Georgetown University New Science Center

Mechanical Systems Existing Conditions Evaluation Report

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GEORGETOWN UNIVERSITY NEW SCIENCE CENTER

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Executive Summary

This report will evaluate the mechanical system of the New Science Center of Georgetown University as it was designed by the mechanical consultants on the project. The building is consists primarily of labs and offices, and intends to achieve LEED Silver certification. Overall, the HVAC system is complex and highly energy efficient.

Design influences of the system include site conditions, client goals and requirements, program and layout requirements. Site conditions that need to be considered include climate conditions and available energy sources. Client goals include providing a safe, comfortable environment that allows occupants to complete experiments and work productivity, and maximizing energy efficiency to reduce operating costs and minimize carbon footprint. The program influences for the building involve building space size, usage, occupancy, and temperature setpoints. These affect heating and cooling loads, ventilation and exhaust requirements, and equipment characteristics such as size and noise.

The building uses a Dedicated Outdoor Air System with VAV terminal supply and exhaust units. The AHUs precondition supply air that is distributed through a ducted system to active chilled beams at each space. Chilled beam induction heating and cooling is used in all physics and biology labs, offices, recitation rooms, corridors, common spaces, and conference rooms. Fan coil units are used in chemistry labs, and unit heaters are used in the loading dock, mechanical spaces, and emergency stairs.

Other energy saving equipment used includes VFD motors in all fans and pumps, enthalpy recovery wheels in AHUs, and an energy recovery water source heat pump

Sophisticated controls monitor and manage all setpoints and operating sequences on all equipment. Pressure, temperature, and humidity is monitored and adjusted throughout the building based on these controls. Occupancy schedules and occupancy sensors determine airflow requirements and temperature setpoints. Alarms are incorporated to advise system operators of maintenance needs and operating problems.

The mechanical system's heating and cooling loads were determined to be 1,462 MBh and 230 tons, respectfully. The annual energy costs are approximately $184,101. This works out to approximately $1.45/SF-yr. The mechanical rooms and equipment take up about 14% of the building's floor area at approximately 21,549 SF.

As-designed, the mechanical system of the New Science Center meets the requirements for various LEED points that will assist in attaining LEED Silver certification.

Contents

Introduction

The New Science Complex is a 154,000 SF research facility being built on the Georgetown University campus in Washington, DC. The building is to house the Physics, Biology, and Chemistry departments. It will consist primarily of labs, classrooms, offices, and conference rooms. The building stands five stories above grade and is designed to achieve LEED Silver Certification.

The building is conditioned by (4) Air Handling Units, an active chilled beam system, fan coil units, and steam and hot water unit heaters. The AHUs supply 100% outdoor air to all occupied spaces within the building. The chilled beams are used in offices, physics and biology labs, conference rooms, computer labs, and some of the lounges. Fan coil units are used in the chemistry labs. Steam and hot water unit heaters are used in emergency stairwells, entrance vestibules, the loading dock, and the mechanical penthouse.

This report will first address the design influences of the mechanical system, followed by a summary and evaluation of the mechanical system chosen by the designers.

Design Influences

Site Conditions

Climate conditions of the building's location have a large impact on the design of the mechanical system and equipment. The New Science Center is located in Washington, DC. Outdoor design conditions for this location vary drastically throughout summer and winter seasons. The heating and cooling systems must accommodate a wide range of outdoor air conditions. The values listed in Table 1 are outdoor design conditions from ASHRAE Handbook of Fundamentals 2009 for the Washington, DC area.

TABLE 1

ASHRAE Weather Data for Washington, DC*		
	DB Temp [°F]	WB Temp [°F]
Summer Design (0.4%)	93.5	75.1
Winter Design (99.6%)	10.7	-

* Washington DC Dulles International Airport

Energy sources for mechanical systems are typically dependent on availability, cost, and system characteristics. Since the New Science Center is to be a part of the Georgetown University campus, the system is to be integrated into the district steam and chilled water plant of the university. The Georgetown University district plant consists of three gas/oil fired high pressure boilers, eight electric motor driven chillers, and a thermal storage tank. In this building's case, the system characteristics and equipment were chosen based on the energy source (district steam and chilled water).

Client Goals and Requirements

Georgetown University is building the New Science Center to expand and upgrade their existing Physics, Biology, and Chemistry departments. As required by the client and code, these spaces are to provide a safe, healthy, and comfortable environment for the students and teachers occupying them.

All new buildings on Georgetown University are required to achieve a minimum of LEED Silver certification to comply with the campus planning and sustainability initiatives. This affected many aspects New Science Center's mechanical system design, envelope, and building materials.

