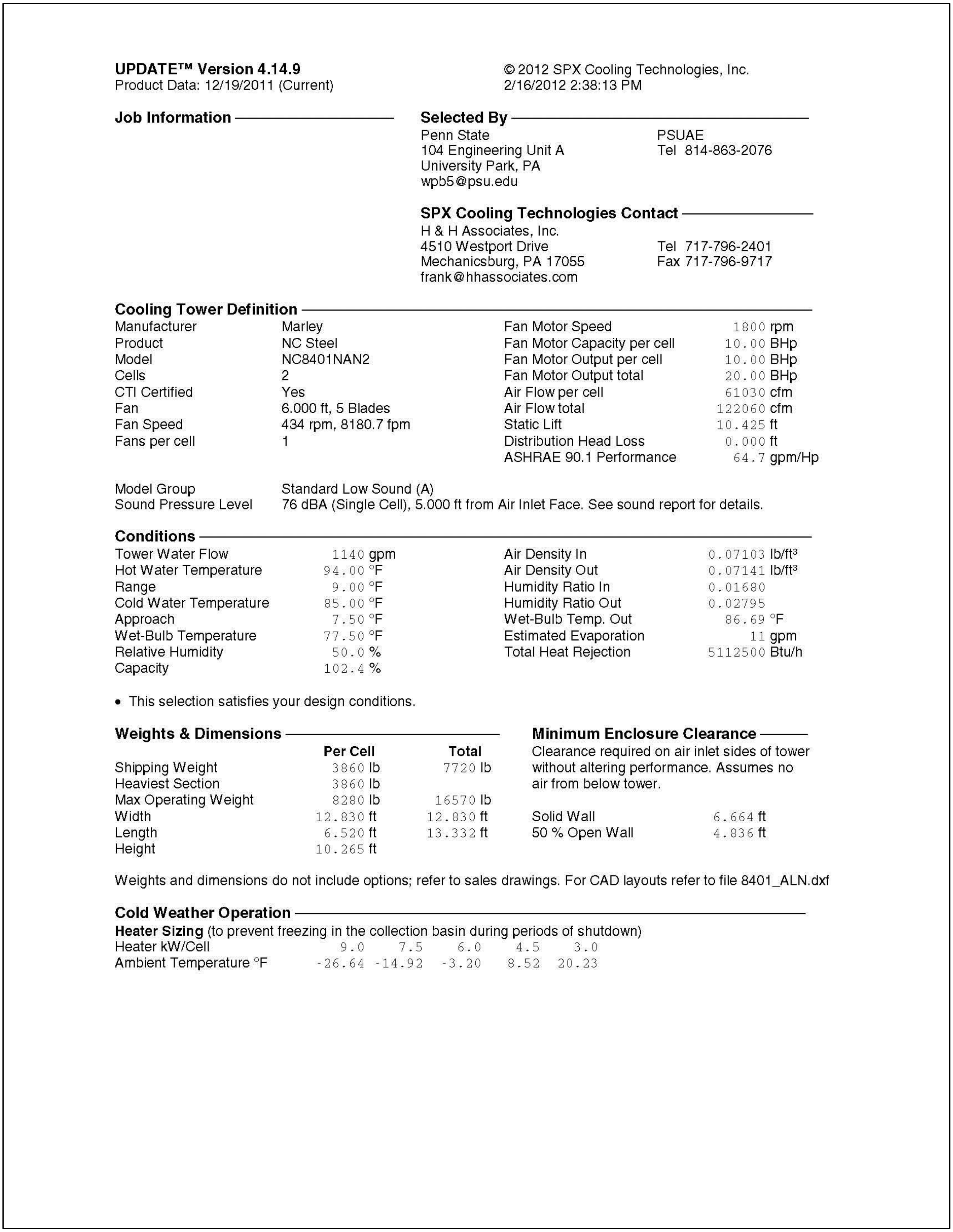
Unit Data	Evaporator	Abs./Cond.
EWT (°F):	58.0	85.0
LWT (deg,. °F):	42.0	101.2
Flow Rate (gpm):	570.0	1370.0
Pressure Drop (ft):	24.4	17.7
Circuit No. of Passes:	3	Abs: 2; Cond: 1
Fouling Factor:	0.00010	0.00025
Design Working Pressure (psig):	150.0	150.0
Fluid Type (%):	WATER	WATER
Nozzle Arrangements:	(E1) In: C ; Out: E	(AC5)Abs In: G ; Cond Out: B

Generator Data		Electrical Data		Other	
Generator No. of Passes:	1	Power:	460/3/60	Rigging Wt. (lb):	19735
Steam Consumption (lb/hr):	6776.5	kW:	7.3	Operating Wt. (lb):	27549
Steam Press at Gen (psig):	7.2	N/F Disconnect:	30	Hot Surface Insul. (ft^2):	152
Steam Press at Valve (psig):	15.0	Max. Fuse Size:	30	Cold Surface Insul. (ft^2):	44
Fouling Factor	0.00000	Wire Ampacity:	21.2		
		Total Amps:	18.8		

Notes:	

Project Name: PENN
Printed: 01/30/2012 at 12:15
Unit Folder: ABS

York Contract No.:
Performance
Page 1 of 1



UPDATE™ Version 4.14.9
Product Data: 12/19/2011 (Current)

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2/16/2012 2:38:13 PM

Job Information

Selected By

Penn State
104 Engineering Unit A
University Park, PA
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PSUAE
Tel 814-863-2076

SPX Cooling Technologies Contact

H & H Associates, Inc.
4510 Westport Drive
Mechanicsburg, PA 17055
frank@hhassociates.com

Tel 717-796-2401
Fax 717-796-9717

Cooling Tower Definition

Manufacturer	Marley	Fan Motor Speed	1800 rpm
Product	NC Steel	Fan Motor Capacity per cell	10.00 BHp
Model	NC8401NAN2	Fan Motor Output per cell	10.00 BHp
Cells	2	Fan Motor Output total	20.00 BHp
CTI Certified	Yes	Air Flow per cell	61030 cfm
Fan	6.000 ft, 5 Blades	Air Flow total	122060 cfm
Fan Speed	434 rpm, 8180.7 fpm	Static Lift	10.425 ft
Fans per cell	1	Distribution Head Loss	0.000 ft
		ASHRAE 90.1 Performance	64.7 gpm/Hp

Model Group	Standard Low Sound (A)
Sound Pressure Level	76 dBA (Single Cell), 5.000 ft from Air Inlet Face. See sound report for details.

Conditions

Tower Water Flow	1140 gpm	Air Density In	0.07103 lb/ft³
Hot Water Temperature	94.00 °F	Air Density Out	0.07141 lb/ft³
Range	9.00 °F	Humidity Ratio In	0.01680
Cold Water Temperature	85.00 °F	Humidity Ratio Out	0.02795
Approach	7.50 °F	Wet-Bulb Temp. Out	86.69 °F
Wet-Bulb Temperature	77.50 °F	Estimated Evaporation	11 gpm
Relative Humidity	50.0 %	Total Heat Rejection	5112500 Btu/h
Capacity	102.4 %		

- This selection satisfies your design conditions.

Weights & Dimensions

	Per Cell	Total
Shipping Weight	3860 lb	7720 lb
Heaviest Section	3860 lb	
Max Operating Weight	8280 lb	16570 lb
Width	12.830 ft	12.830 ft
Length	6.520 ft	13.332 ft
Height	10.265 ft	

Minimum Enclosure Clearance

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

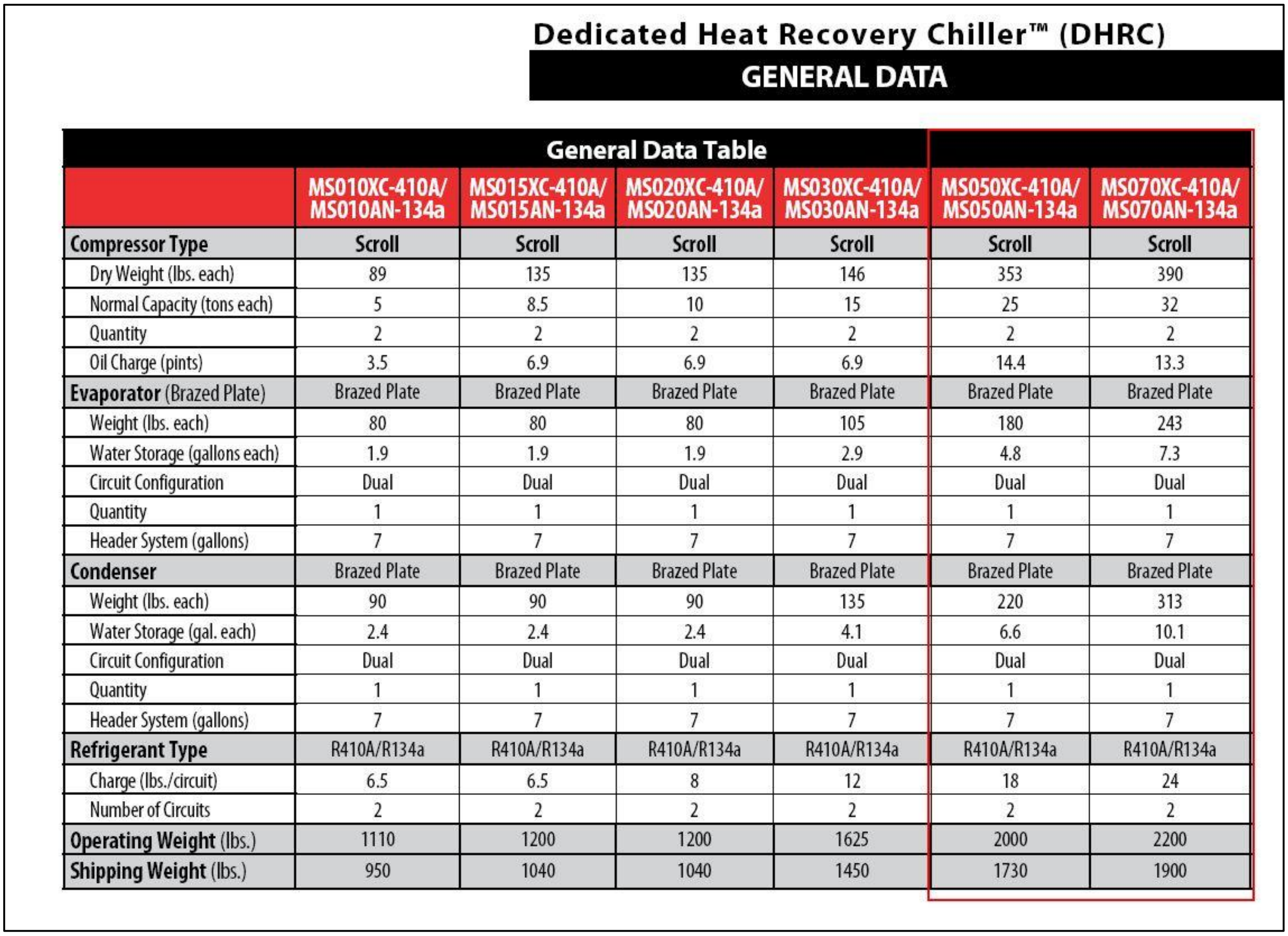
Solid Wall	6.664 ft
50 % Open Wall	4.836 ft

Weights and dimensions do not include options; refer to sales drawings. For CAD layouts refer to file 8401_ALN.dxf

Cold Weather Operation

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

Heater kW/Cell	9.0	7.5	6.0	4.5	3.0
Ambient Temperature °F	-26.64	-14.92	-3.20	8.52	20.23



Dedicated Heat Recovery Chiller™ (DHRC)

GENERAL DATA

General Data Table

	MS010XC-410A/ MS010AN-134a	MS015XC-410A/ MS015AN-134a	MS020XC-410A/ MS020AN-134a	MS030XC-410A/ MS030AN-134a	MS050XC-410A/ MS050AN-134a	MS070XC-410A/ MS070AN-134a
Compressor Type	Scroll	Scroll	Scroll	Scroll	Scroll	Scroll
Dry Weight (lbs. each)	89	135	135	146	353	390
Normal Capacity (tons each)	5	8.5	10	15	25	32
Quantity	2	2	2	2	2	2
Oil Charge (pints)	3.5	6.9	6.9	6.9	14.4	13.3
Evaporator (Brazed Plate)	Brazed Plate	Brazed Plate	Brazed Plate	Brazed Plate	Brazed Plate	Brazed Plate
Weight (lbs. each)	80	80	80	105	180	243
Water Storage (gallons each)	1.9	1.9	1.9	2.9	4.8	7.3
Circuit Configuration	Dual	Dual	Dual	Dual	Dual	Dual
Quantity	1	1	1	1	1	1
Header System (gallons)	7	7	7	7	7	7
Condenser	Brazed Plate	Brazed Plate	Brazed Plate	Brazed Plate	Brazed Plate	Brazed Plate
Weight (lbs. each)	90	90	90	135	220	313
Water Storage (gal. each)	2.4	2.4	2.4	4.1	6.6	10.1
Circuit Configuration	Dual	Dual	Dual	Dual	Dual	Dual
Quantity	1	1	1	1	1	1
Header System (gallons)	7	7	7	7	7	7
Refrigerant Type	R410A/R134a	R410A/R134a	R410A/R134a	R410A/R134a	R410A/R134a	R410A/R134a
Charge (lbs./circuit)	6.5	6.5	8	12	18	24
Number of Circuits	2	2	2	2	2	2
Operating Weight (lbs.)	1110	1200	1200	1625	2000	2200
Shipping Weight (lbs.)	950	1040	1040	1450	1730	1900

Appendix C: Life-Cycle Cost Calculations

Alternative 1: Purchased District Steam and Chilled Water									
	ELECTRIC		**STEAM**		**CHILLED WATER**		**COOLING TOWER MAKE-UP**		
Ann. Use	5,286,290	kWh	55,111	therms	180,510.00	therms	0	1000 gal.	
Unit Cost	$ 0.08	$/kWh	$ 1.14	$/therm	$ 1.40	$/therm	$ 2.16	/1000 gal.	
Ann. Cost	$ 422,903		$ 62,827		$ 252,714		$ -		
	Discount Rate	2.30	%	(OMB 30 Year)					
Date	Year	Capital	Other Mat.	Elect. Escalation	Nat. Gas Escalation	Elect. Cost	Steam Cost	Chilled Water Cost	Make-Up Water Cost
2011	1	$ -	$ 3,000	1.00	1.00	$ 422,903	$ 62,827	$ 252,714	$ -
2012	2	$ -	$ 3,000	0.99	0.99	$ 418,674	$ 62,198	$ 250,187	$ -
2013	3	$ -	$ 3,000	0.98	0.97	$ 414,445	$ 60,942	$ 247,660	$ -
2014	4	$ -	$ 3,000	0.97	0.94	$ 410,216	$ 59,057	$ 245,133	$ -
2015	5	$ -	$ 3,000	0.97	0.95	$ 410,216	$ 59,685	$ 245,133	$ -
2016	6	$ -	$ 3,000	0.97	0.95	$ 410,216	$ 59,685	$ 245,133	$ -
2017	7	$ -	$ 3,000	0.98	0.96	$ 414,445	$ 60,313	$ 247,660	$ -
2018	8	$ -	$ 3,000	0.99	0.96	$ 418,674	$ 60,313	$ 250,187	$ -
2019	9	$ -	$ 3,000	0.99	0.97	$ 418,674	$ 60,942	$ 250,187	$ -
2020	10	$ -	$ 3,000	1.00	0.99	$ 422,903	$ 62,198	$ 252,714	$ -
2021	11	$ -	$ 3,000	1.00	1.01	$ 422,903	$ 63,455	$ 252,714	$ -
2022	12	$ -	$ 3,000	1.00	1.03	$ 422,903	$ 64,711	$ 252,714	$ -
2023	13	$ -	$ 3,000	1.00	1.05	$ 422,903	$ 65,968	$ 252,714	$ -
2024	14	$ -	$ 3,000	1.00	1.07	$ 422,903	$ 67,224	$ 252,714	$ -
2025	15	$ -	$ 3,000	1.01	1.10	$ 427,132	$ 69,109	$ 255,241	$ -
2026	16	$ -	$ 3,000	1.01	1.11	$ 427,132	$ 69,737	$ 255,241	$ -
2027	17	$ -	$ 3,000	1.02	1.13	$ 431,361	$ 70,994	$ 257,768	$ -
2028	18	$ -	$ 3,000	1.02	1.14	$ 431,361	$ 71,622	$ 257,768	$ -
2029	19	$ -	$ 3,000	1.02	1.15	$ 431,361	$ 72,251	$ 257,768	$ -
2030	20	$ -	$ 3,000	1.02	1.15	$ 431,361	$ 72,251	$ 257,768	$ -
2031	21	$ -	$ 3,000	1.02	1.16	$ 431,361	$ 72,879	$ 257,768	$ -
2032	22	$ -	$ 3,000	1.03	1.17	$ 435,590	$ 73,507	$ 260,295	$ -
2033	23	$ -	$ 3,000	1.03	1.19	$ 435,590	$ 74,764	$ 260,295	$ -
2034	24	$ -	$ 3,000	1.04	1.21	$ 439,819	$ 76,020	$ 262,823	$ -
2035	25	$ -	$ 3,000	1.04	1.23	$ 439,819	$ 77,277	$ 262,823	$ -
2036	26	$ -	$ 3,000	1.05	1.24	$ 444,048	$ 77,905	$ 265,350	$ -
2037	27	$ -	$ 3,000	1.05	1.26	$ 444,048	$ 79,161	$ 265,350	$ -
2038	28	$ -	$ 3,000	1.05	1.27	$ 444,048	$ 79,790	$ 265,350	$ -
2039	29	$ -	$ 3,000	1.06	1.29	$ 448,277	$ 81,046	$ 267,877	$ -
2040	30	$ -	$ 3,000	1.06	1.31	$ 448,277	$ 82,303	$ 267,877	$ -
	Column NPV	$ -	$ 64,499			$ 9,160,401	$ 1,454,382	$5,473,975	$ -
		Total NPV						**$ 16,153,256**	

