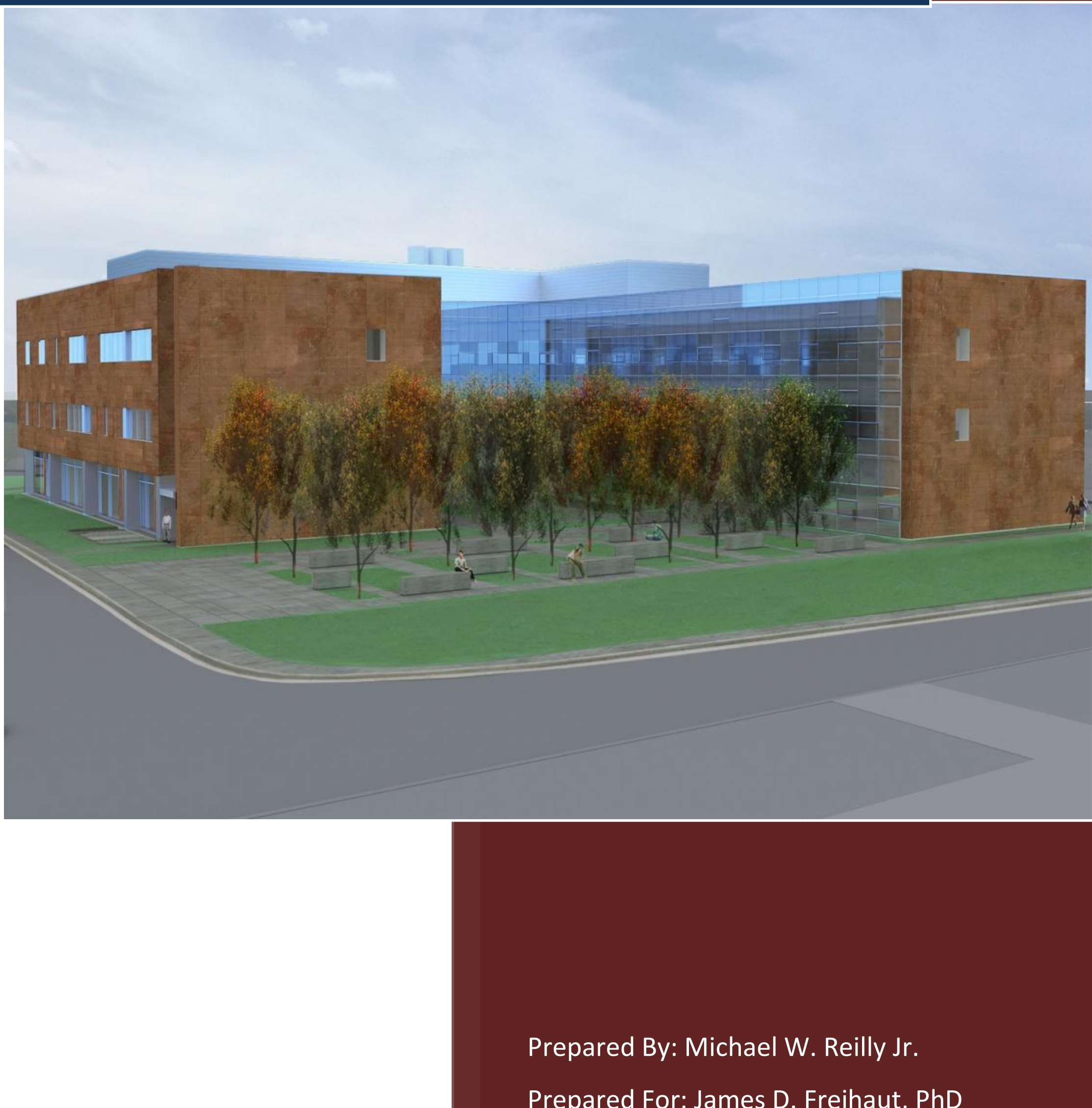
Nassau Community College Life Sciences Building