The Georgetown University utilities department requires the system to tie into the existing district steam and chilled supply. This has a large influence on the system and equipment chosen for the mechanical design. GU utilities also requires a specific subcontractor and manufacturer to be used to integrate the Building Automation System and controls with the campus monitoring and operations system.

Another important design concern of the client is the costs involved in the mechanical design. This includes both capital cost and operating costs. Money is often the limiting factor when it comes to efficiency and sophistication of mechanical systems. Generally, a higher initial investment in the system and equipment will lead to decreased operating costs and long term savings. Investing in sustainable technologies improves the client's public image for being environmentally conscious.

Program and Layout

The building will consist of primarily of lab, classroom, and office spaces. Each space has unique loads, however particular attention must be put towards the lab spaces within the building. Proper ventilation and exhaust are essential in proper design of lab spaces.

Table 2 contains indoor air temperature setpoints based on space usage as defined in the contract documents.

TABLE 2

Indoor Design Setpoints [°F]	
Office, Circulation Spaces & Toilet Rooms	
Occupied cooling	75
Occupied heating	70
Unoccupied cooling	78
Unoccupied heating	65
Laboratory and Lab Equipment Spaces	
Occupied cooling	74
Occupied heating	72
Unoccupied cooling	78
Unoccupied heating	68

In Technical Report 1: *ASHRAE Standard 62.1 and 90.1 Compliance Report* minimum ventilation rates were determined based on the ventilation rate procedure of ASHRAE 62.1. The minimum total ventilation requirement for this building according to ASHRAE Standard 62.1 is 32,465 cfm. The designer ventilation requirements are not available.

Heating and cooling loads of the building were estimated in Technical Report 2: *Building and Plant Energy Analysis Report*. The peak heating and cooling loads were determined to be 1,462 MBh and 230 tons, respectfully. These values were calculated using Trane TRACE 700 energy modeling software. Many assumptions were taken into account to determine these values. See Technical Report 2: *Building and Plant Energy Analysis Report* for an in-depth description and justification of these assumptions.

System Design and Equipment

The system chosen by the design engineers of this project is summarized in the introduction on page 4 of this report. Figures 1 and 2 are schematic flow diagrams of the mechanical system as designed.