Alternative 2: Primary/Secondary Centrifugal Chiller									
	ELECTRIC		**STEAM**		**CHILLED WATER**		**COOLING TOWER MAKE-UP**		
Ann. Use	6,488,933	kWh	55,111	therms	0	therms	5,575.00	1000 gal.	
Unit Cost	$ 0.08	$/kWh	$ 1.14	$/therm	$ 1.40	$/therm	$ 2.16	/1000 gal.	
Ann. Cost	$ 519,115		$ 62,827		$ -		$ 12,042		
	Discount Rate	2.30	%	(OMB 30 Year)					
Date	Year	Capital	Other Mat.	Elect. Escalation	Nat. Gas Escalation	Elect. Cost	Steam Cost	Chilled Water Cost	Make-Up Water Cost
2011	1	$ 807,454	$ 3,000	1.00	1.00	$ 519,115	$ 62,827	$ -	$ 12,042
2012	2	$ -	$ 3,000	0.99	0.99	$ 513,923	$ 62,198	$ -	$ 12,042
2013	3	$ -	$ 3,000	0.98	0.97	$ 508,732	$ 60,942	$ -	$ 12,042
2014	4	$ -	$ 3,000	0.97	0.94	$ 503,541	$ 59,057	$ -	$ 12,042
2015	5	$ -	$ 3,000	0.97	0.95	$ 503,541	$ 59,685	$ -	$ 12,042
2016	6	$ -	$ 3,000	0.97	0.95	$ 503,541	$ 59,685	$ -	$ 12,042
2017	7	$ -	$ 3,000	0.98	0.96	$ 508,732	$ 60,313	$ -	$ 12,042
2018	8	$ -	$ 3,000	0.99	0.96	$ 513,923	$ 60,313	$ -	$ 12,042
2019	9	$ -	$ 3,000	0.99	0.97	$ 513,923	$ 60,942	$ -	$ 12,042
2020	10	$ -	$ 3,000	1.00	0.99	$ 519,115	$ 62,198	$ -	$ 12,042
2021	11	$ -	$ 3,000	1.00	1.01	$ 519,115	$ 63,455	$ -	$ 12,042
2022	12	$ -	$ 3,000	1.00	1.03	$ 519,115	$ 64,711	$ -	$ 12,042
2023	13	$ -	$ 3,000	1.00	1.05	$ 519,115	$ 65,968	$ -	$ 12,042
2024	14	$ -	$ 3,000	1.00	1.07	$ 519,115	$ 67,224	$ -	$ 12,042
2025	15	$ -	$ 3,000	1.01	1.10	$ 524,306	$ 69,109	$ -	$ 12,042
2026	16	$ -	$ 3,000	1.01	1.11	$ 524,306	$ 69,737	$ -	$ 12,042
2027	17	$ -	$ 3,000	1.02	1.13	$ 529,497	$ 70,994	$ -	$ 12,042
2028	18	$ -	$ 3,000	1.02	1.14	$ 529,497	$ 71,622	$ -	$ 12,042
2029	19	$ -	$ 3,000	1.02	1.15	$ 529,497	$ 72,251	$ -	$ 12,042
2030	20	$ -	$ 3,000	1.02	1.15	$ 529,497	$ 72,251	$ -	$ 12,042
2031	21	$ -	$ 3,000	1.02	1.16	$ 529,497	$ 72,879	$ -	$ 12,042
2032	22	$ -	$ 3,000	1.03	1.17	$ 534,688	$ 73,507	$ -	$ 12,042
2033	23	$ -	$ 3,000	1.03	1.19	$ 534,688	$ 74,764	$ -	$ 12,042
2034	24	$ -	$ 3,000	1.04	1.21	$ 539,879	$ 76,020	$ -	$ 12,042
2035	25	$ -	$ 3,000	1.04	1.23	$ 539,879	$ 77,277	$ -	$ 12,042
2036	26	$ -	$ 3,000	1.05	1.24	$ 545,070	$ 77,905	$ -	$ 12,042
2037	27	$ -	$ 3,000	1.05	1.26	$ 545,070	$ 79,161	$ -	$ 12,042
2038	28	$ -	$ 3,000	1.05	1.27	$ 545,070	$ 79,790	$ -	$ 12,042
2039	29	$ -	$ 3,000	1.06	1.29	$ 550,262	$ 81,046	$ -	$ 12,042
2040	30	$ -	$ 3,000	1.06	1.31	$ 550,262	$ 82,303	$ -	$ 12,042
	Column NPV	$ 807,454	$ 64,499			$ 11,244,413	$ 1,454,382	$0.00	$ 258,897
		Total NPV						**$13,829,644**	

Alternative 3: VPF Centrifugal Chiller									
	ELECTRIC		**STEAM (NAT. GAS)**		**CHILLED WATER**		**COOLING TOWER MAKE-UP**		
Ann. Use	6,470,107	kWh	55,111	therm	0	therm	5575	1000 gal.	
Unit Cost	$ 0.08	$/kWh	$ 1.14	$/therm	$ 1.40	$/therm	$ 2.16	/1000 gal.	
Ann. Cost	$ 517,609		$ 62,827		$ -		$ 12,042		
	Discount Rate	2.30	%	(OMB 30 Year)					
Date	Year	Capital	Other Mat.	Elect. Escalation	Nat. Gas Escalation	Elect. Cost	Steam Cost	Chilled Water Cost	Make-Up Water Cost
2011	1	$ 773,894	$ 3,000	1.00	1.00	$ 517,609	$ 62,827	$ -	$ 12,042
2012	2	$ -	$ 3,000	0.99	0.99	$ 512,432	$ 62,198	$ -	$ 12,042
2013	3	$ -	$ 3,000	0.98	0.97	$ 507,256	$ 60,942	$ -	$ 12,042
2014	4	$ -	$ 3,000	0.97	0.94	$ 502,080	$ 59,057	$ -	$ 12,042
2015	5	$ -	$ 3,000	0.97	0.95	$ 502,080	$ 59,685	$ -	$ 12,042
2016	6	$ -	$ 3,000	0.97	0.95	$ 502,080	$ 59,685	$ -	$ 12,042
2017	7	$ -	$ 3,000	0.98	0.96	$ 507,256	$ 60,313	$ -	$ 12,042
2018	8	$ -	$ 3,000	0.99	0.96	$ 512,432	$ 60,313	$ -	$ 12,042
2019	9	$ -	$ 3,000	0.99	0.97	$ 512,432	$ 60,942	$ -	$ 12,042
2020	10	$ -	$ 3,000	1.00	0.99	$ 517,609	$ 62,198	$ -	$ 12,042
2021	11	$ -	$ 3,000	1.00	1.01	$ 517,609	$ 63,455	$ -	$ 12,042
2022	12	$ -	$ 3,000	1.00	1.03	$ 517,609	$ 64,711	$ -	$ 12,042
2023	13	$ -	$ 3,000	1.00	1.05	$ 517,609	$ 65,968	$ -	$ 12,042
2024	14	$ -	$ 3,000	1.00	1.07	$ 517,609	$ 67,224	$ -	$ 12,042
2025	15	$ -	$ 3,000	1.01	1.10	$ 522,785	$ 69,109	$ -	$ 12,042
2026	16	$ -	$ 3,000	1.01	1.11	$ 522,785	$ 69,737	$ -	$ 12,042
2027	17	$ -	$ 3,000	1.02	1.13	$ 527,961	$ 70,994	$ -	$ 12,042
2028	18	$ -	$ 3,000	1.02	1.14	$ 527,961	$ 71,622	$ -	$ 12,042
2029	19	$ -	$ 3,000	1.02	1.15	$ 527,961	$ 72,251	$ -	$ 12,042
2030	20	$ -	$ 3,000	1.02	1.15	$ 527,961	$ 72,251	$ -	$ 12,042
2031	21	$ -	$ 3,000	1.02	1.16	$ 527,961	$ 72,879	$ -	$ 12,042
2032	22	$ -	$ 3,000	1.03	1.17	$ 533,137	$ 73,507	$ -	$ 12,042
2033	23	$ -	$ 3,000	1.03	1.19	$ 533,137	$ 74,764	$ -	$ 12,042
2034	24	$ -	$ 3,000	1.04	1.21	$ 538,313	$ 76,020	$ -	$ 12,042
2035	25	$ -	$ 3,000	1.04	1.23	$ 538,313	$ 77,277	$ -	$ 12,042
2036	26	$ -	$ 3,000	1.05	1.24	$ 543,489	$ 77,905	$ -	$ 12,042
2037	27	$ -	$ 3,000	1.05	1.26	$ 543,489	$ 79,161	$ -	$ 12,042
2038	28	$ -	$ 3,000	1.05	1.27	$ 543,489	$ 79,790	$ -	$ 12,042
2039	29	$ -	$ 3,000	1.06	1.29	$ 548,665	$ 81,046	$ -	$ 12,042
2040	30	$ -	$ 3,000	1.06	1.31	$ 548,665	$ 82,303	$ -	$ 12,042
	Column NPV	$ 773,894	$ 64,499			$ 11,211,790	$ 1,454,382	$0.00	$ 258,897
		Total NPV						**$ 13,763,462**	

Alternative 4: Primary/Secondary Absorption Chiller									
	ELECTRIC		**STEAM (NAT. GAS)**		**CHILLED WATER**		**COOLING TOWER MAKE-UP**		
Ann. Use	5,830,308	kWh	193,917	therm	0	therm	8,515	1000 gal.	
Unit Cost	$ 0.08	$/kWh	$ 1.14	$/therm	$ 1.40	$/therm	$ 2.16	/1000 gal.	
Ann. Cost	$ 466,425		$ 221,065		$ -		$ 18,392		
	Discount Rate	2.30	%	(OMB 30 Year)					
Date	Year	Capital	Other Mat.	Elect. Escalation	Nat. Gas Escalation	Elect. Cost	Steam Cost	Chilled Water Cost	Make-Up Water Cost
2011	1	$ 1,046,344	$ 3,000	1.00	1.00	$ 466,425	$ 221,065	$ -	$ 18,392
2012	2	$ -	$ 3,000	0.99	0.99	$ 461,760	$ 218,855	$ -	$ 18,392
2013	3	$ -	$ 3,000	0.98	0.97	$ 457,096	$ 214,433	$ -	$ 18,392
2014	4	$ -	$ 3,000	0.97	0.94	$ 452,432	$ 207,801	$ -	$ 18,392
2015	5	$ -	$ 3,000	0.97	0.95	$ 452,432	$ 210,012	$ -	$ 18,392
2016	6	$ -	$ 3,000	0.97	0.95	$ 452,432	$ 210,012	$ -	$ 18,392
2017	7	$ -	$ 3,000	0.98	0.96	$ 457,096	$ 212,223	$ -	$ 18,392
2018	8	$ -	$ 3,000	0.99	0.96	$ 461,760	$ 212,223	$ -	$ 18,392
2019	9	$ -	$ 3,000	0.99	0.97	$ 461,760	$ 214,433	$ -	$ 18,392
2020	10	$ -	$ 3,000	1.00	0.99	$ 466,425	$ 218,855	$ -	$ 18,392
2021	11	$ -	$ 3,000	1.00	1.01	$ 466,425	$ 223,276	$ -	$ 18,392
2022	12	$ -	$ 3,000	1.00	1.03	$ 466,425	$ 227,697	$ -	$ 18,392
2023	13	$ -	$ 3,000	1.00	1.05	$ 466,425	$ 232,119	$ -	$ 18,392
2024	14	$ -	$ 3,000	1.00	1.07	$ 466,425	$ 236,540	$ -	$ 18,392
2025	15	$ -	$ 3,000	1.01	1.10	$ 471,089	$ 243,172	$ -	$ 18,392
2026	16	$ -	$ 3,000	1.01	1.11	$ 471,089	$ 245,383	$ -	$ 18,392
2027	17	$ -	$ 3,000	1.02	1.13	$ 475,753	$ 249,804	$ -	$ 18,392
2028	18	$ -	$ 3,000	1.02	1.14	$ 475,753	$ 252,015	$ -	$ 18,392
2029	19	$ -	$ 3,000	1.02	1.15	$ 475,753	$ 254,225	$ -	$ 18,392
2030	20	$ -	$ 3,000	1.02	1.15	$ 475,753	$ 254,225	$ -	$ 18,392
2031	21	$ -	$ 3,000	1.02	1.16	$ 475,753	$ 256,436	$ -	$ 18,392
2032	22	$ -	$ 3,000	1.03	1.17	$ 480,417	$ 258,646	$ -	$ 18,392
2033	23	$ -	$ 3,000	1.03	1.19	$ 480,417	$ 263,068	$ -	$ 18,392
2034	24	$ -	$ 3,000	1.04	1.21	$ 485,082	$ 267,489	$ -	$ 18,392
2035	25	$ -	$ 3,000	1.04	1.23	$ 485,082	$ 271,910	$ -	$ 18,392
2036	26	$ -	$ 3,000	1.05	1.24	$ 489,746	$ 274,121	$ -	$ 18,392
2037	27	$ -	$ 3,000	1.05	1.26	$ 489,746	$ 278,542	$ -	$ 18,392
2038	28	$ -	$ 3,000	1.05	1.27	$ 489,746	$ 280,753	$ -	$ 18,392
2039	29	$ -	$ 3,000	1.06	1.29	$ 494,410	$ 285,174	$ -	$ 18,392
2040	30	$ -	$ 3,000	1.06	1.31	$ 494,410	$ 289,596	$ -	$ 18,392
	Column NPV	$ 1,046,344	$ 64,499			$ 10,103,108	$ 5,117,480	$0.00	$ 395,427
		Total NPV						**$ 16,726,857**	

Alternative 5: VPF Absorption Chiller									
	ELECTRIC		**STEAM (NAT. GAS)**		**CHILLED WATER**		**COOLING TOWER MAKE-UP**		
Ann. Use	5,775,767	kWh	193,917	therm	0	therms	8,185	1000 gal.	
Unit Cost	$ 0.08	$/kWh	$ 1.14	$/therm	$ 1.40	$/therm	$ 2.16	/1000 gal.	
Ann. Cost	$ 462,061		$ 221,065		$ -		$ 17,680		
	Discount Rate	2.30	%	(OMB 30 Year)					
Date	Year	Capital	Other Mat.	Elect. Escalation	Nat. Gas Escalation	Elect. Cost	Steam Cost	Chilled Water Cost	Make-Up Water Cost
2011	1	$ 1,012,784	$ 3,000	1.00	1.00	$ 462,061	$ 221,065	$ -	$ 17,680
2012	2	$ -	$ 3,000	0.99	0.99	$ 457,441	$ 218,855	$ -	$ 17,680
2013	3	$ -	$ 3,000	0.98	0.97	$ 452,820	$ 214,433	$ -	$ 17,680
2014	4	$ -	$ 3,000	0.97	0.94	$ 448,200	$ 207,801	$ -	$ 17,680
2015	5	$ -	$ 3,000	0.97	0.95	$ 448,200	$ 210,012	$ -	$ 17,680
2016	6	$ -	$ 3,000	0.97	0.95	$ 448,200	$ 210,012	$ -	$ 17,680
2017	7	$ -	$ 3,000	0.98	0.96	$ 452,820	$ 212,223	$ -	$ 17,680
2018	8	$ -	$ 3,000	0.99	0.96	$ 457,441	$ 212,223	$ -	$ 17,680
2019	9	$ -	$ 3,000	0.99	0.97	$ 457,441	$ 214,433	$ -	$ 17,680
2020	10	$ -	$ 3,000	1.00	0.99	$ 462,061	$ 218,855	$ -	$ 17,680
2021	11	$ -	$ 3,000	1.00	1.01	$ 462,061	$ 223,276	$ -	$ 17,680
2022	12	$ -	$ 3,000	1.00	1.03	$ 462,061	$ 227,697	$ -	$ 17,680
2023	13	$ -	$ 3,000	1.00	1.05	$ 462,061	$ 232,119	$ -	$ 17,680
2024	14	$ -	$ 3,000	1.00	1.07	$ 462,061	$ 236,540	$ -	$ 17,680
2025	15	$ -	$ 3,000	1.01	1.10	$ 466,682	$ 243,172	$ -	$ 17,680
2026	16	$ -	$ 3,000	1.01	1.11	$ 466,682	$ 245,383	$ -	$ 17,680
2027	17	$ -	$ 3,000	1.02	1.13	$ 471,303	$ 249,804	$ -	$ 17,680
2028	18	$ -	$ 3,000	1.02	1.14	$ 471,303	$ 252,015	$ -	$ 17,680
2029	19	$ -	$ 3,000	1.02	1.15	$ 471,303	$ 254,225	$ -	$ 17,680
2030	20	$ -	$ 3,000	1.02	1.15	$ 471,303	$ 254,225	$ -	$ 17,680
2031	21	$ -	$ 3,000	1.02	1.16	$ 471,303	$ 256,436	$ -	$ 17,680
2032	22	$ -	$ 3,000	1.03	1.17	$ 475,923	$ 258,646	$ -	$ 17,680
2033	23	$ -	$ 3,000	1.03	1.19	$ 475,923	$ 263,068	$ -	$ 17,680
2034	24	$ -	$ 3,000	1.04	1.21	$ 480,544	$ 267,489	$ -	$ 17,680
2035	25	$ -	$ 3,000	1.04	1.23	$ 480,544	$ 271,910	$ -	$ 17,680
2036	26	$ -	$ 3,000	1.05	1.24	$ 485,164	$ 274,121	$ -	$ 17,680
2037	27	$ -	$ 3,000	1.05	1.26	$ 485,164	$ 278,542	$ -	$ 17,680
2038	28	$ -	$ 3,000	1.05	1.27	$ 485,164	$ 280,753	$ -	$ 17,680
2039	29	$ -	$ 3,000	1.06	1.29	$ 489,785	$ 285,174	$ -	$ 17,680
2040	30	$ -	$ 3,000	1.06	1.31	$ 489,785	$ 289,596	$ -	$ 17,680
	Column NPV	$ 1,012,784	$ 64,499			$ 10,008,596	$ 5,117,480	$0.00	$ 380,103
		Total NPV						**$ 16,583,461**	

