Coppin State University Physical Education Complex - Technical Report 3

Mechanical Systems Existing Condition Evaluation

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Location: Baltimore, MD

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Executive Summary

This report summarizes the intent, function and design of mechanical systems within The Coppin State Physical Education Complex. It also analyzes the overall operation and energy consumption of the building.

The complex utilizes a variable air volume (VAV) system to serve the various spaces in the complex. Highly efficient boilers, chillers and cooling towers help serve the loads of the complex, which are located in the future central utility plant. The plant also has connections and space anticipating the future renovations to the campus.

ASHRAE Standard 62.1 was utilized to analyze the ventilation rates of the complex. The ventilation rate procedure from section 6 of the Standard was used to calculate the ventilation rates of the complex. A majority of the spaces within the complex are compliant with only a few areas not meeting the requirements. Design loads were calculated and compared to the design loads performed by the engineer on the project. Most of the results for the design load model were relatively close to those modeled by the design engineer. The main reason for these discrepancies was due to the fact that a block load analysis was used for the model while the engineer used a space by space method.

The mechanical systems were approximately 18.5% of the overall cost of construction, which leads to about $101 per square foot. This high cost per square foot is most likely due to the high efficient mechanical equipment as well as the building's desire for a minimum of LEED® Certification.

Mechanical System Description

Building Summary

The new Physical Education Complex at Coppin State University was designed to support the health and human performance academic programs, the indoor and outdoor athletic teams and the West Baltimore community outreach mission of the University. The Complex features laboratories, classrooms, faculty and staff offices, dance studio, auxiliary gym, racquetball courts, fitness center, 4,100 seat arena and an eight lane NCAA regulation pool. It also houses a future satellite central utility plant with the associated maintenance and support service shops. Outdoor improvements include an outdoor track, soccer field, softball field, tennis courts, and a new campus entrance.

Design Objectives

The main design objectives for the Complex were to meet all ASHRAE Standards including ventilation requirements, acceptable indoor air quality, minimum energy requirements and more. In the middle of the design process LEED® certification was made another objective. The design was an energy efficient building using mainly a traditional Variable Air Volume (VAV) system. Single zone VAV, energy recovery units and dehumidification units were also implemented for the more complex spaces. The central utility plant is comprised of boilers, chillers and pumps with an accompanying cooling tower on the roof of the complex. After the completion of the complex it was able to successfully achieve a LEED® Silver Rating.

Site and System Initial Cost

Coppin State's Physical Education Complex is located in Baltimore, MD on Gwynns Falls Parkway. This project alone expands the size of the Coppin campus by about a third. Adding this complex to the campus not only helps the athletic teams at the university, but also contributes to economic development and quality of life in West Baltimore.

The estimated cost of the mechanical systems within the complex is $24,936,900, which is approximately 18.5% of the overall cost. This is approximately $101 per square foot.

Energy Sources

Possible energy sources that the complex is able to utilize include electricity, natural gas and fuel oil. The fuel oil is stored in a 20,000-gallon underground double wall fiberglass tank. The fuel oil rates will not be considered for this report since the fuel is considered a back-up source of fuel. The electricity and natural gas are provided by Baltimore Gas and Electric (BGE); these rates are listed below in Table 1.

Table 1 – Local Energy Rates

	Modeled	Designed
Electricity Cost ($/kWh)	0.12	0.1112
Natural Gas Cost ($/Therm)	1.138	1.227

Design Criteria

The complex is located in Baltimore, MD so the design conditions for Baltimore were used for the design. The outdoor design conditions for Baltimore were obtained from ASHRAE Fundamentals 2005, shown in Table 2. Indoor design conditions were defined by the engineer and were unique for some of the more complex spaces as seen below in Table 3.

Table 2 - Outdoor Design Conditions

	Dry Bulb	Wet Bulb
Summer	95°F	78°F
Winter	0°F	-

Table 3 - Indoor Design Conditions

		Dry Bulb	Relative Humidity (occupied)	Dry Bulb (unoccupied)
Typical Spaces	**Cooling**	75°F	60% maximum	85°F
	Heating	70°F	no minimum	55°F
Arena and Aux. Gym	**Cooling**	75°F	50% maximum	85°F
	Heating	70°F	30% minimum	55°F
Pool	-	80°F - 86°F	50% - 60%	-
Utility Spaces	**Heating**	60°F	-	-

Design Requirements

Ventilation

In order to verify that the complex's mechanical systems provide enough ventilation, a ventilation rate calculation from ASHRAE Standard 62.1 was performed. This procedure looks at the outdoor air intake rates based on the space types/application, number of occupants and the floor area of each space. Since some of the zones are very similar when considering space type, only nine of the fourteen air handing units were analyzed; the units considered address each type of zone.