FIGURE 1

Chilled Water Flow Diagram

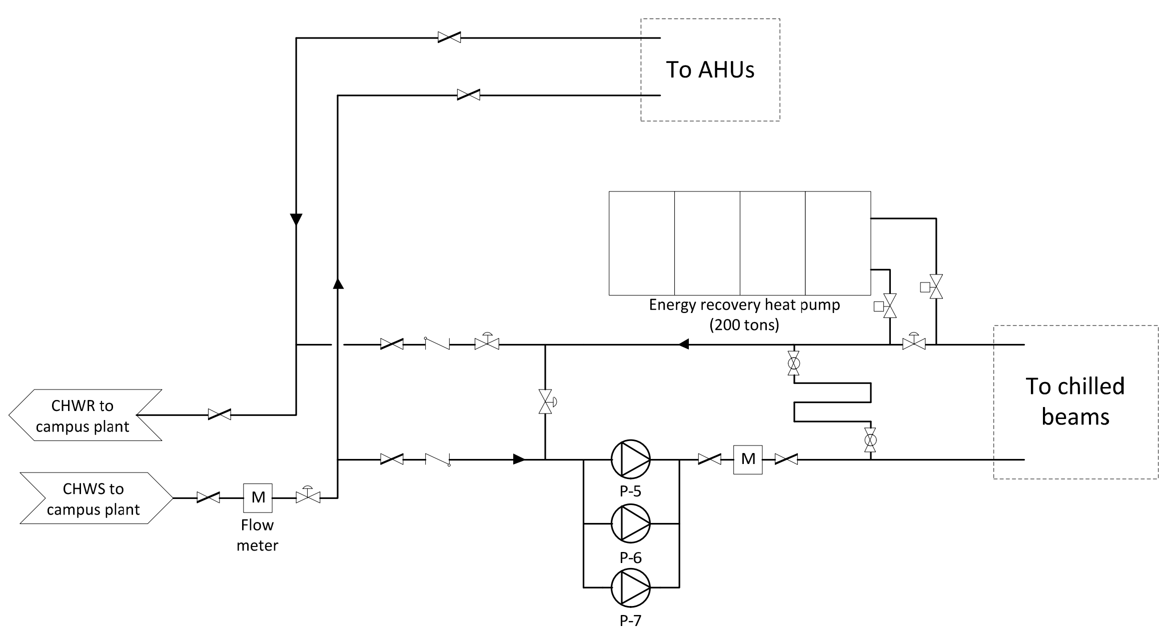
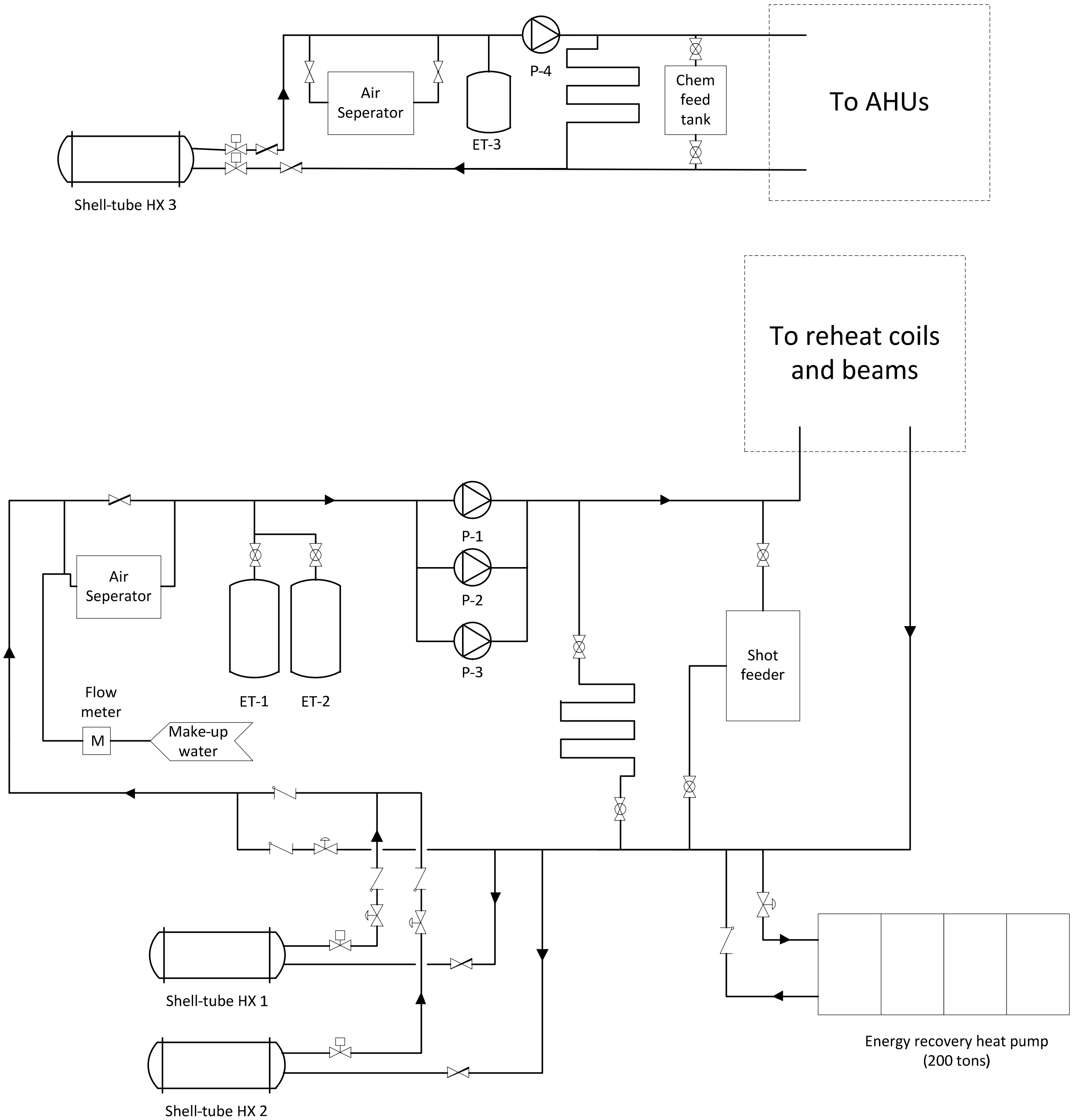