VPF Centrifugal Chiller with 100 ton HR									
	ELECTRIC		**STEAM (NAT. GAS)**		**CHILLED WATER**		**COOLING TOWER MAKE-UP**		
Ann. Use	6,425,125	kWh	44,325	therm	0	therms	4,891	1000 gal.	
Unit Cost	$ 0.08	$/kWh	$ 1.14	$/therm	$ 1.40	$/therm	$ 2.16	/1000 gal.	
Ann. Cost	$ 514,010		$ 50,531		$ -		$ 10,565		
	Discount Rate	2.30	%	(OMB 30 Year)					
Date	Year	Capital	Other Mat.	Elect. Escalation	Nat. Gas Escalation	Elect. Cost	Steam Cost	Chilled Water Cost	Make-Up Water Cost
2011	1	$ 833,894	$ 3,000	1.00	1.00	$ 514,010	$ 50,531	$ -	$ 10,565
2012	2	$ -	$ 3,000	0.99	0.99	$ 508,870	$ 50,025	$ -	$ 10,565
2013	3	$ -	$ 3,000	0.98	0.97	$ 503,730	$ 49,015	$ -	$ 10,565
2014	4	$ -	$ 3,000	0.97	0.94	$ 498,590	$ 47,499	$ -	$ 10,565
2015	5	$ -	$ 3,000	0.97	0.95	$ 498,590	$ 48,004	$ -	$ 10,565
2016	6	$ -	$ 3,000	0.97	0.95	$ 498,590	$ 48,004	$ -	$ 10,565
2017	7	$ -	$ 3,000	0.98	0.96	$ 503,730	$ 48,509	$ -	$ 10,565
2018	8	$ -	$ 3,000	0.99	0.96	$ 508,870	$ 48,509	$ -	$ 10,565
2019	9	$ -	$ 3,000	0.99	0.97	$ 508,870	$ 49,015	$ -	$ 10,565
2020	10	$ -	$ 3,000	1.00	0.99	$ 514,010	$ 50,025	$ -	$ 10,565
2021	11	$ -	$ 3,000	1.00	1.01	$ 514,010	$ 51,036	$ -	$ 10,565
2022	12	$ -	$ 3,000	1.00	1.03	$ 514,010	$ 52,046	$ -	$ 10,565
2023	13	$ -	$ 3,000	1.00	1.05	$ 514,010	$ 53,057	$ -	$ 10,565
2024	14	$ -	$ 3,000	1.00	1.07	$ 514,010	$ 54,068	$ -	$ 10,565
2025	15	$ -	$ 3,000	1.01	1.10	$ 519,150	$ 55,584	$ -	$ 10,565
2026	16	$ -	$ 3,000	1.01	1.11	$ 519,150	$ 56,089	$ -	$ 10,565
2027	17	$ -	$ 3,000	1.02	1.13	$ 524,290	$ 57,099	$ -	$ 10,565
2028	18	$ -	$ 3,000	1.02	1.14	$ 524,290	$ 57,605	$ -	$ 10,565
2029	19	$ -	$ 3,000	1.02	1.15	$ 524,290	$ 58,110	$ -	$ 10,565
2030	20	$ -	$ 3,000	1.02	1.15	$ 524,290	$ 58,110	$ -	$ 10,565
2031	21	$ -	$ 3,000	1.02	1.16	$ 524,290	$ 58,615	$ -	$ 10,565
2032	22	$ -	$ 3,000	1.03	1.17	$ 529,430	$ 59,121	$ -	$ 10,565
2033	23	$ -	$ 3,000	1.03	1.19	$ 529,430	$ 60,131	$ -	$ 10,565
2034	24	$ -	$ 3,000	1.04	1.21	$ 534,570	$ 61,142	$ -	$ 10,565
2035	25	$ -	$ 3,000	1.04	1.23	$ 534,570	$ 62,153	$ -	$ 10,565
2036	26	$ -	$ 3,000	1.05	1.24	$ 539,711	$ 62,658	$ -	$ 10,565
2037	27	$ -	$ 3,000	1.05	1.26	$ 539,711	$ 63,668	$ -	$ 10,565
2038	28	$ -	$ 3,000	1.05	1.27	$ 539,711	$ 64,174	$ -	$ 10,565
2039	29	$ -	$ 3,000	1.06	1.29	$ 544,851	$ 65,184	$ -	$ 10,565
2040	30	$ -	$ 3,000	1.06	1.31	$ 544,851	$ 66,195	$ -	$ 10,565
	Column NPV	$ 833,894	$ 64,499			$ 11,133,842	$ 1,169,739	$0.00	$ 227,133
		Total NPV						**$ 13,429,107**	

VPF Centrifugal Chiller with 100 ton HR and Condensate Recovery									
	ELECTRIC		**STEAM (NAT. GAS)**		**CHILLED WATER**		**COOLING TOWER MAKE-UP**		
Ann. Use	6,440,675	kWh	44,325	therm	0	therms	3,960	1000 gal.	
Unit Cost	$ 0.08	$/kWh	$ 1.14	$/therm	$ 1.40	$/therm	$ 2.16	/1000 gal.	
Ann. Cost	$ 515,254		$ 50,531		$ -		$ 8,553		
	Discount Rate	2.30	%	(OMB 30 Year)					
Date	Year	Capital	Other Mat.	Elect. Escalation	Nat. Gas Escalation	Elect. Cost	Steam Cost	Chilled Water Cost	Make-Up Water Cost
2011	1	$ 844,984	$ 3,000	1.00	1.00	$ 515,254	$ 50,531	$ -	$ 8,553
2012	2	$ -	$ 3,000	0.99	0.99	$ 510,101	$ 50,025	$ -	$ 8,553
2013	3	$ -	$ 3,000	0.98	0.97	$ 504,949	$ 49,015	$ -	$ 8,553
2014	4	$ -	$ 3,000	0.97	0.94	$ 499,796	$ 47,499	$ -	$ 8,553
2015	5	$ -	$ 3,000	0.97	0.95	$ 499,796	$ 48,004	$ -	$ 8,553
2016	6	$ -	$ 3,000	0.97	0.95	$ 499,796	$ 48,004	$ -	$ 8,553
2017	7	$ -	$ 3,000	0.98	0.96	$ 504,949	$ 48,509	$ -	$ 8,553
2018	8	$ -	$ 3,000	0.99	0.96	$ 510,101	$ 48,509	$ -	$ 8,553
2019	9	$ -	$ 3,000	0.99	0.97	$ 510,101	$ 49,015	$ -	$ 8,553
2020	10	$ -	$ 3,000	1.00	0.99	$ 515,254	$ 50,025	$ -	$ 8,553
2021	11	$ -	$ 3,000	1.00	1.01	$ 515,254	$ 51,036	$ -	$ 8,553
2022	12	$ -	$ 3,000	1.00	1.03	$ 515,254	$ 52,046	$ -	$ 8,553
2023	13	$ -	$ 3,000	1.00	1.05	$ 515,254	$ 53,057	$ -	$ 8,553
2024	14	$ -	$ 3,000	1.00	1.07	$ 515,254	$ 54,068	$ -	$ 8,553
2025	15	$ -	$ 3,000	1.01	1.10	$ 520,407	$ 55,584	$ -	$ 8,553
2026	16	$ -	$ 3,000	1.01	1.11	$ 520,407	$ 56,089	$ -	$ 8,553
2027	17	$ -	$ 3,000	1.02	1.13	$ 525,559	$ 57,099	$ -	$ 8,553
2028	18	$ -	$ 3,000	1.02	1.14	$ 525,559	$ 57,605	$ -	$ 8,553
2029	19	$ -	$ 3,000	1.02	1.15	$ 525,559	$ 58,110	$ -	$ 8,553
2030	20	$ -	$ 3,000	1.02	1.15	$ 525,559	$ 58,110	$ -	$ 8,553
2031	21	$ -	$ 3,000	1.02	1.16	$ 525,559	$ 58,615	$ -	$ 8,553
2032	22	$ -	$ 3,000	1.03	1.17	$ 530,712	$ 59,121	$ -	$ 8,553
2033	23	$ -	$ 3,000	1.03	1.19	$ 530,712	$ 60,131	$ -	$ 8,553
2034	24	$ -	$ 3,000	1.04	1.21	$ 535,864	$ 61,142	$ -	$ 8,553
2035	25	$ -	$ 3,000	1.04	1.23	$ 535,864	$ 62,153	$ -	$ 8,553
2036	26	$ -	$ 3,000	1.05	1.24	$ 541,017	$ 62,658	$ -	$ 8,553
2037	27	$ -	$ 3,000	1.05	1.26	$ 541,017	$ 63,668	$ -	$ 8,553
2038	28	$ -	$ 3,000	1.05	1.27	$ 541,017	$ 64,174	$ -	$ 8,553
2039	29	$ -	$ 3,000	1.06	1.29	$ 546,169	$ 65,184	$ -	$ 8,553
2040	30	$ -	$ 3,000	1.06	1.31	$ 546,169	$ 66,195	$ -	$ 8,553
	Column NPV	$ 844,984	$ 64,499			$ 11,160,788	$ 1,169,739	$0.00	$ 183,875
		Total NPV						**$ 13,423,885**	

Appendix D: Condensate Recovery Calculations

January	Typical Weather (°F)				Design						
Hour	OADB	OAWB	MADB	MAWB	Htg (Btuh)	Clg (Tons)	CFM	Mixed Air HR	Supply Air HR	Condensate	
1	33.3	30.1	33.3	30.1	-2,808,939	0.0	0.0	0.002823	0.006189	0.0	
2	31.6	28.5	31.6	28.5	-2,495,189	0.0	0.0	0.002595	0.006189	0.0	
3	30.1	27.2	30.1	27.2	-3,375,892	0.0	0.0	0.002446	0.006189	0.0	
4	28.9	25.8	28.9	25.8	-3,435,575	0.0	0.0	0.002214	0.006189	0.0	
5	28.0	25.3	28.0	25.3	-3,398,188	0.0	0.0	0.002227	0.006189	0.0	
6	27.4	24.7	27.4	24.7	-3,418,113	0.0	0.0	0.002150	0.006189	0.0	
7	27.2	24.7	27.2	24.7	-3,231,107	0.0	0.0	0.002189	0.006189	0.0	
8	27.8	25.2	27.8	25.2	-2,328,699	0.0	0.0	0.002234	0.006189	0.0	
9	29.3	26.5	29.3	26.5	-1,985,170	0.0	0.0	0.002368	0.006189	0.0	
10	31.6	28.3	31.6	28.3	-1,927,919	0.0	0.0	0.002526	0.006189	0.0	
11	34.4	30.4	34.4	30.4	-932,590	0.0	0.0	0.002713	0.006189	0.0	
12	37.5	32.5	37.5	32.5	-1,128,333	0.0	0.0	0.002728	0.006189	0.0	
13	40.3	34.5	40.3	34.5	-900,523	12.7	2,672.6	0.002871	0.006189	38.7	
14	42.6	36.5	42.6	36.5	-1,211,406	22.7	4,773.7	0.003149	0.006189	63.4	
15	44.1	37.4	44.1	37.4	-899,453	27.9	5,864.2	0.003177	0.006189	77.2	
16	44.7	37.5	44.7	37.5	-1,139,770	23.7	4,973.3	0.003083	0.006189	67.5	
17	44.5	37.5	44.5	37.5	-1,078,751	16.2	3,410.1	0.003128	0.006189	45.6	
18	43.9	37.6	43.9	37.6	-1,136,271	0.0	0.0	0.003304	0.006189	0.0	
19	43.0	37.2	43.0	37.2	-866,269	0.0	0.0	0.003343	0.006189	0.0	
20	41.8	36.8	41.8	36.8	-621,384	0.0	0.0	0.003450	0.006189	0.0	
21	40.3	35.7	40.3	35.7	-557,112	0.0	0.0	0.003345	0.006189	0.0	
22	38.6	34.5	38.6	34.5	-672,011	0.0	0.0	0.003252	0.006189	0.0	
23	36.9	33.3	36.9	33.3	-2,588,091	0.0	0.0	0.003169	0.006189	0.0	Days/Month
24	35.0	31.5	35.0	31.5	-1,809,302	0.0	0.0	0.002994	0.006189	0.0	31
									Total	292.4	9064.8

February	Typical Weather (°F)				Design						
Hour	OADB	OAWB			Htg (Btuh)	Clg (Tons)	CFM	Mixed Air HR	Supply Air HR	Condensate	
1	34.4	30.4	34.4	30.4	-3,534,586	0.0	0.0	0.002713	0.006189	0.0	
2	33.0	29.3	33.0	29.3	-2,499,214	0.0	0.0	0.002598	0.006189	0.0	
3	31.8	28.3	31.8	28.3	-2,684,531	0.0	0.0	0.002486	0.006189	0.0	
4	30.8	27.4	30.8	27.4	-3,402,589	0.0	0.0	0.002375	0.006189	0.0	
5	30.1	26.7	30.1	26.7	-3,199,349	0.0	0.0	0.002277	0.006189	0.0	
6	29.6	26.2	29.6	26.2	-3,294,605	0.0	0.0	0.002208	0.006189	0.0	
7	29.5	26.2	29.5	26.2	-1,808,017	0.0	0.0	0.002228	0.006189	0.0	
8	29.9	26.8	29.9	26.8	-1,175,227	0.0	0.0	0.00235	0.006189	0.0	
9	31.1	27.9	31.1	27.9	-1,078,260	0.0	0.0	0.002487	0.006189	0.0	
10	33.0	28.8	33.0	28.8	-1,126,898	0.0	0.0	0.002422	0.006189	0.0	
11	35.3	29.9	35.3	29.9	-1,207,537	0.0	0.0	0.002356	0.006189	0.0	
12	37.8	31.8	37.8	31.8	-1,133,648	0.0	0.0	0.002551	0.006189	0.0	
13	40.1	33.0	40.1	33.0	-1,374,379	8.4	1,771.2	0.002336	0.006189	29.8	
14	41.9	34.7	41.9	34.7	-1,385,558	16.2	3,405.9	0.00259	0.006189	53.6	
15	43.2	35.5	43.2	35.5	-1,280,075	20.0	4,210.6	0.002614	0.006189	65.8	
16	43.6	35.8	43.6	35.8	-1,490,378	17.0	3,576.1	0.002643	0.006189	55.4	
17	43.4	35.9	43.4	35.9	-1,310,676	11.5	2,424.7	0.002728	0.006189	36.7	
18	43.0	35.8	43.0	35.8	-1,411,051	0.0	0.0	0.002778	0.006189	0.0	
19	42.3	36.0	42.3	36.0	-1,046,684	0.0	0.0	0.003015	0.006189	0.0	
20	41.3	35.9	41.3	35.9	-742,175	0.0	0.0	0.0032	0.006189	0.0	
21	40.1	35.0	40.1	35.0	-657,639	0.0	0.0	0.003112	0.006189	0.0	
22	38.7	34.0	38.7	34.0	-720,183	0.0	0.0	0.003035	0.006189	0.0	
23	37.3	32.9	37.3	32.9	-2,222,592	0.0	0.0	0.002926	0.006189	0.0	Days/Month
24	35.8	31.5	35.8	31.5	-1,160,643	0.0	0.0	0.002836	0.006189	0.0	28
									Total	241.2	6753.8