The summary of the calculation is shown below in Table 4, while the detailed analysis of ASHRAE Standard 62.1 can be found in Technical Report 1. At the conclusion of this procedure it was discovered that three of the air handling units were not compliant. A reason for this finding can be from the occupancy values used. For these calculations a number given by the architect or the number of chairs/seats in an area were used for number of occupants in a given space. The zones that did not meet these requirements include high occupancy areas such as the dance studio and auxiliary gym. These areas will rarely be occupied at maximum level, but if they are the units may need to be resized or adjusted to meet these airflow rates.

Table 4 - Ventilation Rate Procedure Summary

Unit	Design Min CFM	ASHRAE 62.1 Min OA	Compliance
3	3800	1653	YES
4	3400	1599	YES
5	31000	13133	YES
6	31000	13133	YES
7	2800	1018	YES
8	7500	3593	YES
9	2300	8232	NO
10	2300	8232	NO
11	9150	11064	NO

Heating and Cooling Loads

An energy model was simulated in Carrier's HAP version 4.50 which analyzed the entire complex. Examples of the templates and data used can be found in Technical Report 2. Table 5 compares the summary of the energy model results to the engineer's design. The block load energy model resulted in different values than those designed for each air handling unit and energy recovery unit. The differences in these values could be consequences of the safety factors applied by the mechanical engineer or the details put into each space. The main reason for these differences is most likely due to the fact that a block load analysis was used in the model while the mechanical engineer used a space by space method for the design.

Table 5 – Modeled vs. Designed Energy Analysis

		AHU-1	AHU-2	AHU-3	AHU-4	AHU-5/6	AHU-7	AHU-8
Cooling (MBH)	Designed	621	397	650	637	6540	509	1029
	Modeled	281.4	267.8	411.8	362.1	3084.2	245.1	481.9
Supply Air (cfm)	Designed	12250	9000	13750	14750	80000	11500	19600
	Modeled	5023	8453	12411	11426	72892	7316	16290
Ventilation Air (cfm)	Designed	4000	1975	3800	3400	62000	2800	7500
	Modeled	2062	1362	1694	1190	10800	762	1399
Heating (MBH)	Designed	529	389	594	637	1728	497	847
	Modeled	127.5	91.3	142	161.5	899.7	122.1	182.7

		AHU-9/10	AHU-11	AHU-12	AHU-13	AHU-14	ERU-1	ERU-2
Cooling (MBH)	Designed	958	1404	539	596	-	733	1091
	Modeled	779.9	8601.1	418.8	430.6	-	267	488.8
Supply Air (cfm)	Designed	23000	28000	13000	13950	4800	9820	14100
	Modeled	19057	22157	10162	8453	4773	9765	14022
Ventilation Air (cfm)	Designed	4600	9150	2600	2500	480	9820	1410
	Modeled	4295	5140	2168	2329	136	401	1190
Heating (MBH)	Designed	497	1210	562	603	207	283	404
	Modeled	386.9	352.2	201.8	185.9	140.4	71.5	162.4

Annual Energy Use

Table 6 below shows the annual energy consumption used by the complex broken down by component type which was performed for Technical Report 2. Referencing Figure 1, the largest consumer of energy in the building is the cooling tower fans. This big percentage is due to the large flow rate of the condenser at 1,015 GPM. The cooling tower for the complex is a very large tower and was sized with expansion in mind. The lights, electrical equipment, and air system fans consume the next largest amount of energy.