Figure 2

Hot Water Flow Diagram



Equipment

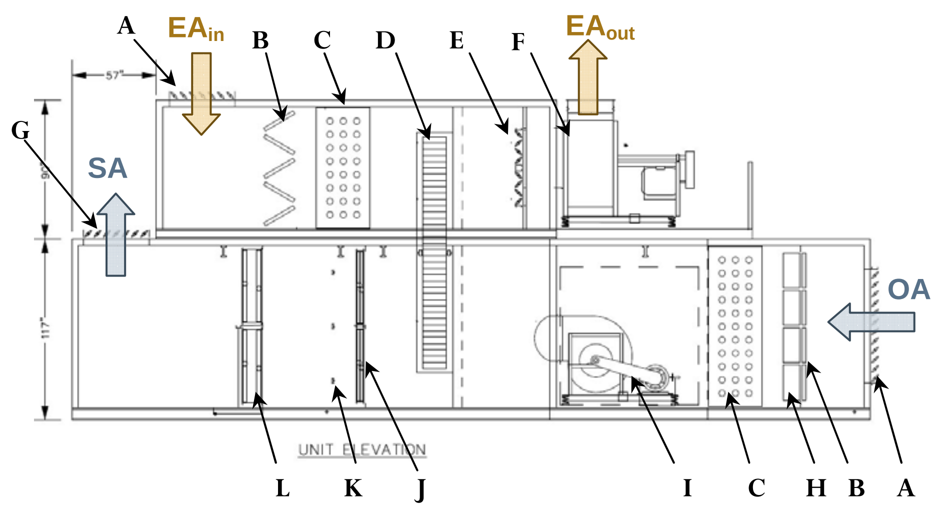
Air Handling Units

Four identical built-up AHUs supply 100% outdoor air throughout the building. These are custom designed and engineered by Haakon Industries. Each contains four mixed-flow fans powered by electric motors with Variable Frequency Drives. Two fans are configured in parallel for supply air and two in parallel for exhaust for each AHU. VFDs adjust the airflow capacity to the meet the amount required by the building. This saves electrical energy consumption by reducing the power used by the motors at part load. Each AHU has a capacity range of 50,000 cfm to 15,000 cfm. Supply air from all four AHUs enters a common plenum from which is distributed throughout the building through a ducted system. All AHUs were sized for 15% additional capacity for future growth.

Each AHU also contains a heating and cooling coil, a steam humidifier, and an enthalpy recovery wheel. The enthalpy recovery wheel provides sensible and latent energy recovery from the exhaust air to the supply air, reducing the loads on the heating and cooling coils.

FIGURE 3

Typical Air Handling Unit Detail



A - Inlet air dampers
B - Pre-filters
C - Sound attenuator
D - Enthalpy wheel
E - Fan isolation damper
F - Exhaust fan
G - Discharge dampers
H - Final filters
I - Supply fan
J - HW coil
K - Steam humidifier
L - Cooling coil

TABLE 3

Air Handling Units – Fan Schedule						
	Supply fans			Exhaust fans		
	capacity [cfm]	motor HP	control	capacity [cfm]	motor HP	control
AHU-1	54,402	2@50	VFD	54,402	2@40	VFD
AHU-2	54,402	2@50	VFD	54,402	2@40	VFD
AHU-3	54,402	2@50	VFD	54,402	2@40	VFD
AHU-4	54,402	2@50	VFD	54,402	2@40	VFD

Table 4

Air Handling Units – Preheating/Cooling						
	Preheat HW Coil		Cooling Coil		Enthalpy Wheel	
	EWT [°F]	GPM	EWT	GPM	Effectiveness Sens.	Effectiveness Latent
AHU-1	80	80	45	398.8	76%	74%
AHU-2	80	80	45	398.8	76%	74%
AHU-3	80	80	45	398.8	76%	74%
AHU-4	80	80	45	398.8	76%	74%

Variable Air Volume terminal units

VAV terminal units are used throughout the building to adjust airflow based on load and ventilation requirements of each zone. This improves efficiency and control of the air handling system and saves energy by reducing fan power during part load. These are also essential in maintaining proper pressurization of critical spaces within the building to prevent infiltration of hazardous contaminants into adjacent spaces. VAV supply and exhaust boxes are used throughout the offices, recitation spaces, and conference rooms. Special VAV valves are used in lab spaces for more precise control of ventilation and exhaust rates. The VAV terminal units specified vary based on the airflow range to each space. Most supply VAV terminal units used throughout the building include a hot water re-heat coil.

Pumps

All pumps used in the mechanical system design utilize Variable Frequency Drives. This saves motor energy when operating at part load. Some pumps are configured in parallel to increase efficiency at part loads and for redundancy. The pump schedule can be found in Table 5.