March	Typical Weather (°F)				Design						
Hour	OADB	OAWB			Htg (Btuh)	Clg (Tons)	CFM	Mixed Air HR	Supply Air HR	Condensate	
1	44.1	39.1	44.1	39.1	-2,498,451	0.0	0.0	0.003884	0.006189	0.0	
2	42.3	37.7	42.3	37.7	-647,043	0.0	0.0	0.003706	0.006189	0.0	
3	40.6	36.3	40.6	36.3	-2,723,540	0.0	0.0	0.003518	0.006189	0.0	
4	39.2	35.1	39.2	35.1	-941,547	0.0	0.0	0.003354	0.006189	0.0	
5	38.2	34.7	38.2	34.7	-2,229,930	0.0	0.0	0.003424	0.006189	0.0	
6	37.6	34.1	37.6	34.1	-1,247,825	0.0	0.0	0.003321	0.006189	0.0	
7	37.4	34.0	37.4	34.0	-1,206,158	0.0	0.0	0.003327	0.006189	0.0	
8	37.9	34.5	37.9	34.5	-721,003	0.0	0.0	0.00341	0.006189	0.0	
9	39.6	35.5	39.6	35.5	-581,693	17.3	3,641.2	0.003422	0.006189	44.0	
10	42.3	37.0	42.3	37.0	-692,873	37.8	7,940.1	0.003419	0.006189	96.1	
11	45.5	39.1	45.5	39.1	-494,307	70.2	14,745.6	0.003569	0.006189	168.8	
12	48.9	41.4	48.9	41.4	-450,304	105.8	22,227.6	0.00379	0.006189	233.0	
13	52.1	43.5	52.1	43.5	-413,009	124.0	26,057.9	0.004005	0.006189	248.6	
14	54.7	45.5	54.7	45.5	-355,771	146.5	30,772.8	0.004342	0.006189	248.3	
15	56.4	46.4	56.4	46.4	-413,264	151.7	31,882.2	0.004385	0.006189	251.3	
16	57.0	46.9	57.0	46.9	-450,268	148.1	31,125.8	0.00449	0.006189	231.0	
17	56.8	46.2	56.8	46.2	-651,583	138.9	29,190.7	0.004199	0.006189	253.8	
18	56.1	46.2	56.1	46.2	-772,888	130.1	27,335.4	0.004357	0.006189	218.8	
19	55.1	46.2	55.1	46.2	-790,882	99.2	20,832.5	0.004584	0.006189	146.1	
20	53.7	46.4	53.7	46.4	-677,783	72.7	15,279.3	0.004996	0.006189	79.6	
21	52.1	45.6	52.1	45.6	-717,861	46.8	9,826.9	0.004978	0.006189	52.0	
22	50.2	44.4	50.2	44.4	-648,364	22.5	4,727.5	0.004847	0.006189	27.7	
23	48.2	42.7	48.2	42.7	-875,981	7.8	1,632.6	0.004525	0.006189	11.9	Days/Month
24	46.1	40.8	46.1	40.8	-1,289,363	0.0	0.0	0.004161	0.006189	0.0	31
									Total	2311.1	71643.3

April	Typical Weather (°F)				Design						
Hour	OADB	OAWB			Htg (Btuh)	Clg (Tons)	CFM	Mixed Air HR	Supply Air HR	Condensate	
1	52.3	47.4	52.3	47.4	-698,027	42.8	8,999.0	0.005799	0.006189	15.3	
2	50.4	45.9	50.4	45.9	-1,551,985	32.2	6,757.2	0.005506	0.006189	20.2	
3	48.7	44.8	48.7	44.8	-774,726	28.1	5,906.2	0.005373	0.006189	21.1	
4	47.3	43.5	47.3	43.5	-1,074,682	23.3	4,885.1	0.005091	0.006189	23.4	
5	46.2	42.8	46.2	42.8	-979,292	24.5	5,156.1	0.005023	0.006189	26.3	
6	45.6	42.2	45.6	42.2	-994,728	26.0	5,462.9	0.00489	0.006189	31.0	
7	45.3	42.2	45.3	42.2	-324,395	43.7	9,186.0	0.004958	0.006189	49.4	
8	45.8	42.1	45.8	42.1	-201,785	76.5	16,073.5	0.0048	0.006189	97.5	
9	47.0	42.4	47.0	42.4	-198,231	94.9	19,947.9	0.004662	0.006189	133.1	
10	49.0	43.2	49.0	43.2	-199,482	122.1	25,660.8	0.00457	0.006189	181.5	
11	51.6	44.5	51.6	44.5	-201,577	166.5	34,975.1	0.004577	0.006189	246.3	
12	54.3	46.5	54.3	46.5	-181,898	216.8	45,560.4	0.004908	0.006189	255.0	
13	57.1	49.0	57.1	49.0	-143,968	250.2	52,576.0	0.005502	0.006189	157.8	
14	59.6	50.7	59.6	50.7	-144,709	273.4	57,433.8	0.005803	0.006189	96.9	
15	61.6	52.3	61.6	52.3	-144,055	287.0	60,306.0	0.006192	0.006189	0.8	
16	62.9	53.3	62.9	53.3	-156,753	282.5	59,356.3	0.006437	0.006189	64.3	
17	63.4	53.6	63.4	53.6	-190,697	277.4	58,289.0	0.006488	0.006189	76.1	
18	63.1	53.6	63.1	53.6	-240,116	269.5	56,624.9	0.006556	0.006189	90.8	
19	62.5	53.8	62.5	53.8	-248,286	230.6	48,457.9	0.006803	0.006189	130.0	
20	61.4	53.8	61.4	53.8	-244,370	193.2	40,599.7	0.007055	0.006189	153.6	
21	60.0	53.3	60.0	53.3	-252,243	158.4	33,273.2	0.007099	0.006189	132.3	
22	58.3	52.2	58.3	52.2	-222,431	110.7	23,263.5	0.006891	0.006189	71.4	
23	56.4	50.5	56.4	50.5	-368,088	64.9	13,644.6	0.006428	0.006189	14.2	Days/Month
24	54.3	48.9	54.3	48.9	-201,590	50.5	10,614.8	0.006088	0.006189	4.7	30
									Total	2093.0	62790.1

May	Typical Weather (°F)				Design							
Hour	OADB	OAWB			Htg (Btuh)		Clg (Tons)	CFM	Mixed Air HR	Supply Air HR	Condensate	
1	63.1	55.6	63.1	55.6	-1,792		168.7	35,443.6	0.007679	0.006189	230.7	
2	61.3	54.4	61.3	54.4	-12,227		143.1	30,066.9	0.007411	0.006189	160.5	
3	59.9	53.2	59.9	53.2	-135,494		126.3	26,543.3	0.007067	0.006189	101.8	
4	58.8	52.4	58.8	52.4	-267,476		118.9	24,973.8	0.006884	0.006189	75.8	
5	58.1	51.9	58.1	51.9	-225,046		117.1	24,612.4	0.006776	0.006189	63.1	
6	57.9	52.4	57.9	52.4	-163,714		133.2	27,980.5	0.00709	0.006189	110.1	
7	58.5	52.8	58.5	52.8	0		181.1	38,055.3	0.007169	0.006189	162.9	
8	60.3	53.1	60.3	53.1	0		264.3	55,540.7	0.006921	0.006189	177.6	
9	63.1	54.4	63.1	54.4	0		291.8	61,316.6	0.007	0.006189	217.3	
10	66.5	56.4	66.5	56.4	0		345.7	72,629.0	0.007364	0.006189	372.8	
11	70.1	58.8	70.1	58.8	0		437.8	91,978.1	0.007971	0.006189	716.1	
12	73.4	60.3	73.4	60.3	0		428.3	89,984.2	0.008145	0.006189	769.0	
13	76.2	62.0	75.4	61.4	0		441.3	92,730.3	0.008387	0.006189	890.5	
14	78.0	63.0	76.1	61.7	0		464.2	97,531.4	0.00842	0.006189	950.7	
15	78.6	62.9	76.3	61.7	0		469.0	98,539.9	0.008375	0.006189	941.1	
16	78.4	62.9	76.2	61.7	0		470.5	98,848.7	0.008397	0.006189	953.6	
17	77.7	62.5	75.9	61.5	0		480.5	100,952.0	0.008337	0.006189	947.4	
18	76.6	62.2	75.6	61.4	0		496.8	104,389.4	0.008341	0.006189	981.5	
19	75.2	61.7	75.1	61.2	0		538.3	113,106.9	0.008327	0.006189	1056.5	
20	73.4	61.7	73.4	61.7	0		494.7	103,931.3	0.00904	0.006189	1294.6	
21	71.5	61.8	71.5	61.8	0		462.2	97,106.9	0.009542	0.006189	1422.6	
22	69.4	60.5	69.4	60.5	0		356.8	74,967.6	0.009189	0.006189	982.6	
23	67.2	59.0	67.2	59.0	0		247.0	51,886.9	0.008758	0.006189	582.4	Days/Month
24	65.1	57.0	65.1	57.0	-436		196.2	41,225.8	0.008036	0.006189	332.7	31
										Total	14494.1	449315.8

June	Typical Weather (°F)				Design							
Hour	OADB	OAWB			Htg (Btuh)		Clg (Tons)	CFM	Mixed Air HR	Supply Air HR	Condensate	
1	72.2	65.5	72.2	65.5	0		324.7	68,227.2	0.01189	0.006189	1699.4	
2	70.1	63.8	70.1	63.8	0		293.4	61,638.1	0.0112	0.006189	1349.5	
3	68.3	62.4	68.3	62.4	0		267.2	56,143.7	0.01067	0.006189	1099.2	
4	66.9	61.1	66.9	61.1	0		255.2	53,622.4	0.01015	0.006189	928.0	
5	66.1	60.5	66.1	60.5	-9		252.3	53,015.2	0.009949	0.006189	870.9	
6	65.8	60.3	65.8	60.3	0		263.6	55,381.0	0.009892	0.006189	896.0	
7	66.2	60.3	66.2	60.3	0		329.4	69,216.8	0.009799	0.006189	1091.7	
8	67.4	60.3	67.4	60.3	0		430.1	90,362.4	0.009523	0.006189	1316.3	
9	69.2	60.5	69.2	60.5	0		438.5	92,133.6	0.009235	0.006189	1226.1	
10	71.6	61.2	71.6	61.2	0		469.8	98,703.8	0.009131	0.006189	1268.7	
11	74.3	62.2	74.3	62.2	0		520.0	109,257.6	0.00916	0.006189	1418.2	
12	77.1	63.6	75.7	61.9	0		565.4	118,792.5	0.008642	0.006189	1273.1	
13	79.8	65.1	76.7	62.4	0		574.4	120,689.8	0.00874	0.006189	1345.1	
14	82.2	66.8	77.5	63.0	0		604.0	126,904.9	0.008953	0.006189	1532.5	
15	84.0	68.2	78.2	63.5	0		618.1	129,865.3	0.009128	0.006189	1667.5	
16	85.2	69.2	78.6	63.9	0		617.6	129,760.3	0.009306	0.006189	1767.1	
17	85.6	69.2	78.7	63.9	0		617.0	129,646.8	0.009283	0.006189	1752.5	
18	85.3	69.6	78.6	64.0	0		632.8	132,958.1	0.009374	0.006189	1850.2	
19	84.5	70.6	78.3	64.4	0		621.0	130,487.2	0.009717	0.006189	2011.3	
20	83.1	70.9	77.8	64.5	0		595.0	125,007.5	0.009901	0.006189	2027.4	
21	81.3	70.8	77.2	64.4	0		568.5	119,452.2	0.00997	0.006189	1973.3	
22	79.2	70.2	76.5	64.2	0		498.6	104,757.1	0.009994	0.006189	1741.5	
23	76.9	68.8	75.7	63.7	0		402.1	84,487.7	0.009838	0.006189	1347.0	Days/Month
24	74.5	67.2	74.5	67.2	0		361.0	75,854.2	0.01259	0.006189	2121.4	30
										Total	35573.8	1067213.6

July	Typical Weather (°F)				Design						
Hour	OADB	OAWB	MADB	MAWB	Htg (Btuh)	Clg (Tons)	CFM	Entering HR	Leaving HR	Condensate	
1	73.3	66.8	73.3	66.8	0	405.5	85,191.5	0.01257	0.006189	2375.0	
2	72.0	66.0	72.0	66.0	0	379.5	79,745.5	0.0123	0.006189	2129.1	
3	71.0	65.6	71.0	65.6	0	365.5	76,789.2	0.01224	0.006189	2030.1	
4	70.4	65.3	70.4	65.3	0	358.8	75,381.5	0.01217	0.006189	1969.8	
5	70.2	65.4	70.2	65.4	0	357.9	75,200.8	0.01229	0.006189	2004.5	
6	70.6	66.0	70.6	66.0	0	356.0	74,797.4	0.01262	0.006189	2101.6	
7	71.8	66.9	71.8	66.9	0	435.8	91,570.5	0.01299	0.006189	2720.9	
8	73.6	67.6	73.6	67.6	0	541.3	113,739.3	0.01309	0.006189	3429.3	
9	75.9	68.5	75.3	63.6	0	551.3	115,834.1	0.009862	0.006189	1858.8	
10	78.5	69.7	76.2	64.0	0	582.0	122,280.3	0.009927	0.006189	1997.0	
11	81.0	70.8	77.1	64.4	0	637.7	133,977.2	0.009993	0.006189	2226.7	
12	83.3	71.7	77.9	64.7	0	677.8	142,402.6	0.01002	0.006189	2383.5	
13	85.1	71.9	78.5	64.8	0	669.8	140,725.9	0.009947	0.006189	2310.6	
14	86.3	72.3	79.0	65.0	0	687.6	144,480.6	0.009971	0.006189	2387.4	
15	86.7	71.8	79.1	64.8	0	683.9	143,694.8	0.009809	0.006189	2272.7	
16	86.5	71.6	79.0	64.7	0	680.8	143,033.0	0.009763	0.006189	2233.5	
17	85.9	71.6	78.8	64.7	0	698.3	146,722.5	0.009809	0.006189	2320.6	
18	84.9	71.5	78.5	64.7	0	721.9	151,668.5	0.009878	0.006189	2444.5	
19	83.6	71.8	78.0	64.8	0	709.2	149,004.3	0.01006	0.006189	2520.0	
20	82.0	71.0	77.5	64.5	0	673.2	141,452.9	0.00997	0.006189	2336.7	
21	80.3	71.0	76.9	64.5	0	652.6	137,116.2	0.01011	0.006189	2348.9	
22	78.5	70.2	76.2	64.2	0	579.4	121,734.0	0.01006	0.006189	2058.8	
23	76.6	69.1	75.6	63.8	0	485.2	101,950.0	0.009929	0.006189	1665.9	Days/Month
24	74.9	67.8	74.9	67.8	0	439.5	92,345.8	0.01294	0.006189	2723.8	31
									Total	54849.7	1700341.4

August	Typical Weather (°F)				Design						
Hour	OADB	OAWB			Htg (Btuh)	Clg (Tons)	CFM	Entering HR	Leaving HR	Condensate	
1	70.7	64.2	70.7	64.2	0	331.9	69,735.8	0.01133	0.006189	1566.4	
2	69.2	63.3	69.2	63.3	0	305.3	64,155.2	0.01107	0.006189	1368.1	
3	68.0	62.5	68.0	62.5	0	281.7	59,194.5	0.01081	0.006189	1195.1	
4	67.1	62.1	67.1	62.1	0	276.3	58,059.9	0.01075	0.006189	1157.0	
5	66.6	61.8	66.6	61.8	0	276.4	58,076.7	0.01067	0.006189	1137.0	
6	66.4	61.8	66.4	61.8	0	284.4	59,751.3	0.01072	0.006189	1182.8	
7	66.9	62.3	66.9	62.3	0	355.1	74,608.3	0.01093	0.006189	1545.4	
8	68.4	63.2	68.4	63.2	0	468.4	98,422.2	0.01119	0.006189	2150.5	
9	70.7	64.5	70.7	64.5	0	484.8	101,863.8	0.01154	0.006189	2381.4	
10	73.5	65.8	73.5	65.8	0	516.6	108,547.5	0.01181	0.006189	2665.7	
11	76.5	66.6	75.5	63.0	0	560.1	117,685.2	0.009413	0.006189	1657.7	
12	79.3	68.2	76.5	63.5	0	604.6	127,041.4	0.009518	0.006189	1847.8	
13	81.6	69.6	77.3	64.0	0	619.0	130,056.5	0.009673	0.006189	1979.7	
14	83.0	70.2	77.8	64.2	0	639.7	134,399.5	0.009695	0.006189	2058.7	
15	83.6	69.9	78.0	64.1	0	637.0	133,832.2	0.00958	0.006189	1982.8	
16	83.4	69.3	77.9	63.9	0	626.8	131,701.7	0.009467	0.006189	1886.2	
17	82.8	69.3	77.7	63.9	0	642.7	135,029.8	0.009513	0.006189	1961.0	
18	81.9	69.1	77.4	63.8	0	660.5	138,778.2	0.009514	0.006189	2016.0	
19	80.7	69.1	77.0	63.8	0	633.5	133,107.3	0.009606	0.006189	1987.2	
20	79.3	69.0	76.5	63.8	0	600.6	126,188.4	0.009721	0.006189	1947.3	
21	77.6	68.8	75.9	63.7	0	575.4	120,895.7	0.009792	0.006189	1903.1	
22	75.9	67.9	75.3	63.4	0	496.8	104,374.7	0.009727	0.006189	1613.4	
23	74.1	66.6	74.1	66.6	0	398.1	83,638.8	0.01224	0.006189	2211.2	Days/Month
24	72.3	65.6	72.3	65.6	0	365.9	76,885.9	0.01194	0.006189	1931.9	31
									Total	43333.3	1343331.2