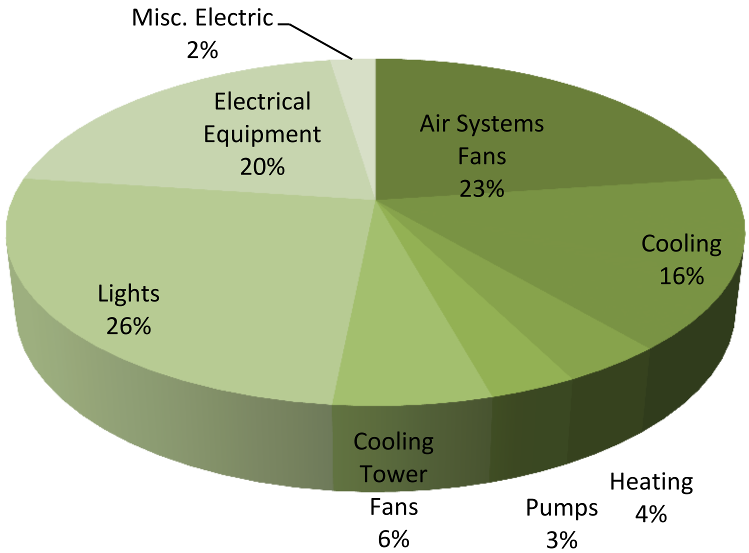
This annual energy consumption was compared to the Commercial Buildings Energy Consumption Survey (CBECS) 2003. In Table E2A (Major Fuel Consumption Intensities by End Use for all Buildings) of CBECS a building with the same range of square footage as the complex consumed an average of 100,200 BTU/SF. When comparing this value to the complex at approximately 92,000 BTU/SF the numbers produced by the model appear accurate.

These results were also compared to the engineer's results. Since the complex is a LEED® Silver Building an energy consumption study had to be performed for EA Credit 1. The engineer compared their results to the ASHRAE Standard 90.1 Baseline. These results can be seen in Appendix A. When comparing the engineer's results to the results done in Technical Report 2 the results are much higher. This is most likely due to the block loading method used for this report compared to the room by room method used by the engineer.

Table 6- Annual Energy Consumption

	Energy (kWh)
Air Systems Fans	1,434,527
Cooling	1,010,456
Heating	751,846
Pumps	201,676
Cooling Tower Fans	3,653,707
Lights	1,621,230
Electrical Equipment	1,289,010
Misc. Electric	150,600
Grand Total	**10,113,052**

Figure 1- Annual Energy Consumption Percentages



Lost Space

There are a total of 3 mechanical rooms located throughout the complex. The mechanical engineer strategically placed multiple air handling units (AHUs) outside to cut down on the amount of interior mechanical spaces. Table 7 below summarizes the space lost by mechanical rooms and the associated shafts. This value is almost 10% of the entire complex which is a considerable amount. Since the complex will also serve as a future central utility plant, more floor space was given to the main mechanical room for the future expansion.

Table 7 - Square Footage Lost by Mechanical Spaces

	Mechanical Rooms	Shaft Space	Total
Overall Building	23581	389	23970

System Operation

Equipment Summary

The complex is served by fourteen air handling units which are all variable air volume (VAV) units. Some of the units are single zone while others are conventionally zoned. There are a total of 154 air terminal units connected to their associated air handling unit. For the more challenging spaces the complex has two energy recovery units serving the locker rooms and a dehumidification unit for the pool area. All of these units are specified in Table 8,9 and 10.

Table 8 - Air Handling Units

Unit	Area Served	CFM	Min OA (CFM)
AHU - 1	Shops (Level 1)	12250	4400
AHU - 2	Central Services (Level 1)	9000	1975
AHU - 3	Facility Maintenance (Level 2)	13750	3800
AHU - 4	Facility Maintenance (Level 3)	14750	3400
AHU - 5	Arena	40000	31000
AHU - 6	Arena	40000	31000
AHU - 7	Arena Offices (Level 3)	11500	2800
AHU - 8	Concourse (Level 2)	19600	7500
AHU - 9	Auxiliary Gym	11500	2300
AHU - 10	Auxiliary Gym	11500	2300
AHU - 11	Classrooms, Dance (Levels 1 &2)	28000	9150
AHU - 12	Multipurpose Room	13000	2600
AHU - 13	Fitness	13950	2500
AHU - 14	Vehicle Maintenance	4800	480

Table 9 - Energy recovery Units

Unit	Area Served	CFM	Wheel Type	Wheel Diameter (inches)
ERU-1	South Lockers	9820	Airfoil Plenum	22
ERU-2	East Lockers, Sports Med, Pool Lockers	14100	Airfoil Plenum	27

Table 10 - Pool Dehumidification Unit

Unit	Area Served	Cooling Capacity (MBH)	Supply Fan (CFM)	Return Fan (CFM)
PDU-1	Pool	730,000	28,000	29,450

A primary/secondary flow system is used for the water side of the mechanical system. The complex has two 500 ton centrifugal chillers which utilize a 1000 ton cooling tower to cool its condenser water. To heat the building three 250HP dual-fuel boilers were used. The major waterside equipment can be seen in Tables 11,12 and 13.