Garden City, NY

Final Thesis Report

Mechanical System Alternatives Analysis



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Abstract

Nassau Community College Life Sciences Building

Building Information

- Location: Garden City, New York
- Size: 72,400 sq. ft.
- Occupancy: Classrooms/Laboratories/Office
- Levels: 3, penthouse, basement
- Cost: $30 million
- Construction Dates: March 2010 - January 2012
- Delivery method: Single Prime Contract

Project Team

Owner:	Nassau Community College
Architect:	Cannon Design
Structural:	Cannon Design
Mechanical:	Cannon Design
Electrical:	Cannon Design
Plumbing/FP:	AMA Consulting Engineers, P.C.
AV:	CMS Innovative Consultants
Site/Civil:	Dvirka & Bartilucci Consulting Engineers
Landscape:	Michael Michel, ASLA
Code:	Code Consultants, Inc.
IT/Security:	TM Technology Partners, Inc/
Acoustical:	Cerami & Associates, Inc.

Architecture

- Exterior Façade: copper rainscreen panels, porcelain stone tiles and clear, low-e, insulated glass.
- Penthouse exterior: corrugated anodized aluminum and painted frameless metal powder coated louvers
- Architectural canopies over entrances

Structural

- Lateral foreces resisted by a moment frame on the west and east exterior walls and a braced frame on the north and south exterior walls.
- Foundation is a combination of slab-on-grade for west wing and spread and wall footings for the remaining
- Typical beam size is a W24X55
- Composite deck system with 6 1/4", 3000 psi concrete.

Mechanical

- Central Utility Plant provides campus lhigh temperature hot water and chilled water loops in primary/secondary system.
- (1) 100% outdoor air system serving the chemistry labs. (2) AHU's in a variable air volume system serving the basement, 1st and 3rd floors.
- Heat recovery run-around loop from lab exhaust fans to 100% outdoor air system for energy savings.

Electrical

- (2) Indoor 1500 kVA substations stepping 13.8 kV down to 480Y/277V.
- (3) secondary transformers on each floor dropping to 208Y/120V.
- 500 kW/625 kVA emergency generator providing 480Y/277V, 3-phase power to fire protection system, emergency lighting, penthouse, and critical laboratory loads.

Michael W. Reilly Jr | Mechanical | www.engr.psu.edu/ae/thesis/portfolios/2011/mwr5047/index.html

Executive Summary

The first alternative in this report is aimed at reducing the energy consumption of the Life Sciences Building by decentralizing the air system for all but the laboratory spaces. The decentralized air system study encompasses calculations for chilled beams in the offices and classrooms as well as designing a new dedicated outdoor air unit and energy, first cost and life cycle cost analyses. The energy analysis illustrates the electricity consumption of the new chilled water pumps, new fans as well as the cost of chilled water from the campus loop. The first cost compares the differences in the existing VAV system and the new decentralized system and the life cycle cost compares the net present values of each system for a thirty year life cycle.

The second alternative is the addition of the chiller plant to the Life Sciences Building. This study was performed for two reasons: the Nassau County Central Utility Plant is nearing chilled water capacity and for educational purposes. The study centers about the comparison between primary/secondary and variable primary flow pumping configurations. The analysis is similar to the decentralized air system study in the effect that it compares energy consumption, first cost and the life cycle cost of each system.

Following the mechanical alternatives, two breadth topics were studied: daylighting and architecture. The daylighting analysis is centered about LEED Credit 8.1, which requires certain daylight levels during specified dates and times. The daylighting analysis leads into the architecture study, which is the design of permanent exterior shades on the Life Sciences Building in order to comply with LEED daylighting requirements as well as performing well throughout the year and maintaining continuity with the existing structure.

The following are main points determined by the depth analyses:

- Decentralized Air system
    - 49.9% reduction in supply airflow with a dedicated outdoor air system
    - 18% increase in chilled water flow with the chilled beams
    - 20% increase in energy costs with the chilled beam/DOAS system due to chilled water costs
    - $253,700 reduction in first cost with chilled beams/DOAS
- Chiller Plant Design
    - 5% decrease in energy costs with the variable primary flow chiller plant
    - $26,000 reduction in first cost with the variable primary flow configuration

Acknowledgements

Many people have been involved with my senior thesis project and I would like to take this time to express my gratitude for their support.