September	Typical Weather (°F)				Design							
Hour	OADB	OAWB			Htg (Btuh)		Clg (Tons)	CFM	Entering HR	Leaving HR	Condensate	
1	65.8	59.7			-794		217.3	45,646.6	0.009514	0.006189	663.1	
2	64.1	58.5	64.1	58.5	-5,444		188.9	39,694.1	0.009165	0.006189	516.1	
3	62.6	57.5	62.6	57.5	-15,891		173.0	36,338.7	0.008906	0.006189	431.4	
4	61.5	56.5	61.5	56.5	-161,619		163.2	34,288.0	0.008568	0.006189	356.4	
5	60.6	56.0	60.6	56.0	-53,531		163.4	34,338.4	0.008483	0.006189	344.2	
6	60.0	55.3	60.0	55.3	-47,044		165.3	34,720.8	0.008218	0.006189	307.8	
7	59.8	55.5	59.8	55.5	0		227.7	47,848.5	0.008378	0.006189	457.6	
8	60.6	55.7	60.6	55.7	0		352.2	74,005.2	0.00831	0.006189	685.8	
9	62.6	56.5	62.6	56.5	0		376.7	79,142.5	0.008315	0.006189	735.1	
10	65.8	57.9	65.8	57.9	0		418.8	87,990.2	0.008411	0.006189	854.2	
11	69.5	59.9	69.5	59.9	0		436.8	91,772.2	0.008788	0.006189	1042.1	
12	73.1	61.9	73.1	61.9	0		483.4	101,557.1	0.009239	0.006189	1353.3	
13	76.3	63.9	75.5	62.0	0		500.4	105,135.3	0.008753	0.006189	1177.7	
14	78.4	65.0	76.2	62.4	0		521.8	109,627.4	0.008855	0.006189	1276.9	
15	79.1	65.1	76.4	62.4	0		529.2	111,190.7	0.008809	0.006189	1272.8	
16	78.9	64.5	76.4	62.2	0		518.5	108,944.6	0.008677	0.006189	1184.2	
17	78.4	64.1	76.2	62.1	0		522.0	109,667.4	0.008658	0.006189	1183.0	
18	77.5	63.8	75.9	62.0	0		525.9	110,495.2	0.008661	0.006189	1193.4	
19	76.3	63.9	75.5	62.0	0		493.3	103,649.8	0.008753	0.006189	1161.1	
20	74.8	64.6	74.8	64.6	0		472.2	99,214.3	0.01066	0.006189	1938.0	
21	73.1	64.2	73.1	64.2	0		508.9	106,931.7	0.01078	0.006189	2144.9	
22	71.3	63.6	71.3	63.6	0		407.1	85,534.0	0.01079	0.006189	1719.4	
23	69.5	62.5	69.5	62.5	0		295.0	61,980.6	0.01046	0.006189	1156.6	Days/Month
24	67.6	61.1	67.6	61.1	0		251.2	52,786.1	0.009987	0.006189	875.9	30
										Total	24031.0	720930.9

October	Typical Weather (°F)				Design							
Hour	OADB	OAWB			Htg (Btuh)		Clg (Tons)	CFM	Entering HR	Leaving HR	Condensate	
1	50.4	46.4	50.4	46.4	-954,377		42.3	8,894.0	0.005745	0.006189	17.3	
2	48.9	44.9	48.9	44.9	-663,532		32.1	6,742.5	0.005375	0.006189	24.0	
3	47.6	43.8	47.6	43.8	-1,003,064		25.1	5,269.6	0.00516	0.006189	23.7	
4	46.6	42.9	46.6	42.9	-632,292		23.0	4,826.2	0.004977	0.006189	25.6	
5	45.8	42.4	45.8	42.4	-1,206,843		22.5	4,721.2	0.004934	0.006189	25.9	
6	45.3	42.0	45.3	42.0	-710,892		25.7	5,395.6	0.004869	0.006189	31.1	
7	45.1	41.8	45.1	41.8	-474,932		38.6	8,114.5	0.004825	0.006189	48.4	
8	46.1	42.7	46.1	42.7	-170,894		77.6	16,294.1	0.005001	0.006189	84.6	
9	48.7	44.2	48.7	44.2	-344,863		94.2	19,781.9	0.005095	0.006189	94.6	
10	52.5	46.7	52.5	46.7	-169,494		127.0	26,688.3	0.005413	0.006189	90.5	
11	56.8	49.4	56.8	49.4	-176,266		172.2	36,181.1	0.005772	0.006189	65.9	
12	60.6	52.0	60.6	52.0	-170,257		227.4	47,775.0	0.00626	0.006189	14.8	
13	63.2	53.2	63.2	53.2	-169,325		244.4	51,351.1	0.006315	0.006189	28.3	
14	64.1	53.0	64.1	53.0	-183,147		265.4	55,763.4	0.006001	0.006189	45.8	
15	64.0	52.7	64.0	52.7	-187,602		276.0	57,994.8	0.005861	0.006189	83.1	
16	63.5	52.0	63.5	52.0	-210,358		265.2	55,719.3	0.0056	0.006189	143.4	
17	62.7	51.7	62.7	51.7	-236,776		258.1	54,233.8	0.005623	0.006189	134.1	
18	61.7	51.9	61.7	51.9	-243,118		255.0	53,569.9	0.005956	0.006189	54.5	
19	60.4	52.0	60.4	52.0	-225,653		224.7	47,205.6	0.006305	0.006189	23.9	
20	58.9	52.2	58.9	52.2	-200,768		197.2	41,427.6	0.006754	0.006189	102.3	
21	57.2	51.2	57.2	51.2	-206,702		158.5	33,292.1	0.006611	0.006189	61.4	
22	55.5	50.3	55.5	50.3	-202,770		111.2	23,362.2	0.006529	0.006189	34.7	
23	53.8	49.1	53.8	49.1	-275,521		70.2	14,747.7	0.006303	0.006189	7.3	Days/Month
24	52.0	47.7	52.0	47.7	-204,937		55.2	11,591.8	0.006014	0.006189	8.9	31
										Total	1273.9	39490.4

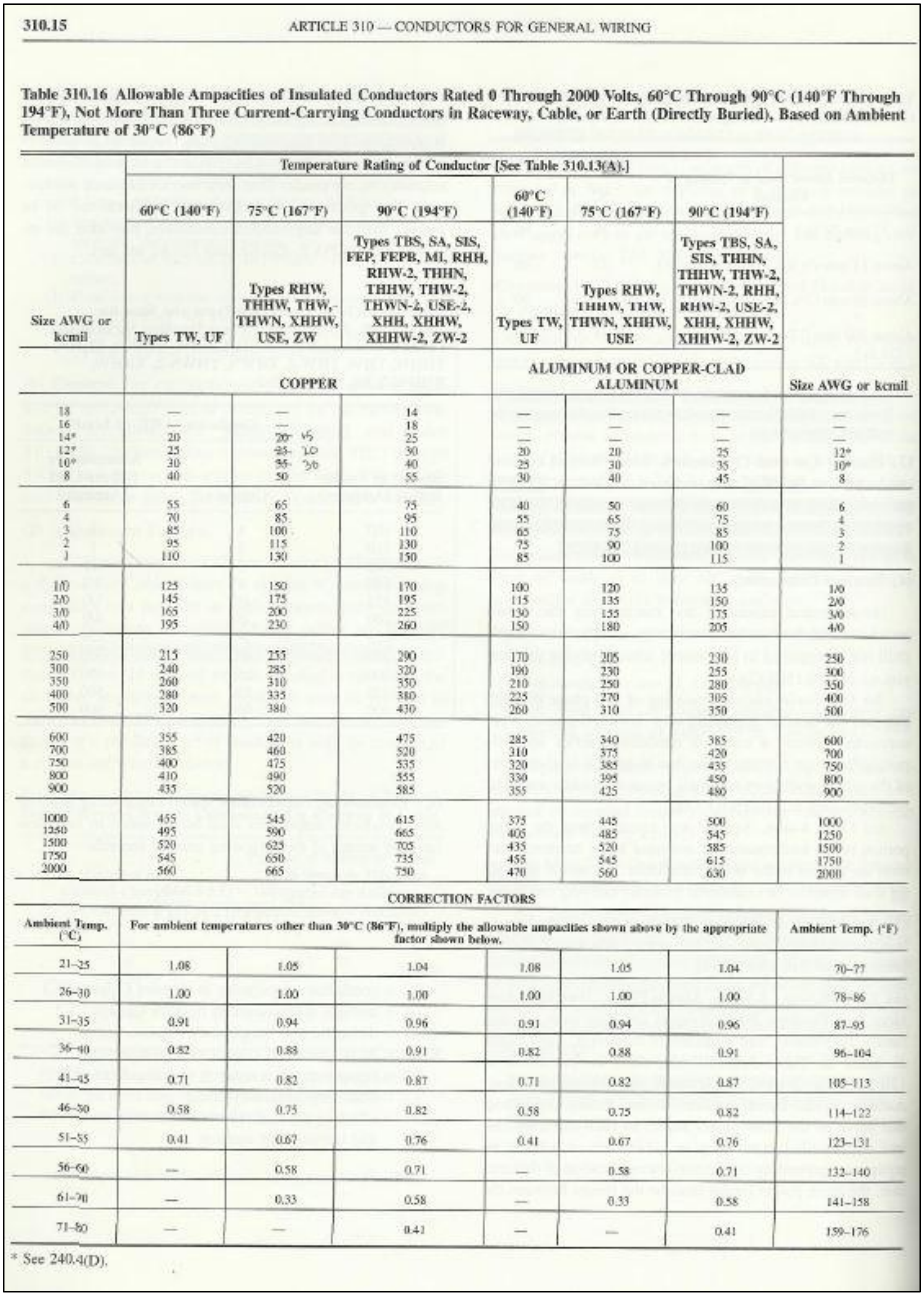
November	Typical Weather (°F)				Design							
Hour	OADB	OAWB			Htg (Btuh)		Clg (Tons)	CFM	Entering HR	Leaving HR	Condensate	
1	45.3	40.3	45.3	40.3	-2,365,413		9.5	1,998.2	0.004125	0.006189	18.0	
2	43.6	39.0	43.6	39.0	-575,899		5.8	1,212.3	0.003955	0.006189	11.8	
3	42.2	37.9	42.2	37.9	-2,529,625		0.0	0.0	0.003811	0.006189	0.0	
4	41.1	36.7	41.1	36.7	-548,420		0.0	0.0	0.003567	0.006189	0.0	
5	40.5	36.3	40.5	36.3	-2,371,255		0.0	0.0	0.00354	0.006189	0.0	
6	40.2	36.5	40.2	36.5	-532,971		0.0	0.0	0.003689	0.006189	0.0	
7	40.8	37.3	40.8	37.3	-1,049,796		5.1	1,080.0	0.003879	0.006189	10.9	
8	42.6	39.4	42.6	39.4	-283,285		24.2	5,074.2	0.00435	0.006189	40.8	
9	45.3	41.4	45.3	41.4	-533,904		42.5	8,923.4	0.004604	0.006189	61.8	
10	48.6	44.0	48.6	44.0	-202,751		75.2	15,808.7	0.005025	0.006189	80.4	
11	52.1	46.0	52.1	46.0	-210,589		113.7	23,881.2	0.005168	0.006189	106.5	
12	55.4	47.6	55.4	47.6	-230,151		150.8	31,678.4	0.005193	0.006189	137.9	
13	58.1	49.0	58.1	49.0	-223,118		175.0	36,761.0	0.005275	0.006189	146.8	
14	59.8	49.9	59.8	49.9	-223,908		200.5	42,129.3	0.005345	0.006189	155.4	
15	60.4	49.2	60.4	49.2	-308,573		195.3	41,036.7	0.004854	0.006189	239.4	
16	60.2	48.8	60.2	48.8	-358,348		188.4	39,574.4	0.004699	0.006189	257.6	
17	59.6	49.2	59.6	49.2	-343,186		181.3	38,093.1	0.005035	0.006189	192.1	
18	58.5	49.6	58.5	49.6	-299,654		177.2	37,223.2	0.005488	0.006189	114.0	
19	57.1	49.1	57.1	49.1	-352,389		138.8	29,161.3	0.005552	0.006189	81.2	
20	55.4	48.0	55.4	48.0	-437,634		102.5	21,540.6	0.005389	0.006189	75.3	
21	53.5	46.8	53.5	46.8	-502,727		76.1	15,995.7	0.005234	0.006189	66.7	
22	51.4	45.4	51.4	45.4	-576,752		46.8	9,833.2	0.005042	0.006189	49.3	
23	49.3	44.0	49.3	44.0	-475,822		24.8	5,210.7	0.004867	0.006189	30.1	Days/Month
24	47.2	41.9	47.2	41.9	-755,497		15.3	3,206.3	0.004395	0.006189	25.1	30
										Total	1901.0	57029.2

December	Typical Weather (°F)				Design							
Hour	OADB	OAWB			Htg (Btuh)		Clg (Tons)	CFM	Entering HR	Leaving HR	Condensate	
1	33.0	29.9	33.0	29.9	-3,125,682		0.0	0.0	0.002811	0.006189	0.0	
2	32.7	29.7	32.7	29.7	-1,099,832		0.0	0.0	0.002799	0.006189	0.0	
3	32.9	29.8	32.9	29.8	-2,815,318		0.0	0.0	0.002795	0.006189	0.0	
4	33.5	30.7	33.5	30.7	-2,251,573		0.0	0.0	0.002999	0.006189	0.0	
5	34.5	31.6	34.5	31.6	-1,593,697		0.0	0.0	0.00313	0.006189	0.0	
6	35.7	33.1	35.7	33.1	-2,781,539		0.0	0.0	0.003362	0.006189	0.0	
7	37.2	34.8	37.2	34.8	-615,692		0.0	0.0	0.003685	0.006189	0.0	
8	38.9	36.5	38.9	36.5	-613,860		0.0	0.0	0.003982	0.006189	0.0	
9	40.6	38.2	40.6	38.2	-751,177		0.0	0.0	0.004297	0.006189	0.0	
10	42.2	39.5	42.2	39.5	-308,265		0.0	0.0	0.004483	0.006189	0.0	
11	43.7	40.4	43.7	40.4	-641,681		4.4	924.5	0.00453	0.006189	6.7	
12	45.0	41.2	45.0	41.2	-375,394		24.9	5,231.8	0.004584	0.006189	36.7	
13	45.9	41.8	45.9	41.8	-538,598		38.2	8,034.6	0.004644	0.006189	54.2	
14	46.5	41.9	46.5	41.9	-389,871		51.6	10,837.5	0.004553	0.006189	77.5	
15	46.7	41.9	46.7	41.9	-436,279		55.5	11,663.3	0.004508	0.006189	85.7	
16	46.5	41.5	46.5	41.5	-461,515		50.2	10,551.8	0.004376	0.006189	83.6	
17	45.6	40.8	45.6	40.8	-484,752		41.9	8,797.3	0.004274	0.006189	73.6	
18	44.3	40.2	44.3	40.2	-529,663		30.2	6,345.3	0.004308	0.006189	52.1	
19	42.6	38.9	42.6	38.9	-547,191		12.0	2,519.2	0.004138	0.006189	22.6	
20	40.7	37.2	40.7	37.2	-581,936		0.0	0.0	0.003861	0.006189	0.0	
21	38.7	35.7	38.7	35.7	-631,204		0.0	0.0	0.003705	0.006189	0.0	
22	36.8	33.8	36.8	33.8	-872,573		0.0	0.0	0.003384	0.006189	0.0	
23	35.1	32.1	35.1	32.1	-1,882,775		0.0	0.0	0.003116	0.006189	0.0	Days/Month
24	33.8	30.7	33.8	30.7	-1,026,284		0.0	0.0	0.00294	0.006189	0.0	31
										Total	492.7	15272.3

TOTALS

Density Air	
0.0728173	lb/cu.ft.
Annual Total	Condensate
5,543,177	*lbs*
664,649	*gallons*
664.6	*1000 gal.*

Appendix E: Electrical Breadth Information



310.15 ARTICLE 310 — CONDUCTORS FOR GENERAL WIRING

Table 310.16 Allowable Ampacities of Insulated Conductors Rated 0 Through 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)

	Temperature Rating of Conductor [See Table 310.13(A).]						
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			Size AWG or kcmil
18	—	—	14	—	—	—	—
16	—	—	18	—	—	—	—
14*	20	~~20~~ 15	25	—	—	—	—
12*	25	~~25~~ 20	30	20	20	25	12*
10*	30	~~35~~ 30	40	25	30	35	10*
8	40	50	55	30	40	45	8
6	55	65	75	40	50	60	6
4	70	85	95	55	65	75	4
3	85	100	110	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	150	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	190	230	255	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500
600	355	420	475	285	340	385	600
700	385	460	520	310	375	420	700
750	400	475	535	320	385	435	750
800	410	490	555	330	395	450	800
900	435	520	585	355	425	480	900
1000	455	545	615	375	445	500	1000
1250	495	590	665	405	485	545	1250
1500	520	625	705	435	520	585	1500
1750	545	650	735	455	545	615	1750
2000	560	665	750	470	560	630	2000

CORRECTION FACTORS

Ambient Temp. (°C)	For ambient temperatures other than 30°C (86°F), multiply the allowable ampacities shown above by the appropriate factor shown below.						Ambient Temp. (°F)
21–25	1.08	1.05	1.04	1.08	1.05	1.04	70–77
26–30	1.00	1.00	1.00	1.00	1.00	1.00	78–86
31–35	0.91	0.94	0.96	0.91	0.94	0.96	87–95
36–40	0.82	0.88	0.91	0.82	0.88	0.91	96–104
41–45	0.71	0.82	0.87	0.71	0.82	0.87	105–113
46–50	0.58	0.75	0.82	0.58	0.75	0.82	114–122
51–55	0.41	0.67	0.76	0.41	0.67	0.76	123–131
56–60	—	0.58	0.71	—	0.58	0.71	132–140
61–70	—	0.33	0.58	—	0.33	0.58	141–158
71–80	—	—	0.41	—	—	0.41	159–176

* See 240.4(D).