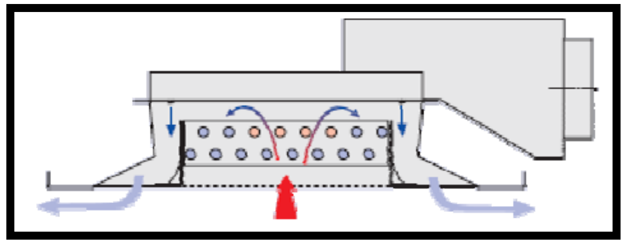
Table 5

Pump Schedule					
Pump	Service	Capacity [gpm]	Head [ft]	Motor HP	RPM
P-1	Reheat HW	300	85	15	1750
P-2	Reheat HW	300	85	15	1750
P-3	Reheat HW	300	85	15	1750
P-4	Preheat HW	270	50	7.5	1750
P-5	CW Supply	500	85	20	1750
P-6	CW Supply	500	85	20	1750
P-7	CW Supply	500	85	20	1750
P-8	Process CW	240	75	10	1750
P-9	Process CW	240	75	10	1750
CP-1 (2)	Condensate Return	90	-	2@7.5	1750
CP-2 (2)	Condensate Return	90	-	2@7.5	3500

Active chilled beams

Four-pipe, active chilled beams are used in all office, lounge, recitation, conference, and biology and physics lab spaces. These serve the remainder of the sensible heating or cooling loads that are not met by the AHU coils. The models used vary in length and nozzle size depending on the design load and ventilation requirements of each space.

FIGURE 4 - CHILLED BEAM DETAIL



Heat pump recovery unit

Large buildings often have simultaneous heating and cooling loads due to internal heat gains and supply air reheat needs. The designers utilize a water source heat pump system to recover waste heat from the chilled beams' chilled water return. Heat from the chilled water return is transferred to the hot water supply serving reheat coils and chilled beams. Four Multistack modules connected in series make up this system.

Controls

The Building Automation System (BAS) monitors pressures, temperatures, and flow rates, and controls various pieces of equipment including controls valves, VFDs, AHUs, Pumps, etc. The mechanical system controls are direct digital type. Direct Digital Control Field Panels (DDCFPs) perform equipment start-up and shut-down sequences.

The occupancy schedule for typical spaces is defined in the contract documents. Spaces are considered "occupied" from 8AM to 6PM Monday through Friday, and "unoccupied" at all other times. Individual lab scheduling is to be determined by Georgetown University. Offices, conference rooms, and research labs use occupancy sensors for monitoring occupancy during irregular hours. All schedules are adjustable by operators through the BAS.

Airflow from the (4) AHUs is controlled by parallel fans with VFDs. Static pressure setpoints in supply ducts are monitored and adjusted for by the BAS. Within each AHU, the enthalpy recovery wheel is utilized prior to the preheat and cooling coils to maintain supply air temperature. When the enthalpy recovery wheels are insufficient to meet the required load, the pre-heating coils use hot water from a shell-and-tube (steam to water) heat exchanger to maintain supply air temperature at 55°F, or the cooling coils use chilled water from the district chilled water supply to cool entering air to 52.2°F. Lead and lag unit changeover for AHUs is based on run time and is adjusted weekly. The unit with the least run time becomes the lead unit and the units with the next lowest run times are sequenced accordingly.

VAV terminal units control airflow to all spaces. Flow rates are based on minimum ventilation rates that vary according to the space occupancy. A reheat coil is located within each unit to reheat precooled air from the AHUs to 55°F.

Four-pipe chilled beams condition the remaining sensible loads of the spaces. Chilled water and hot water flow control valves modulate to meet each zones heating and cooling requirements. Temperature setpoints adjust according to the occupancy schedule described previously in this section. "Occupied" and "un-occupied" setpoints are described in the *Design Influences - Program and Layout* section of this report. Room temperatures are monitored by wall mounted thermostats within each space.

Energy Use

The mechanical system of the New Science Center consumes energy of three types: district steam, district chilled water, and electricity. Operating history and engineer design values are not available for comparison of the simulation values for energy consumption. In Technical Report 2: *Building and Plant Energy Analysis Report*, a Trane TRACE model was created and an energy simulation was run. The simulation consumption data for steam, chilled water, and electricity can be found in Figures 5 through 7.