Table 11 - Chillers

		Evaporator			Condenser		
Unit	Capacity (Tons)	GPM	EWT (°F)	LWT (°F)	GPM	EWT (°F)	LWT (°F)
Chiller 1	500	1000	54	42	1200	85	97
Chiller 2	500	1000	54	42	1200	85	97

Table 12 - Cooling Tower

Unit	Capacity (Tons)	GPM	EWT (°F)	LWT (°F)
Cooling tower 1	1000	1250 per cell	97	85

Table 13 - Boilers

Unit	Capacity (HP)	Gross Output (MBH)
Boiler 1	250	8369
Boiler 2	250	8369
Boiler 3	250	8369

Major parts of the mechanical system are the pumps. The pumps are constant volume on the primary size and variable flow on the secondary side. A duplex variable flow tertiary pump system is utilized to distribute the chilled water to the various air handling units throughout the complex. The pumps associated with all the major equipment and their details, can be found in Appendix B.

Schematics

Figure 2 - Condenser Water Schematic

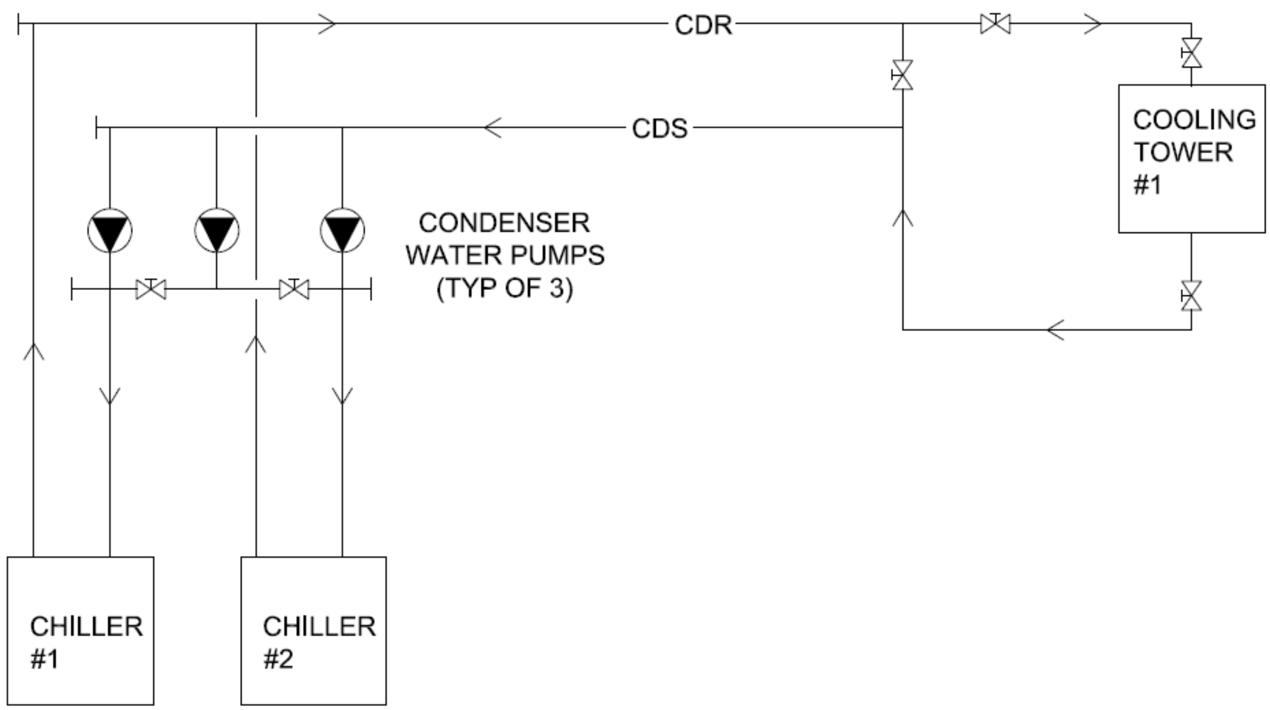


Figure 3 - Chilled Water Schematic

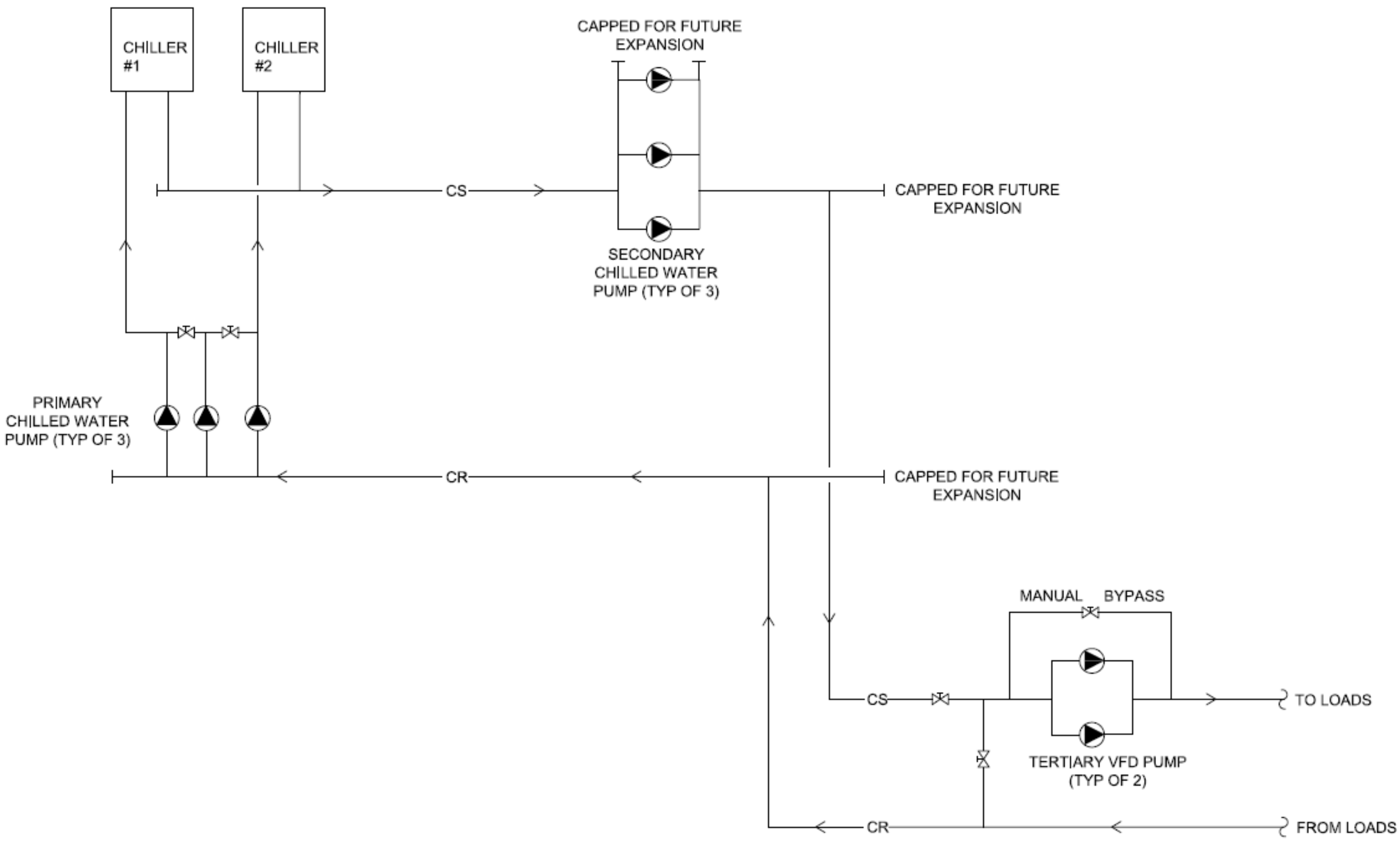
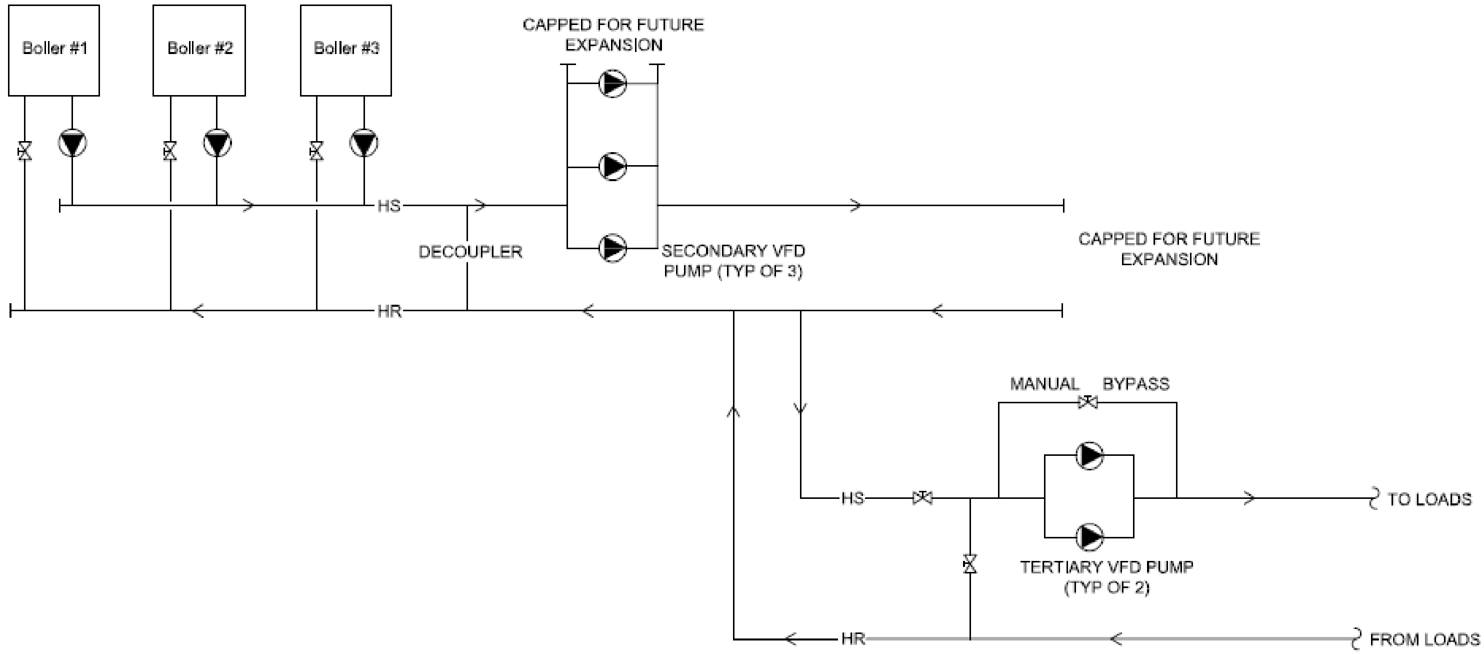