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Dustin Eplee	Faculty Advisor, Energy Wall
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Moses Ling	Mechanical Instructor, Penn State
Michael Palazzolo	Price Industries Representative, Mechanical Technologies
Michael Reilly Sr.	Owner, Reilly Plumbing & Heating

Building Overview

The Nassau Community College Life Sciences Building will house the expanding Chemistry Department and rising Nursing Department. The building will be a cluster of general lecture halls, computer labs, inorganic and organic laboratories, practical skills nursing rooms and faculty offices. The Life Science Building is a “U-shape” where the courtyard façade is a floor-to-floor glass curtain wall system. Faculty offices on all three floors are facing the courtyard and can have periods of high heat transfer through the curtain wall. The classrooms, lecture halls and laboratories, are located along the opposite exterior perimeter. The façade is composed of copper rain screen panels and long strips of glazing. There may also be periods of high heat transfer through this façade, but it was designed for a high aesthetic appeal rather than thermal function.

The design of the Life Sciences Building was highly influenced by the occupants, both students and faculty, as well as its use. It was designed to easily connect to the greater campus with spaces to accommodate the overall student population, not just the Chemistry and Nursing Departments. Furthermore, function played a role in the design because of the hazardous chemical storage and waste spaces that need to be guarded under restricted access but readily available to the classrooms for learning.

Mechanical System Overview

The Life Sciences Building receives conditioned air from three air handlers located in the Penthouse. One of the air handlers is a 100 percent outdoor air unit due to the nature of the chemistry laboratories that it serves. The supply air to the laboratory spaces is exhausted through a laboratory exhaust system. Three large exhaust fans operate as one unit, which pulls contaminated air from the laboratories. Because this air handler is a 100 percent outdoor air unit, a heat recover run-around loop transfers sensible heat from the exhaust fans to the air handler to either pre-heat or pre-cool the incoming outdoor air. All three air handlers are part of a variable air volume (VAV) system with terminal reheat coils.

The Life Sciences Building as well as the Nassau Community College campus is served by a campus-wide high temperature hot water and chilled water system. The high temperature hot water creates building hot water through several heat exchangers for the perimeter radiation, fan coils, cabinet unit heaters and air handler pre-heat coils. The 100 percent outdoor air unit’s pre-heat coil uses a glycol system, which is heated via heat exchanger by the high temperature hot water system. A primary/secondary system is utilized with the chilled water and high temperature hot water systems. Booster pumps have been designed for the chilled water system in the event that there is a decrease in pressure in the primary line. The majority of the heat exchangers and pumps are located along with the service entrance in the basement mechanical equipment room.

The Central Utility Plant that serves Nassau Community College is operated by Suez Energy and is comprised of a boiler and chiller plant. This 60 MW cogeneration facility produces 250 psig steam, 270°F high temperature hot water and 42°F chilled water that are distributed to various surrounding facilities such as Nassau University Medical Center (NUMC), Nassau Veterans Memorial Coliseum and Long Island Marriott Hotel. Figure 1 below is a diagram provided by Parsons Brinckerhoff's report that shows the location of the Central Utility Plant in red as well as the steam loads in blue stars and the high temperature hot water loads in yellow stars. Nassau Community College is denoted by the dotted yellow circle. Nassau Community College uses 50.6% of the high temperature hot water and chilled water produced by the Central Utility Plant compared to all buildings tapped into the high temperature hot water service.