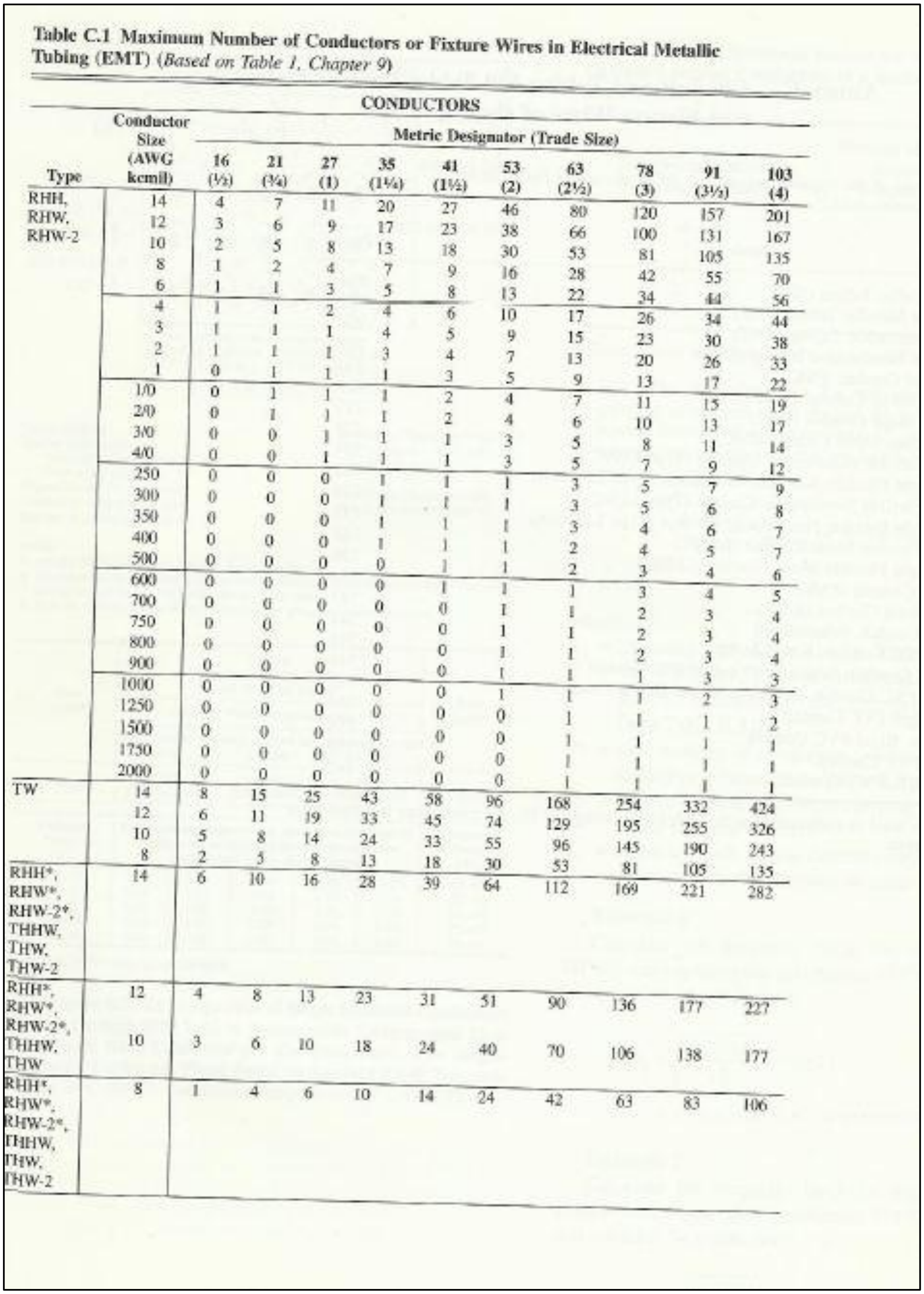


Table C.1 Maximum Number of Conductors or Fixture Wires in Electrical Metallic Tubing (EMT) (*Based on Table 1, Chapter 9*)

		CONDUCTORS									
		Metric Designator (Trade Size)									
Type	Conductor Size (AWG kcmil)	16 (½)	21 (¾)	27 (1)	35 (1¼)	41 (1½)	53 (2)	63 (2½)	78 (3)	91 (3½)	103 (4)
RHH, RHW, RHW-2	14	4	7	11	20	27	46	80	120	157	201
	12	3	6	9	17	23	38	66	100	131	167
	10	2	5	8	13	18	30	53	81	105	135
	8	1	2	4	7	9	16	28	42	55	70
	6	1	1	3	5	8	13	22	34	44	56
	4	1	1	2	4	6	10	17	26	34	44
	3	1	1	1	4	5	9	15	23	30	38
	2	1	1	1	3	4	7	13	20	26	33
	1	0	1	1	1	3	5	9	13	17	22
	1/0	0	1	1	1	2	4	7	11	15	19
	2/0	0	1	1	1	2	4	6	10	13	17
	3/0	0	0	1	1	1	3	5	8	11	14
	4/0	0	0	1	1	1	3	5	7	9	12
	250	0	0	0	1	1	1	3	5	7	9
	300	0	0	0	1	1	1	3	5	6	8
	350	0	0	0	1	1	1	3	4	6	7
	400	0	0	0	1	1	1	2	4	5	7
	500	0	0	0	0	1	1	2	3	4	6
	600	0	0	0	0	1	1	1	3	4	5
	700	0	0	0	0	0	1	1	2	3	4
	750	0	0	0	0	0	1	1	2	3	4
	800	0	0	0	0	0	1	1	2	3	4
	900	0	0	0	0	0	1	1	2	3	3
	1000	0	0	0	0	0	1	1	1	3	3
	1250	0	0	0	0	0	1	1	1	2	3
	1500	0	0	0	0	0	0	1	1	1	2
	1750	0	0	0	0	0	0	1	1	1	1
	2000	0	0	0	0	0	0	1	1	1	1
TW	14	8	15	25	43	58	96	168	254	332	424
	12	6	11	19	33	45	74	129	195	255	326
	10	5	8	14	24	33	55	96	145	190	243
	8	2	5	8	13	18	30	53	81	105	135
RHH*, RHW*, RHW-2*, THHW, THW, THW-2	14	6	10	16	28	39	64	112	169	221	282
RHH*, RHW*, RHW-2*, THHW, THW	12	4	8	13	23	31	51	90	136	177	227
	10	3	6	10	18	24	40	70	106	138	177
RHH*, RHW*, RHW-2*, THHW, THW, THW-2	8	1	4	6	10	14	24	42	63	83	106

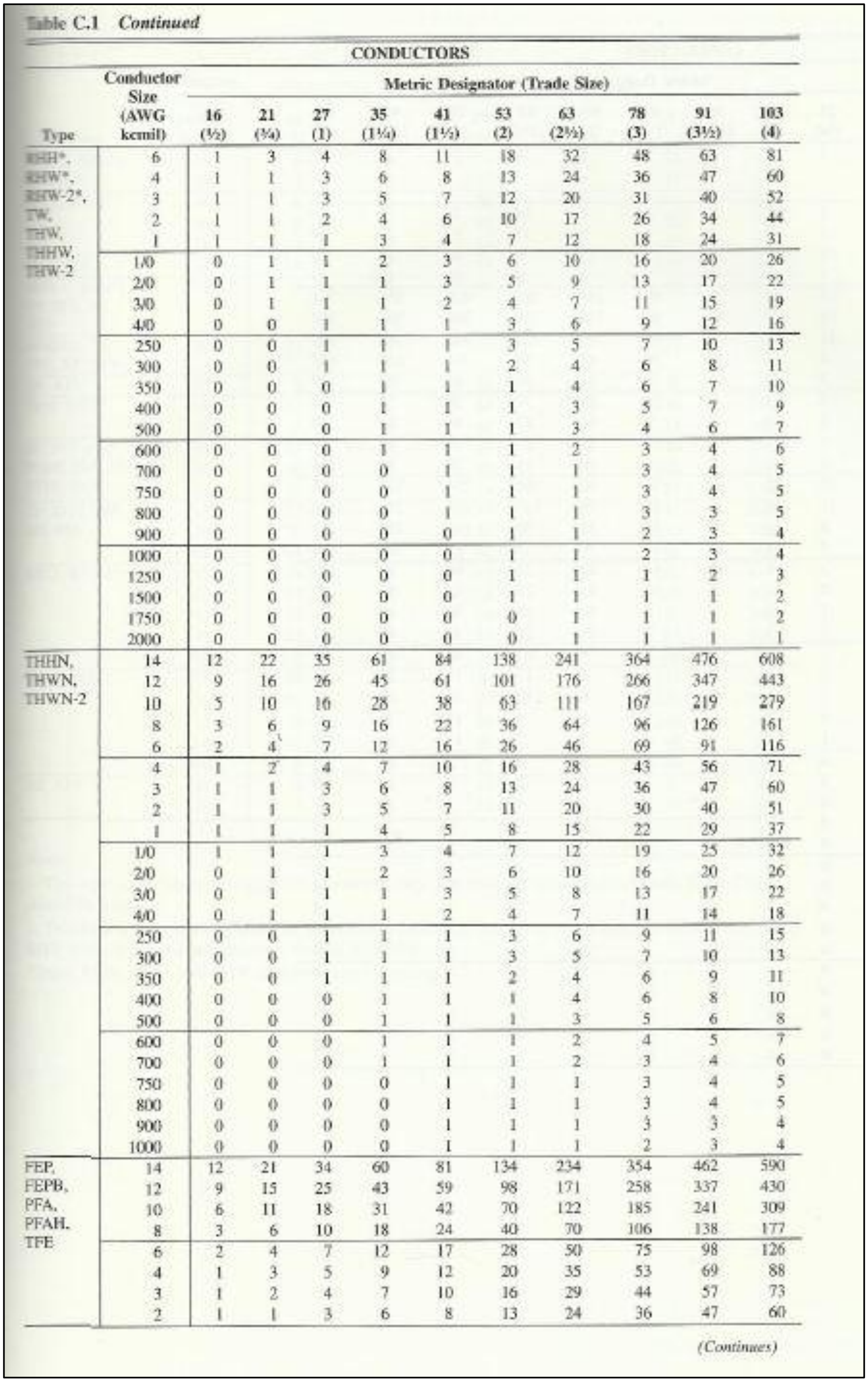


Table C.1 *Continued*

		CONDUCTORS									
	Conductor Size	Metric Designator (Trade Size)									
Type	(AWG kcmil)	16 (½)	21 (¾)	27 (1)	35 (1¼)	41 (1½)	53 (2)	63 (2½)	78 (3)	91 (3½)	103 (4)
RHH*, RHW*, RHW-2*, TW, THW, THHW, THW-2	6	1	3	4	8	11	18	32	48	63	81
	4	1	1	3	6	8	13	24	36	47	60
	3	1	1	3	5	7	12	20	31	40	52
	2	1	1	2	4	6	10	17	26	34	44
	1	1	1	1	3	4	7	12	18	24	31
	1/0	0	1	1	2	3	6	10	16	20	26
	2/0	0	1	1	1	3	5	9	13	17	22
	3/0	0	1	1	1	2	4	7	11	15	19
	4/0	0	0	1	1	1	3	6	9	12	16
	250	0	0	1	1	1	3	5	7	10	13
	300	0	0	1	1	1	2	4	6	8	11
	350	0	0	0	1	1	1	4	6	7	10
	400	0	0	0	1	1	1	3	5	7	9
	500	0	0	0	1	1	1	3	4	6	7
	600	0	0	0	1	1	1	2	3	4	6
	700	0	0	0	0	1	1	1	3	4	5
	750	0	0	0	0	1	1	1	3	4	5
	800	0	0	0	0	1	1	1	3	3	5
	900	0	0	0	0	0	1	1	2	3	4
	1000	0	0	0	0	0	1	1	2	3	4
	1250	0	0	0	0	0	1	1	1	2	3
	1500	0	0	0	0	0	1	1	1	1	2
	1750	0	0	0	0	0	0	1	1	1	2
	2000	0	0	0	0	0	0	1	1	1	1
THHN, THWN, THWN-2	14	12	22	35	61	84	138	241	364	476	608
	12	9	16	26	45	61	101	176	266	347	443
	10	5	10	16	28	38	63	111	167	219	279
	8	3	6	9	16	22	36	64	96	126	161
	6	2	4	7	12	16	26	46	69	91	116
	4	1	2	4	7	10	16	28	43	56	71
	3	1	1	3	6	8	13	24	36	47	60
	2	1	1	3	5	7	11	20	30	40	51
	1	1	1	1	4	5	8	15	22	29	37
	1/0	1	1	1	3	4	7	12	19	25	32
	2/0	0	1	1	2	3	6	10	16	20	26
	3/0	0	1	1	1	3	5	8	13	17	22
	4/0	0	1	1	1	2	4	7	11	14	18
	250	0	0	1	1	1	3	6	9	11	15
	300	0	0	1	1	1	3	5	7	10	13
	350	0	0	1	1	1	2	4	6	9	11
	400	0	0	0	1	1	1	4	6	8	10
	500	0	0	0	1	1	1	3	5	6	8
	600	0	0	0	1	1	1	2	4	5	7
	700	0	0	0	1	1	1	2	3	4	6
	750	0	0	0	0	1	1	1	3	4	5
	800	0	0	0	0	1	1	1	3	4	5
	900	0	0	0	0	1	1	1	3	3	4
	1000	0	0	0	0	1	1	1	2	3	4
FEP, FEPB, PFA, PFAH, TFE	14	12	21	34	60	81	134	234	354	462	590
	12	9	15	25	43	59	98	171	258	337	430
	10	6	11	18	31	42	70	122	185	241	309
	8	3	6	10	18	24	40	70	106	138	177
	6	2	4	7	12	17	28	50	75	98	126
	4	1	3	5	9	12	20	35	53	69	88
	3	1	2	4	7	10	16	29	44	57	73
	2	1	1	3	6	8	13	24	36	47	60

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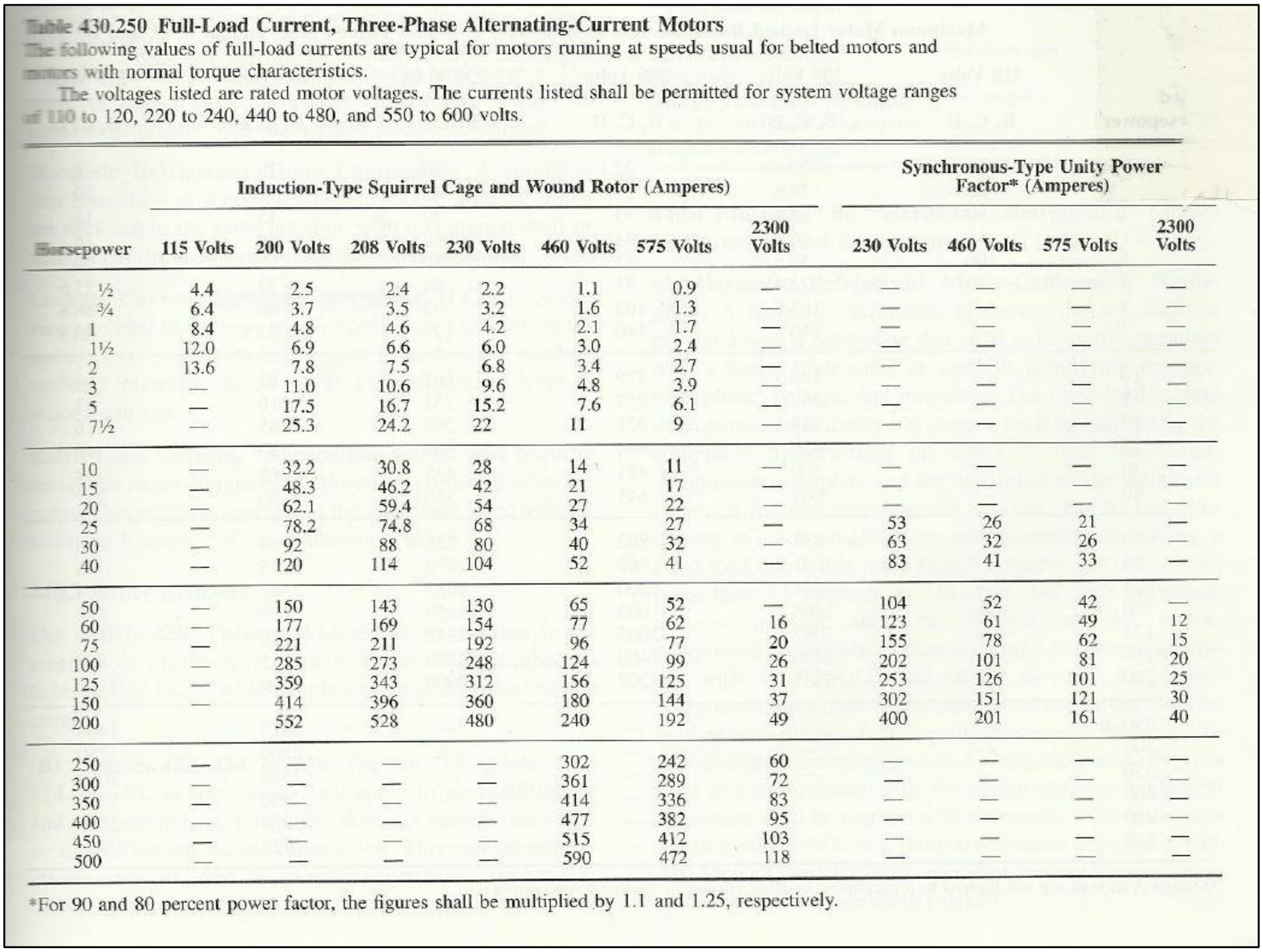


Table 430.250 Full-Load Current, Three-Phase Alternating-Current Motors

The following values of full-load currents are typical for motors running at speeds usual for belted motors and motors with normal torque characteristics.