FIGURE 5

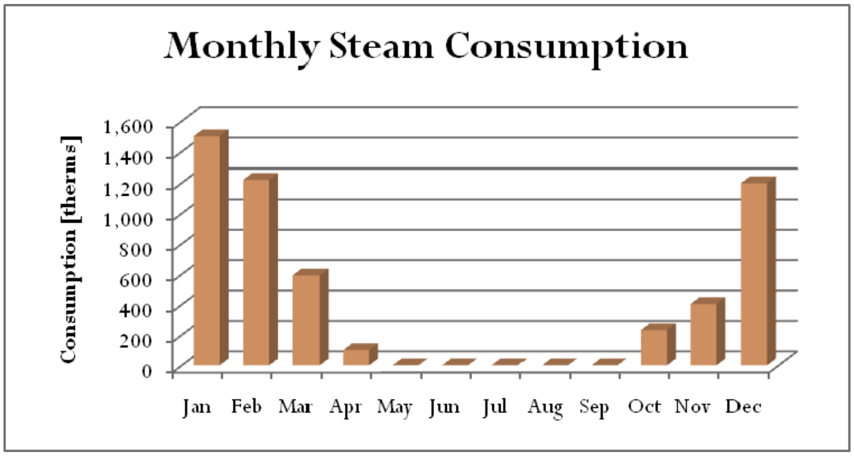


FIGURE 6

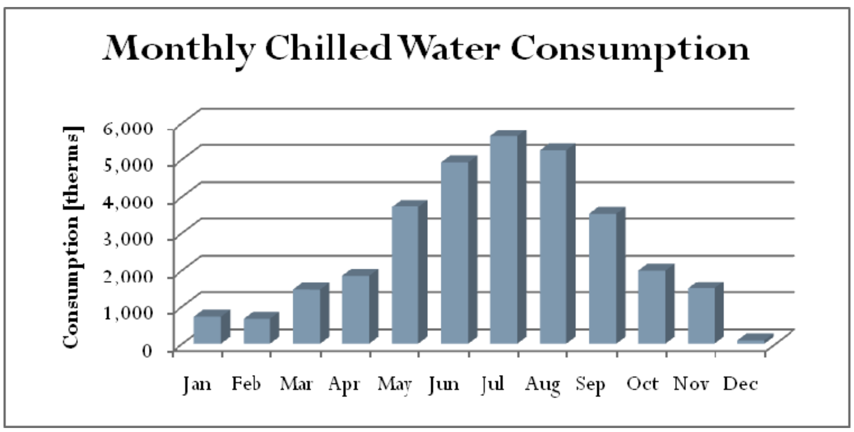
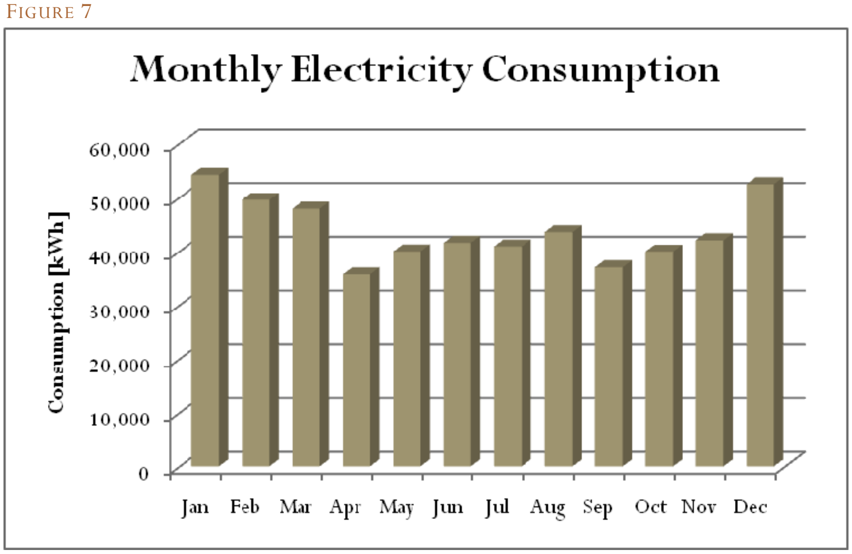