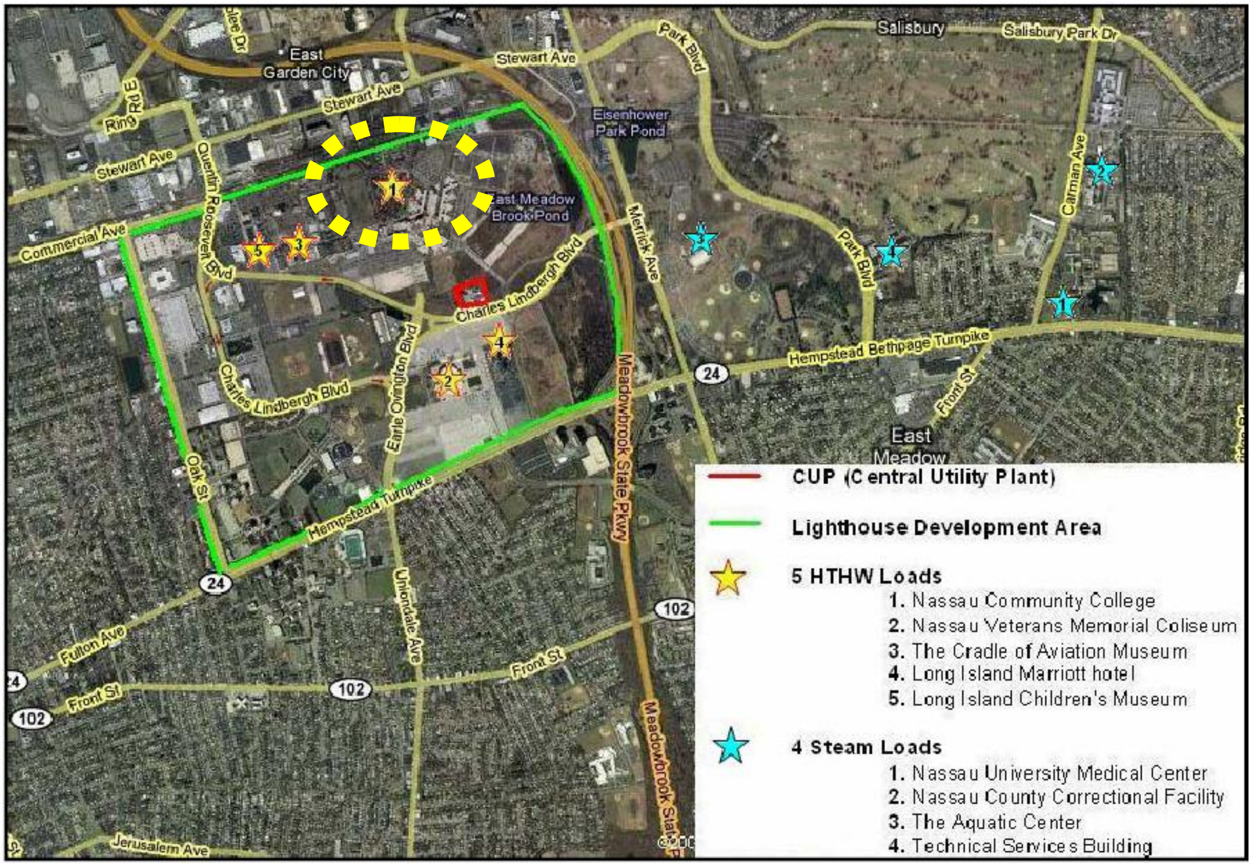

Figure 1 - Location of Central Utility Plan (Red) and NCC (Yellow)

Existing Mechanical System Description

Mechanical Design Objectives

The Life Sciences Building is an educational building located at Nassau Community College. The building was designed with general classrooms and computer labs to be utilized by students of all majors as well as chemistry and nursing laboratories on the upper floors and faculty offices. Therefore a variable air volume system was chosen to accommodate the fluctuations in occupancies throughout the day.

The chemistry laboratories contain hazardous chemicals and require fume hoods and a dedicated one hundred percent outdoor air ventilation system. Because of the high energy consumption of a one hundred percent outdoor air system, a heat recovery system is used between the outdoor air intake and exhaust outlet. The heat recovery system needed careful consideration. Cross-contamination between the supply and exhaust air streams is undesirable. Therefore, a run-around loop pre-heat coil was selected as the major heat recovery component. Furthermore, minimum air change rates must be met in order to maintain proper pressurization within the laboratories. The fume hoods and minimum air change rates are the primary design criteria that determined the structure of the mechanical system for the chemistry laboratories.

Other than the laboratories fume hoods and good practice ideas, all spaces in the Life Sciences Building must comply with the ventilation rates specified 2007 New York State Mechanical Code. This code was also a prime factor in the mechanical system design.