The voltages listed are rated motor voltages. The currents listed shall be permitted for system voltage ranges of 110 to 120, 220 to 240, 440 to 480, and 550 to 600 volts.

	Induction-Type Squirrel Cage and Wound Rotor (Amperes)							Synchronous-Type Unity Power Factor* (Amperes)			
Horsepower	115 Volts	200 Volts	208 Volts	230 Volts	460 Volts	575 Volts	2300 Volts	230 Volts	460 Volts	575 Volts	2300 Volts
½	4.4	2.5	2.4	2.2	1.1	0.9	—	—	—	—	—
¾	6.4	3.7	3.5	3.2	1.6	1.3	—	—	—	—	—
1	8.4	4.8	4.6	4.2	2.1	1.7	—	—	—	—	—
1½	12.0	6.9	6.6	6.0	3.0	2.4	—	—	—	—	—
2	13.6	7.8	7.5	6.8	3.4	2.7	—	—	—	—	—
3	—	11.0	10.6	9.6	4.8	3.9	—	—	—	—	—
5	—	17.5	16.7	15.2	7.6	6.1	—	—	—	—	—
7½	—	25.3	24.2	22	11	9	—	—	—	—	—
10	—	32.2	30.8	28	14	11	—	—	—	—	—
15	—	48.3	46.2	42	21	17	—	—	—	—	—
20	—	62.1	59.4	54	27	22	—	—	—	—	—
25	—	78.2	74.8	68	34	27	—	53	26	21	—
30	—	92	88	80	40	32	—	63	32	26	—
40	—	120	114	104	52	41	—	83	41	33	—
50	—	150	143	130	65	52	—	104	52	42	—
60	—	177	169	154	77	62	16	123	61	49	12
75	—	221	211	192	96	77	20	155	78	62	15
100	—	285	273	248	124	99	26	202	101	81	20
125	—	359	343	312	156	125	31	253	126	101	25
150	—	414	396	360	180	144	37	302	151	121	30
200		552	528	480	240	192	49	400	201	161	40
250	—	—	—	—	302	242	60	—	—	—	—
300	—	—	—	—	361	289	72	—	—	—	—
350	—	—	—	—	414	336	83	—	—	—	—
400	—	—	—	—	477	382	95	—	—	—	—
450	—	—	—	—	515	412	103	—	—	—	—
500	—	—	—	—	590	472	118	—	—	—	—

*For 90 and 80 percent power factor, the figures shall be multiplied by 1.1 and 1.25, respectively.

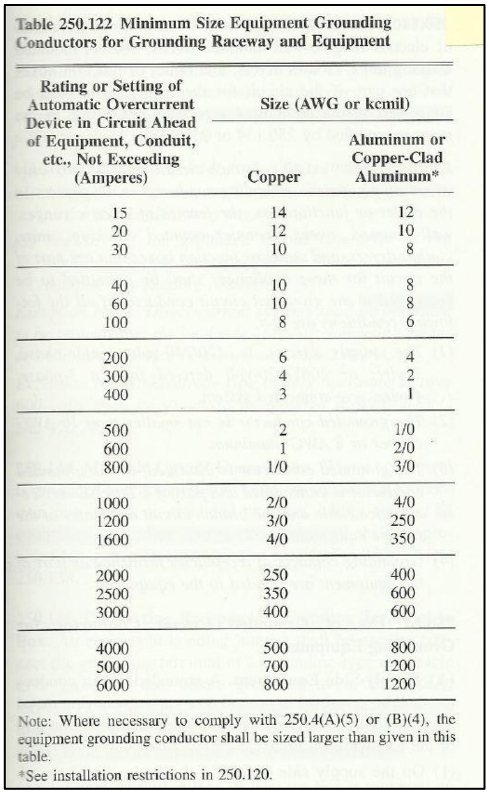
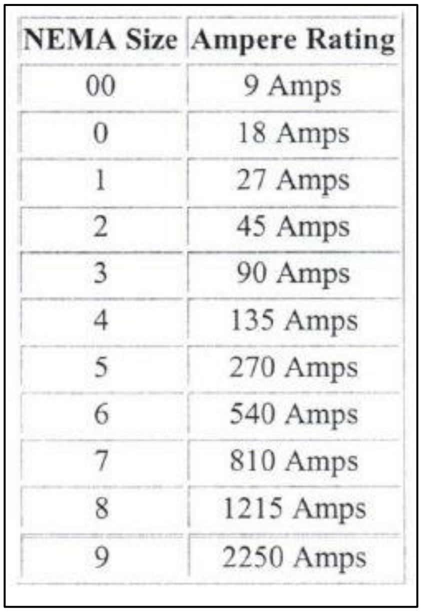


Table 250.122 Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size (AWG or kcmil)	
	Copper	Aluminum or Copper-Clad Aluminum*
15	14	12
20	12	10
30	10	8
40	10	8
60	10	8
100	8	6
200	6	4
300	4	2
400	3	1
500	2	1/0
600	1	2/0
800	1/0	3/0
1000	2/0	4/0
1200	3/0	250
1600	4/0	350
2000	250	400
2500	350	600
3000	400	600
4000	500	800
5000	700	1200
6000	800	1200

Note: Where necessary to comply with 250.4(A)(5) or (B)(4), the equipment grounding conductor shall be sized larger than given in this table.

*See installation restrictions in 250.120.



NEMA Size	Ampere Rating
00	9 Amps
0	18 Amps
1	27 Amps
2	45 Amps
3	90 Amps
4	135 Amps
5	270 Amps
6	540 Amps
7	810 Amps
8	1215 Amps
9	2250 Amps

Voltage: 480/277 **Main Breaker:** 225 **A** **Feeder:** (3) 4/0 - (1) #4 G. in 2-1/2" Conduit

Description	LOAD (VA)			Brk. Trip (A)	EQP-1				LOAD (VA)			Brk. Trip (A)	Description
	A	B	C		Cond. Size	Ckt. #		Cond. Size	A	B	C		
CHWP-1	17400			50		1	2		17400			50	CHWP-2
		17400				3	4			17400			
			17400			5	6				17400		
CHWP-3	17400			50		7	8		17400			50	CHWP-4
		17400				9	10			17400			
			17400			11	12				17400		
CHWP-5	17400			50		13	14		17400			50	CHWP-6
		17400				15	16			17400			
			17400			17	18				17400		
CWP-1	17400			50		19	20		17400			50	CWP-2
		17400				21	22			17400			
			17400			23	24				17400		
CWP-3	17400			50		25	26		4000			15	CRP-1
		17400				27	28			4000			
			17400			29	30				4000		
						31	32						
						33	34						
						35	36						
						37	38						
						39	40						
						41	42						
	87000	87000	87000						73600	73600	73600		

Total Load on Phase A: 160600 VA

Total Load on Phase B: 160600 VA

Total Load on Phase C: 160600 VA

Total Load on Panel: 160.60 kVA Demand

193.80 A

Voltage: 480/277 **Main Breaker:** 1600 A **Feeder:** 4 sets of (3) 400 kcmil - (1) #4/0 G. in 3" Conduit

Description	LOAD (VA)			Brk. Trip (A)	SWGR-MECH 2				LOAD (VA)			Brk. Trip (A)	Description
	A	B	C		Cond. Size	Ckt. #		Cond. Size	A	B	C		
CH-1	244100			600		1	2		244100			600	CH-2
		244100				3	4			244100			
			244100			5	6				244100		
CH-3	244100			600		7	8		11600			30	CT-2
		244100				9	10			11600			
			244100			11	12				11600		
CT-1	11600			30		13	14		152800			450	HRC-1
		11600				15	16			152800			
			11600			17	18				152800		
EQP-1	160600					19	20						
		160600				21	22						
			160600			23	24						
						25	26						
						27	28						
						29	30						
						31	32						
						33	34						
						35	36						
						37	38						
						39	40						
						41	42						
	660400	660400	660400						408500	408500	408500		

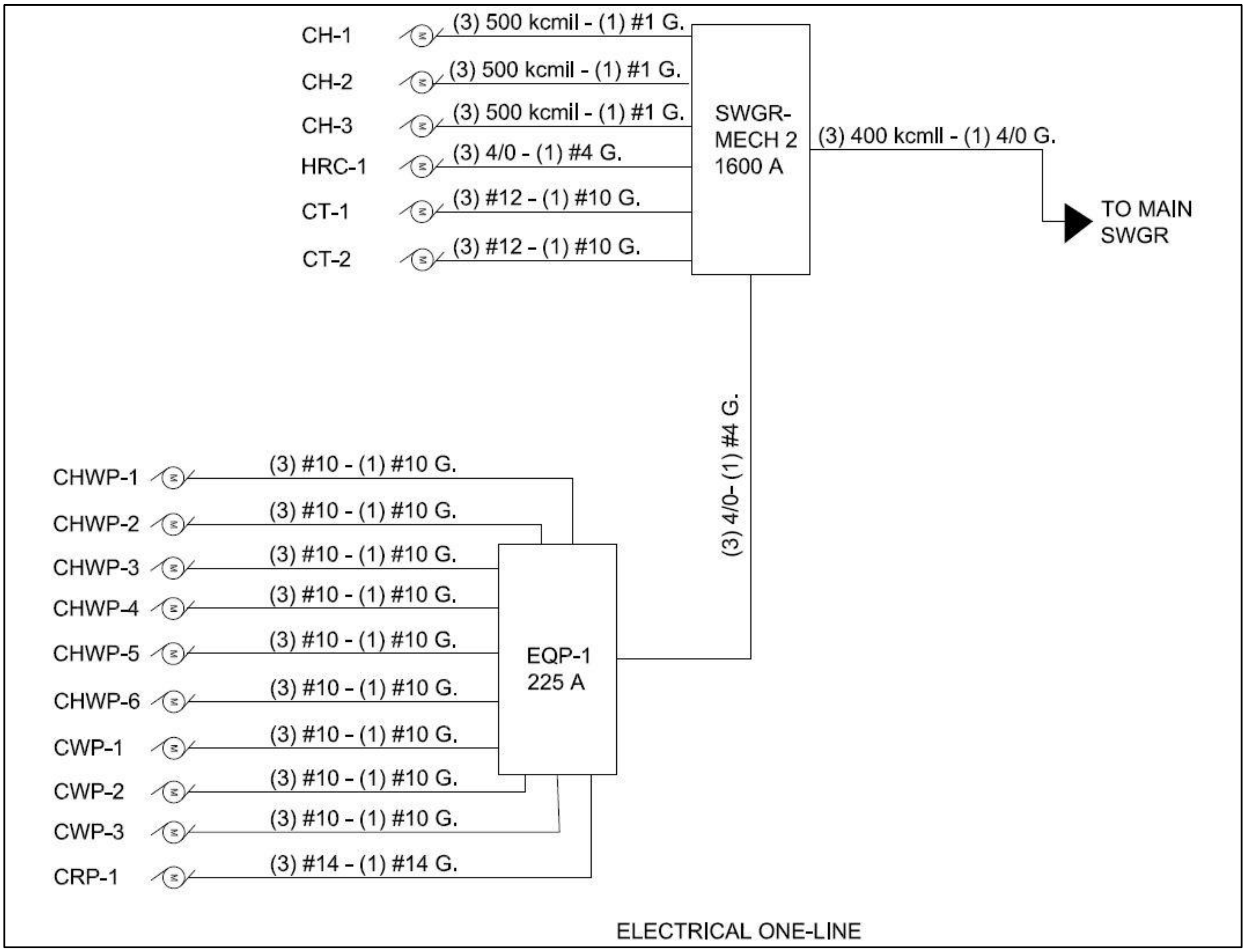
Total Load on Phase A: 1068900 VA

Total Load on Phase B: 1068900 VA

Total Load on Phase C: 1068900 VA

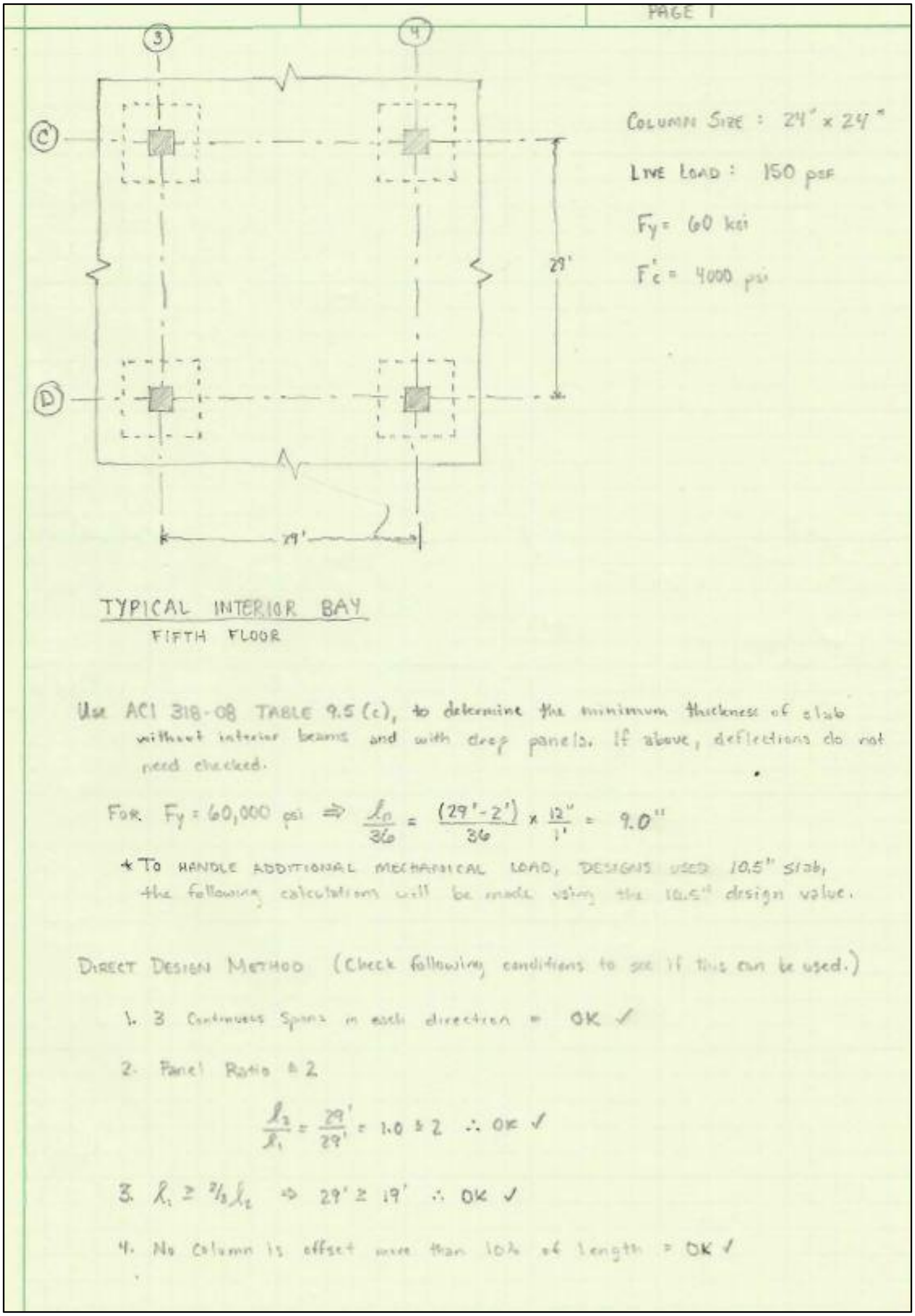
Total Load on Panel: 1068.90 kVA Demand

1287.21 A



ELECTRICAL ONE-LINE

Appendix F: Structural Breadth Calculations



PAGE 1

COLUMN SIZE : 24" x 24"

LIVE LOAD : 150 psf

F_y = 60 ksi

F'_c = 4000 psi

TYPICAL INTERIOR BAY
FIFTH FLOOR

Use ACI 318-08 TABLE 9.5 (c), to determine the minimum thickness of slab without interior beams and with drop panels. If above, deflections do not need checked.

FOR $F_y = 60{,}000$ psi $\Rightarrow \frac{l_n}{36} = \frac{(29'-2')}{36} \times \frac{12''}{1'} = 9.0''$

* TO HANDLE ADDITIONAL MECHANICAL LOAD, DESIGNS USED 10.5" slab, the following calculations will be made using the 10.5" design value.

DIRECT DESIGN METHOD (Check following conditions to see if this can be used.)

1. 3 Continuous Spans in each direction = OK ✓

2. Panel Ratio ≤ 2

$$\frac{l_2}{l_1} = \frac{29'}{29'} = 1.0 \leq 2 \quad \therefore \text{OK} ✓$$

3. $l_1 \geq \frac{2}{3} l_2 \Rightarrow 29' \geq 19' \quad \therefore$ OK ✓

4. No Column is offset more than 10% of length = OK ✓

5. $W_L \leq 2 W_D$

SELF: $W_D = (10.5''/12'')(150\ lb/ft^3) = 131.25$ psf

SUPERIMPOSED: $W_{D_{SID}} = 20$ psf

ADDITIONAL PLANT: $W_{D_{PLANT}} = 25.9$ PSF

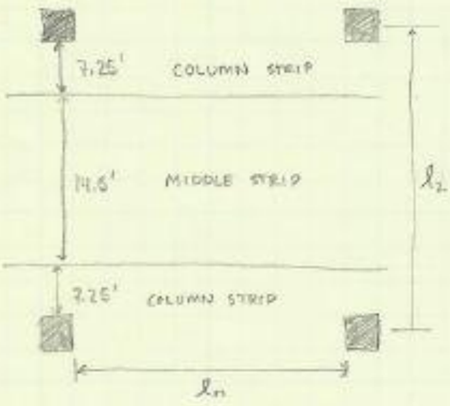
$W_L = 150$ PSF $\leq 2(131.25 + 20 + 25.9)$
150 PSF ≤ 354.3 PSF ∴ OK

USING THE DIRECT DESIGN METHOD IS OK

* DUE TO THE PANEL BE IDENTICAL IN BOTH DIMENSIONS, ONLY NEED TO DESIGN ONE COLUMN AND ONE MIDDLE STRIP FOR ONE FRAME.