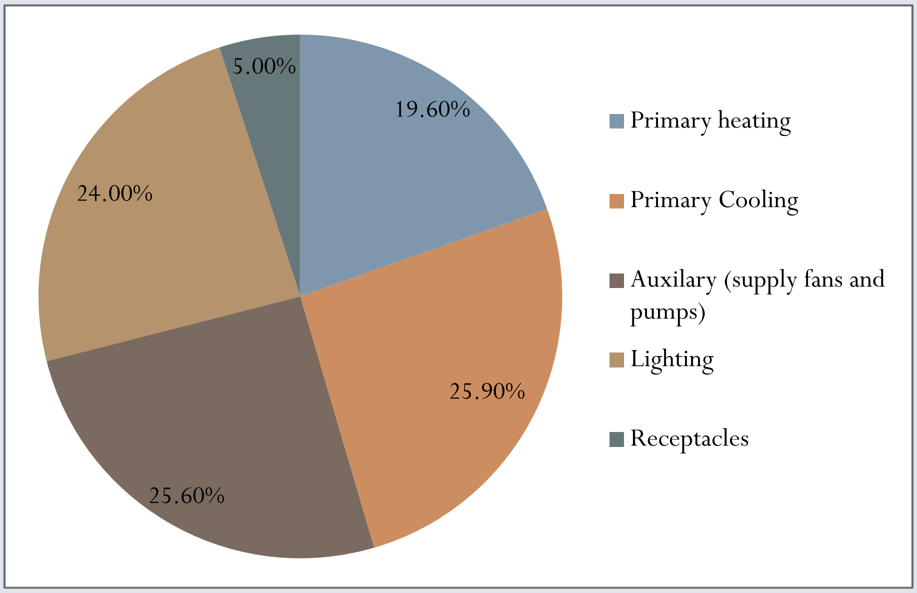
FIGURE 7



The energy consumption distribution among the subsystems from the simulation data are shown in Figure 8. It should be noted that the lab equipment used will consume a large amount of energy and is not represented in this diagram.

FIGURE 8

Electric Energy Subsystem Distribution



Operating Costs

The first costs of the mechanical system are not available for this report. The electric and steam utility costs are summarized in Tables 6 and 7. An annual energy cost summary is included in Table 8.

TABLE 6

Annual Steam Costs

Month	Steam [thems]	Steam [klb]	rate [$/klb]	cost
Jan	1,501	1,792.2	15.30	$27,421
Feb	1,219	1,455.5	15.30	$22,269
Mar	592	706.8	15.30	$10,815
Apr	100	119.4	15.30	$1,827
May	0	0.0	15.30	$0
Jun	0	0.0	15.30	$0
Jul	0	0.0	15.30	$0
Aug	0	0.0	15.30	$0
Sep	0	0.0	15.30	$0
Oct	232	277.0	15.30	$4,238
Nov	403	481.2	15.30	$7,362
Dec	1,198	1,430.4	15.30	$21,885
TOTAL	5,245	6,262.5	15.30	$95,817

Table 7

Annual Electric Utility Costs							
			Unit Costs		Cost		
Month	Consumption [kWh]	Demand [kW]	[$/kWh]	[$/kW]	Consumption	Demand	Total
Jan	59,370	270	0.10906	0.4531	$6,475	$268	$6,743
Feb	54,263	271	0.10906	0.4531	$5,918	$269	$6,187
Mar	58,576	290	0.10906	0.4531	$6,388	$277	$6,666
Apr	48,819	293	0.10906	0.4531	$5,324	$279	$5,603
May	68,249	371	0.10906	0.4531	$7,443	$314	$7,758
Jun	81,481	443	0.10906	0.4531	$8,886	$347	$9,233
Jul	88,972	462	0.10906	0.4531	$9,703	$356	$10,059
Aug	86,956	441	0.10906	0.4531	$9,483	$346	$9,829
Sep	63,752	404	0.10906	0.4531	$6,953	$329	$7,282
Oct	54,054	303	0.10906	0.4531	$5,895	$283	$6,179
Nov	52,827	276	0.10906	0.4531	$5,761	$271	$6,033
Dec	59,198	244	0.10906	0.4531	$6,456	$257	$6,713
TOTAL	776,517	462					**$88,284**

Table 8

Total Energy Costs			
Month	Electric	Steam	Total
Jan	$6,743	$27,421	$34,164
Feb	$6,187	$22,269	$28,456
Mar	$6,666	$10,815	$17,481
Apr	$5,603	$1,827	$7,430
May	$7,758	$0	$7,758
Jun	$9,233	$0	$9,233
Jul	$10,059	$0	$10,059
Aug	$9,829	$0	$9,829
Sep	$7,282	$0	$7,282
Oct	$6,179	$4,238	$10,417
Nov	$6,033	$7,362	$13,395
Dec	$6,713	$21,885	$28,598
TOTAL	$88,284	$95,817	$184,101

The total operating cost per SF per year of the mechanical system is approximately $1.45/SF-yr.

Please note that while many of the design load and operating cost values contained in this report may not be extremely accurate, they will provide a representative baseline system to compare my future design change proposal throughout the remainder of my thesis project.