Figure 4 - Heating Hot Water Schematic



Description of System Operation

Air Side

The complex uses VAV system to condition the spaces. Each air handling unit (AHU) contains heating and cooling coils complete with associated piping and automatic temperature controls. For the zoned VAV systems, each air terminal unit receives conditioned air from the associated AHU which is controlled by a DDC control system. For the single zone VAV systems the AHU will serve as the actual air terminal unit. The associated DDC control system will control the amount of air the given space needs and allow the space to be served without being processed through any actual air terminal units.

Water Side

Cooling is provided by electric-driven high-efficiency centrifugal water chillers complete with remote induced draft cooling towers for heat rejection from the chillers seen in Figures 2 and 3. Each cooling tower is powered by a variable frequency drive to minimize energy consumed at off design outdoor conditions. The chiller refrigerant is environmentally friendly due to the LEED® requirements.

In Figure 4, the three 250HP dual-fuel boilers that provide heating for the building are illustrated. Two of the boilers satisfy the building's heating needs while the third is a standby boiler. The boilers produce water for heating that is distributed via pumps and piping. The heating system is somewhat similar to the chilled water system in that it has constant primary volume boiler pumps and variable flow secondary pumps. The tertiary pumps are arranged so one pump is active while the other is on standby.

Operating History of System

Currently the complex has been fully operational for 10 months. The electricity and natural gas rates for the complex come from a main facility, distributed by the university. Since the complex is so new and the numbers are still being organized and compiled the rates were not available for this report.

LEED Analysis for Mechanical Systems

A LEED® assessment was completed for the complex using LEED-NC 2.2 by the engineers. For this report the newer version of LEED® was used, LEED 2009 for New Construction. The new version includes 3 additional prerequisites and 6 categories for Energy and Atmosphere as well as 2 prerequisites and 5 mechanical system categories in Indoor Environmental Quality. The amount of possible points and their requirements for some of the categories were updated in the newer version as well as the minimum amount of points for each rating was increased as seen in Table 14. Only the credits associated with the mechanical systems were considered for this report.

Table 14 - Points Required for LEED Ratings

	Certified	Silver	Gold	Platinum
LEED-NC 2.2	26-32	33-38	39-51	52-69
LEED 2009	40-49	50-59	60-79	80+

Energy and Atmosphere (EA)

Prerequisite 1 for EA is to have fundamental commissioning of the building's energy systems, Prerequisite 2 is meeting the minimum energy performance and Prerequisite 3 is refrigerant management where no CFC based refrigerants can be used in the complex. All three of these prerequisites were met in order for the complex to even be considered for LEED®.

EA Credit 1 concentrates on optimizing energy performance through three optional compliance paths. The engineer was able to gain 10 points through Option 1, Whole Building Energy Simulation, saving 42% when being compared to the baseline. In the newer version the percentages and their related possible points changed, so with the new points spread the complex would be able to achieve 16 points in this category.

Credit 2 of EA focuses on on-site renewable energy to help decrease the environmental as well as the economical impacts associated with fossil fuel energy use. The design engineers decided not to attempt these points for the complex.

For Credit 3 of EA the complex was able to receive 1 point for having enhanced commissioning of the building. The newer version of LEED® has 2 points possible for this category without changing any of the requirements, so the complex earns a total of 2 points.

EA Credit 4 helps reduce the amount of ozone depletion to minimize the amount of contributions to climate change. LEED-NC 2.2 had only 1 point possible for this category while the newer version has 2 points possible. The complex was able to earn the point in the older version; since the options did not change in this category the complex can earn the maximum number of points available.

Measurement and Verification, EA Credit 5, and Green Power, EA Credit 6, were not attempted for the complex, therefore the possible points in the newer version will not be attempted either.

Indoor Environmental Quality (EQ)

The first prerequisite for IEQ is to establish minimum indoor air quality by meeting the requirements of Sections 4 -7 of ASHRAE Standard 62.1.2007. The design engineer met all the requirements of the standard in order to comply with this prerequisite. Prerequisite 2 requires that an Environmental Tobacco Smoke (ETS) Control be used in the building; since the complex is a smoke free building this prerequisite was achieved.

EQ Credit 1, Outdoor Air Delivery Monitoring, and Credit 2, Increased Ventilation, were not attempted for the complex in the older version, so they will not be considered for this report.

Credit 6.2 of EQ requires controllability of systems for a high level of thermal comfort for the occupants. The new and old versions of LEED® have the same requirements so the 1 point for this credit is accomplished by the complex.

EQ Credit 7.1 involves providing a comfortable thermal environment that helps support the wellbeing of the building's occupants. In order to gain the point associated with this section the building must be compliant with the thermal comfort conditions of ASHRAE Standard 55-2004. The complex overall is compliant with this standard so it gains the point for both the old and new versions. Credit 7.2, Thermal Comfort Verification, was not attempted by the design engineer for this building.

LEED Conclusion

When comparing the older version used in the design of the complex and the newer 2009 version, the complex still has the ability to achieve a LEED® Silver rating. In the sections where the complex achieved more points it was comparable to the point raise illustrated in Table 14, therefore the complex would most likely still be considered a LEED® Silver building under the newer version of LEED®.

Overall Evaluation

Overall the mechanical system of the Coppin State University Physical Education Complex is strategically and intricately designed in a well-planned out manner. VAV systems are very efficient when coupled with efficient boilers and chillers. The design also takes advantage of the complex spaces found within the building by using VAV both in a single zone and multi-space function.