½ Column Strip = $\left(\frac{29'}{4}\right) = 7.25'$

Middle Strip = $\left(\frac{29'}{2}\right) = 14.5'$



Moment: $M_o = \frac{w_u l_2 l_n^2}{8}$

$W_u = 1.2D + 1.6L$
$= 1.2(177.15) + 1.6(150)$

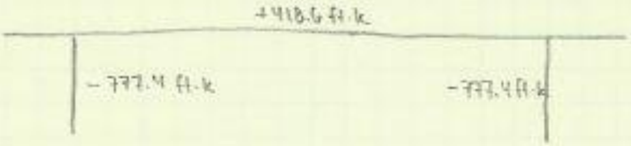
$W_u = 452.58$ PSF

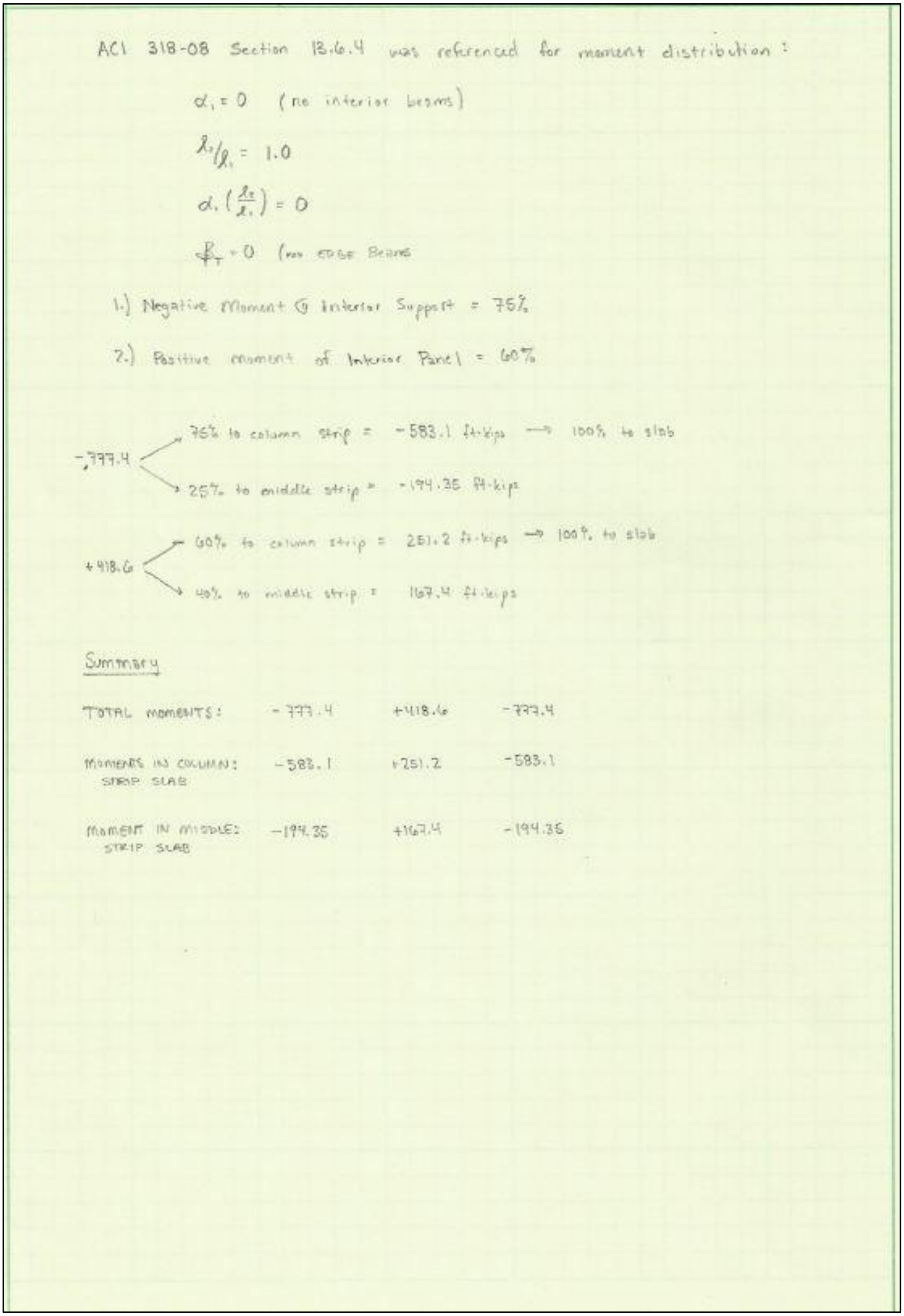
$M_o = \frac{(452.58)(29')(29'-2')^2}{8}$

$M_o = 1,196$ ft·kips

Using ACI 318-08 Section 13.6.3.3: EXTERIOR EDGE FULL RESTRAINED
Interior Negative Factored Moment: $0.65\ M_o$
Positive Factored Moment: $0.35\ M_o$

INTERIOR NEG. FACTORED MOMENT: $0.65 M_o = 0.65(1196) = 777.4$ ft·kips
POSITIVE FACTORED MOMENT: $0.35 M_o = 0.35(1196) = 418.6$ ft kips





ACI 318-08 Section 13.6.4 was referenced for moment distribution :

$\alpha_1 = 0$ (no interior beams)

$\ell_2/\ell_1 = 1.0$

$\alpha_1 \left(\frac{\ell_2}{\ell_1}\right) = 0$

$\beta_T = 0$ (no EDGE Beams

1.) Negative Moment @ Interior Support = 75%

2.) Positive moment of Interior Panel = 60%

$-777.4 \rightarrow$ 75% to column strip = −583.1 ft-kips ⟶ 100% to slab

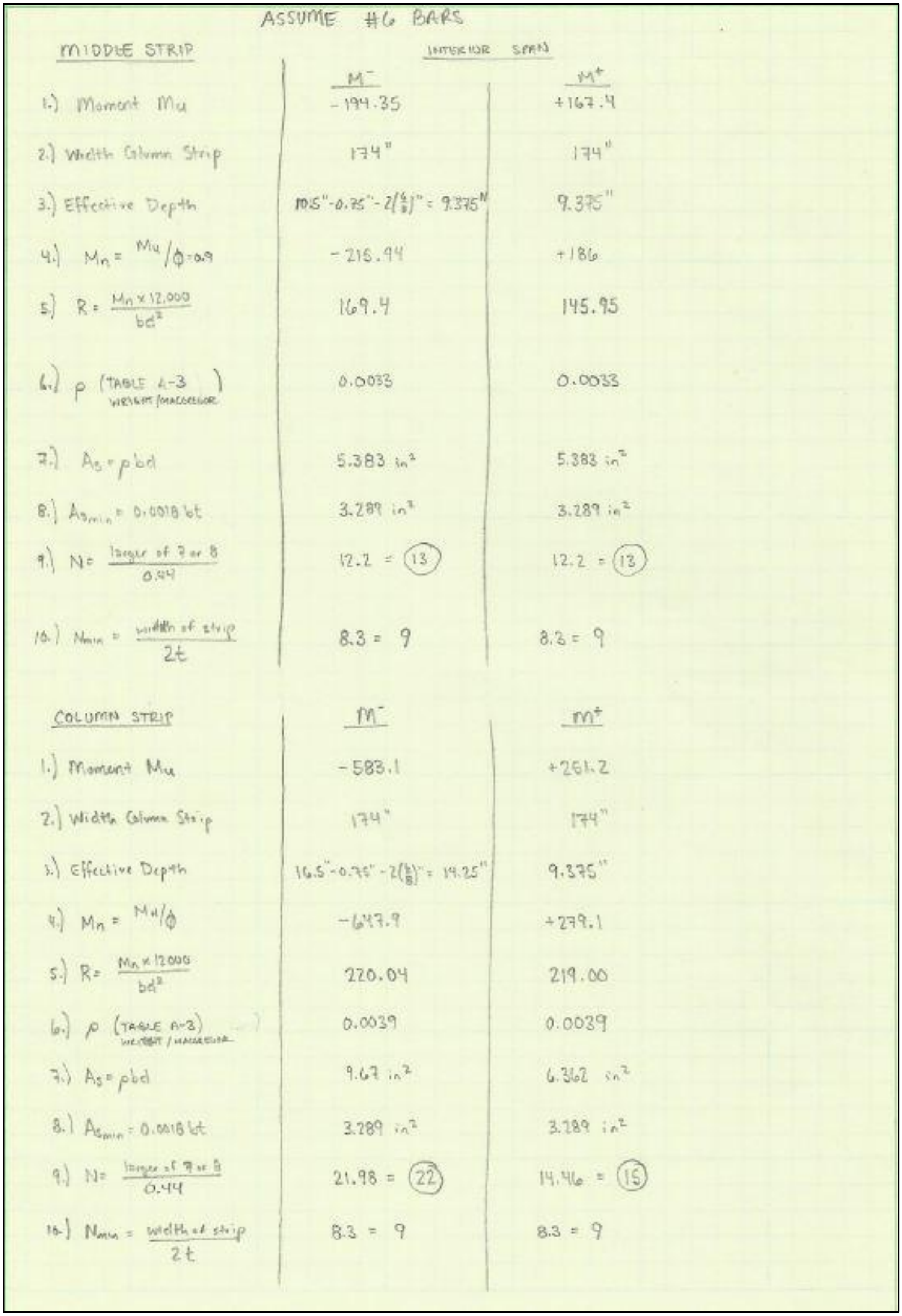
$-777.4 \rightarrow$ 25% to middle strip = −194.35 ft-kips

$+418.6 \rightarrow$ 60% to column strip = 251.2 ft-kips ⟶ 100% to slab

$+418.6 \rightarrow$ 40% to middle strip = 167.4 ft-kips

Summary

TOTAL MOMENTS:	−777.4	+418.6	−777.4
MOMENTS IN COLUMN: STRIP SLAB	−583.1	+251.2	−583.1
MOMENT IN MIDDLE: STRIP SLAB	−194.35	+167.4	−194.35

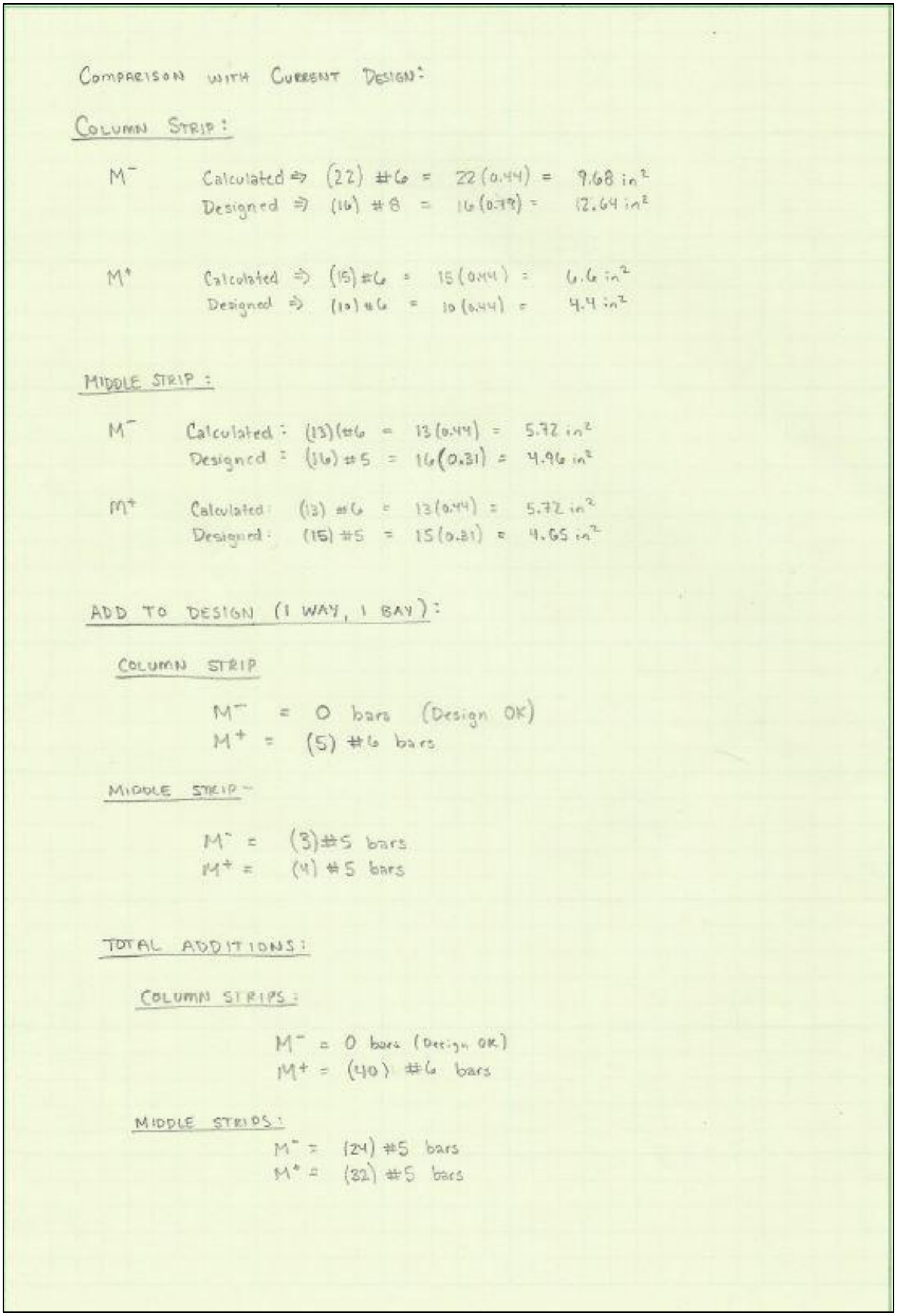


ASSUME #6 BARS

INTERIOR SPAN

MIDDLE STRIP	M^-	M^+
1.) Moment M_u	-194.35	+167.4
2.) Width Column Strip	174"	174"
3.) Effective Depth	10.5" - 0.75" - 2(6/8)" = 9.375"	9.375"
4.) $M_n = M_u / \phi{=}0.9$	-215.94	+186
5.) $R = \frac{M_n \times 12{,}000}{bd^2}$	169.4	145.95
6.) ρ (TABLE A-3 WRIGHT/MACGREGOR)	0.0033	0.0033
7.) $A_s = \rho bd$	5.383 in²	5.383 in²
8.) $A_{s_{min}} = 0.0018\,bt$	3.289 in²	3.289 in²
9.) $N = \frac{\text{larger of 7 or 8}}{0.44}$	12.2 = ⑬	12.2 = ⑬
10.) $N_{min} = \frac{\text{width of strip}}{2t}$	8.3 = 9	8.3 = 9

COLUMN STRIP	M^-	M^+
1.) Moment M_u	-583.1	+261.2
2.) Width Column Strip	174"	174"
3.) Effective Depth	16.5" - 0.75" - 2(6/8)" = 14.25"	9.375"
4.) $M_n = M_u / \phi$	-647.9	+279.1
5.) $R = \frac{M_n \times 12000}{bd^2}$	220.04	219.00
6.) ρ (TABLE A-3 WRIGHT/MACGREGOR)	0.0039	0.0039
7.) $A_s = \rho bd$	9.67 in²	6.362 in²
8.) $A_{s_{min}} = 0.0018\,bt$	3.289 in²	3.289 in²
9.) $N = \frac{\text{larger of 7 or 8}}{0.44}$	21.98 = ㉒	14.46 = ⑮
10.) $N_{min} = \frac{\text{width of strip}}{2t}$	8.3 = 9	8.3 = 9



COMPARISON WITH CURRENT DESIGN:

COLUMN STRIP:

M^- Calculated ⇒ (22) #6 = 22(0.44) = 9.68 in^2
Designed ⇒ (16) #8 = 16(0.79) = 12.64 in^2

M^+ Calculated ⇒ (15) #6 = 15(0.44) = 6.6 in^2
Designed ⇒ (10) #6 = 10(0.44) = 4.4 in^2

MIDDLE STRIP:

M^- Calculated : (13)(#6 = 13(0.44) = 5.72 in^2
Designed : (16) #5 = 16(0.31) = 4.96 in^2

M^+ Calculated : (13) #6 = 13(0.44) = 5.72 in^2
Designed : (15) #5 = 15(0.31) = 4.65 in^2

ADD TO DESIGN (1 WAY, 1 BAY):

COLUMN STRIP

M^- = 0 bars (Design OK)
M^+ = (5) #6 bars

MIDDLE STRIP –

M^- = (3) #5 bars
M^+ = (4) #5 bars

TOTAL ADDITIONS:

COLUMN STRIPS:

M^- = 0 bars (Design OK)
M^+ = (40) #6 bars

MIDDLE STRIPS:

M^- = (24) #5 bars
M^+ = (32) #5 bars