Lost Usable Space

The lost usable space due to the HVAC equipment is approximately 21,549 SF and is summarized in Table 9. The first level contains two mechanical rooms. One advantage of utilizing district heating and cooling is the space saved by exclusion of a chiller and boiler in the building. Levels two through five contain four mechanical shafts consisting of 540 SF per floor. The mechanical penthouse contains the four AHUs and a supply and return plenum. The total area of the mechanical equipment space is approximately 14% of the building's total floor area.

Table 9

HVAC Lost Usable Space	
Level	**Area (SF)**
Level 1	4,936
Level 2	540
Level 3	540
Level 4	540
Level 5	540
Mechanical penthouse	14,453
Total	**21,549**

LEED Assessment

This building is intended to achieve LEED Silver certification. Mechanical designers have a significant role in achieving this goal, especially in the Energy & Atmosphere and Indoor Environmental Quality sections. LEED certification documents are still being prepared for submittal at the time of this report and are not available for reference. This building began construction before the deadline for LEED 3.0 and will be assessed by USGBC based on the LEED 2.2 requirements. This section will assess various points related to the mechanical system based on the newer LEED 3.0 requirements.

Energy & Atmosphere

Credit 1 (Optimize Energy Performance) provides an opportunity for 19 points. This credit involves comparing the building as designed with ASHRAE 90.1 Appendix G. A baseline energy model using Appendix G for the minimum system requirements is compared to an energy model of the system as designed.

Credit 3 (Enhanced Commissioning) will be obtained by designating an independent Commissioning Authority to begin the commissioning from early in the design process and throughout the final design and construction of the project. A systems manual and training must also be provided for operators and building occupants.

Credit 4 (Enhanced Refrigerant Management) is achieved by excluding the use of CFCs and HCFCs as a refrigerant within the building. The water source heat pump is the only piece of equipment using a refrigerant which is R-407C. This is a mixture of R32, R125 and R134a which meet this requirement.

Indoor Environmental Quality

Credit 2 (Increased Ventilation) is easily obtained since this DOAS system provides greater than 30% ventilation rates as required by ASHRAE 62.1.

Credit 5 (Indoor Chemical Pollutant Source Control) is address by allowing for proper storage and disposal of harmful chemicals used in labs, proper pressurization in lab spaces, and exhausting all air with no recirculation

Overall Evaluation Summary

The mechanical system selection of the New Science Center provides an energy efficient solution to meet the design requirements of the building. The system contains a comprehensive monitoring and controls system that will allow for minimal maintainability after the initial balancing of the system. Alarms are set to monitor for any variations from normal operation. This will allow campus operators to easily be able to determine when maintenance or cleaning needs to be performed on specific parts of the system.

Various energy savings strategies were utilized in the mechanical system. Some of the technologies used include air-side enthalpy recovery wheels, a water-side energy recovery heat pump, variable frequency drives in pumps and fans, chilled beams to reduce airflow requirements, low-emittance (low-E) glass, and vertical and horizontal shading devices. A LEED Silver certification will be the outcome of the integration of these strategies into the system design.

An occupancy schedule and occupancy sensors allow for additional energy savings by lowering temperature setpoints and ventilation/exhaust rates when spaces are not in use. All setpoints and schedules can be adjusted by an operator through the Building Operating System allowing for further control.

One advantage of this project is access to district chilled water and district steam from the campus plant. District plants have many benefits both environmentally and economically. Emissions are easier to control and monitoring from one large plant compared to individual plants. District plants also reduce the number of operators necessary for monitoring and maintaining equipment, increase the usable space within the building by reducing the need of boilers and chillers, and can achieve higher efficiencies than separate plants due to cycling equipment based on load requirements of multiple buildings.

Indoor Air Quality is maintained by providing 100% outdoor air, which passes through MERV 14 filters, to all occupied spaces within the building. Proper pressurization of spaces within the building prevents infiltration from hazardous zones within the building. Pressurization is monitored by the BAS and controlled by VFD supply and exhaust fans and VAV supply and exhaust boxes.

Due to the energy intensive equipment and systems that come with any lab building, various opportunities for improved energy savings are available and will be evaluated for this building in future research.

References

Georgetown University – New Science Center construction documents.

2009 ASHRAE Handbook—Fundamentals.

ASHRAE Standard 62.1-2010.

ASHRAE Standard 90.1-2010.

LEED Reference Guide for Green Building Design and Construction, Version 3, 2009 Edition, US Green Building Council.

Appendix A – List of Figures and Tables

List of Figures

List of Tables