The estimated construction cost for the mechanical systems was about 18.5% of the overall cost of construction. This high cost for mechanical systems is most likely due to the highly efficient equipment in the central utility plant as well as the expansion accommodations already installed.

Applying high efficiency chillers and cooling towers was a good solution for this building. There are a few improvements that could be implemented to further reduce the overall energy consumption. One change that could help would be replacing the current chillers with variable flow chillers to create a more efficient system. Other small changes could also be incorporated, but this will be further investigated in the Thesis Proposal Report.

Appendix A – Engineer's Annual Energy Consumption Results

Table 2. Annual Energy Consumption

Component	CSU Phys Ed Complex - Baseline
HVAC Components	
Electric (kWh)	2,549,297
Natural Gas (Therm)	75,931
Fuel Oil (na)	0
Propane (na)	0
Remote HW (na)	0
Remote Steam (na)	0
Remote CW (na)	0
Non-HVAC Components	
Electric (kWh)	2,644,259
Natural Gas (Therm)	0
Fuel Oil (na)	0
Propane (na)	0
Remote HW (na)	0
Remote Steam (na)	0
Totals	
Electric (kWh)	5,193,555
Natural Gas (Therm)	75,931
Fuel Oil (na)	0
Propane (na)	0
Remote HW (na)	0
Remote Steam (na)	0
Remote CW (na)	0

Appendix B – Pumps

Unit	Service	GPM	Size (inches)	HP
P-1	Primary/Boiler Heating Water	670	6.5	7.5
P-2	Primary/Boiler Heating Water	670	6.5	7.5
P-3	Primary/Boiler Heating Water	670	6.5	7.5
P-4	Secondary Heating Water	670	9	20
P-5	Secondary Heating Water	670	9	20
P-6	Secondary Heating Water	670	9	20
P-7	Tertiary Heating Water - PEC	900	12	40
P-8	Tertiary Heating Water - PEC	900	12	40
P-9	Tertiary Heating Water - FMB	300	8.5	10
P-10	Tertiary Heating Water - FMB	300	8.5	10
P-11	Chiller/Primary Chilled Water	1000	8.8	20
P-12	Chiller/Primary Chilled Water	1000	8.8	20
P-13	Chiller/Primary Chilled Water	1000	8.8	20
P-14	Condenser Water	1250	9.8	40
P-15	Condenser Water	1250	9.8	40
P-16	Condenser Water	1250	9.8	40
P-17	Secondary Chilled Water	1000	10.4	30
P-18	Secondary Chilled Water	1000	10.4	30
P-19	Secondary Chilled Water	1000	10.4	30
P-20	Tertiary Chilled Water - PEC	1500	11.5	60
P-21	Tertiary Chilled Water - PEC	1500	11.5	60
P-22	Tertiary Chilled Water - FMB	350	8.2	10
P-23	Tertiary Chilled Water - FMB	350	8.2	10
P-24	Domestic HW Recirc	20	7.1	1
P-25	AHU-1 Preheat Coil Circ	35	4.7	0.5
P-26	AHU-2 Preheat Coil Circ	26	4.6	0.5
P-27	AHU-3 Preheat Coil Circ	40	5.2	0.5
P-28	AHU-4 Preheat Coil Circ	42	5.3	0.5
P-29	AHU-5 Preheat Coil Circ	115	5.7	1.5
P-30	AHU-6 Preheat Coil Circ	115	5.7	1.5
P-31	AHU-7 Preheat Coil Circ	33	4.7	0.5
P-32	AHU-8 Preheat Coil Circ	58	4.9	0.75
P-33	AHU-9 Preheat Coil Circ	33	4.7	0.5
P-34	AHU-10 Preheat Coil Circ	33	4.7	0.5
P-35	AHU-11 Preheat Coil Circ	81	5.2	1
P-36	AHU-12 Preheat Coil Circ	37	4.7	0.5
P-37	AHU-13 Preheat Coil Circ	40	5.2	0.5
P-38	AHU-14 Preheat Coil Circ	14	4.5	0.33
P-39	PDU-1 HX Circulator	100	6.1	1
P-40	Pool Water Heat Exchanger	60	4.9	0.5
P-41	ERU-1 Heating Coil	18	4.6	0.5
P-42	ERU-2 Heating Coil	18	4.6	0.5
P-43	Domestic HW Recirc	15	4.7	0.33

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