Energy Sources

The Life Sciences Building is served with high temperature hot water and chilled water from a local central utility plant owned by the Nassau Energy Corporation. The central utility plant is a cogeneration facility that produces nearly 60 MW of electricity, which is sold to the Long Island Power Authority (LIPA). The Nassau Community College receives its electrical service from LIPA and the campus high temperature hot water and chilled water directly from the central utility plant. Due to the availability of the campus high temperature hot water and chilled water, it is advantageous for the Life Sciences Building to use those utilities rather than to have on-site combustion. Furthermore, the absence of on-site combustion decreased the annual maintenance costs of the building.

According to LIPA, the electrical rates for demand and consumption are not affected by on and off peak hours. Rather they are dependent on the time of year that the electricity is being used. The purchased high temperature hot water and purchased chilled water rates remain the same throughout the year. A summary of the electrical consumption and demand rates can be found in Table 1, high temperature hot water and chilled water rates in Table 2 and Table 3 respectively.

Utility	June – September	October - May
Electrical Consumption	\$0.053/kWh	\$0.0381/kWh
Electrical Demand	\$9.33/kW	\$8.25/kW

Table 1 - Electrical Consumption and Demand Rates

Utility	January - December
Purchased High Temperature Hot Water	\$12/Therm

Table 2 - Purchased High Temperature Hot Water Rate

Utility	January – December
Purchased Chilled Water	\$1.25/Therm

Table 3 - Purchased Chilled Water Rate

In order to visualize the cost of each utility relative to each other, a comparison was made in the units of dollars per kBtu of energy in Table 4. For the purpose of this comparison, the most expensive electricity rate was used, which occurs from June through September. As seen in Table 4, the most expensive utility is the high temperature hot water. This is due to the nature of the high temperature hot water being delivered to the end user at 270°F rather than a typical hot water temperature of 180°F. The electricity and chilled water costs are similar per kBtu.

Utility	$/kBtu
Electricity	0.0155
HTHW	0.12
CHW	0.0125

Table 4 - Energy Cost Comparison

Tax Incentives

The Life Sciences Building receives its electrical service from the Long Island Power Authority (LIPA). LIPA provides a series of incentives that had an influence in the design of the building. Incentives include credits for LEED Certification and lump sums for surpassing the minimum standard set by the 2007 New York State Energy Conservation Code. Based on LIPA, a summary of the incentives available for the Life Sciences Building can be found in Table 5.

Opportunity	Whole Building Projects	LEED Green Building Projects
Project Incentives	Up to $400,000 per project	Up to $500,000 per project
	$800,000 annual cap per customer	$800,000 annual cap per customer
LEED Certification Points	N/A	In addition to Project Incentives, program participants may also receive $1,000 per LEED Certification point related to energy efficiency, up to $25,000
Technical Assistance	LIPA will fund the first $10,000 of the TA Study related to energy conservation measures and cost share with customer 50/50 for the additional amount of the study not to exceed $50,000	LIPA will fund the entire cost of the study up to $50,000 per project
Commissioning	Up to $50,000 per project	LIPA will provide funding up to $100,000 per project for electric energy conservation related equipment and/or systems

Table 5 - 2010 LIPA Incentive Schedule

The Life Sciences Building has submitted an application to the USGBC for LEED accreditation. According to the application, there is a potential for enough points to earn a LEED Gold rating, which is the goal of Nassau Community College and the design team. This presents a potential for a credit from LIPA based on the number of LEED points that have been approved.

While the New York State Energy Conservation Code does not specifically reference ASHRAE Standard 90.1, LIPA requires that the base case for the project must conform to the minimum requirements of Standard 90.1. The mechanical design of the Life Sciences Building was influenced by these opportunities for cost savings.

Design Conditions

The weather data from the ASHRAE Handbook of Fundamentals for the New York City, JFK International Airport station was used in this load and energy analysis due to its similarity in weather conditions to Garden City, NY, which is located 15 miles to the east. The interior design conditions are uniform throughout the building. Table 6 below provides a summary of the heating and cooling weather design and interior conditions, which were input in the Trane TRACE 700 for a load and energy analysis.

Season	Indoor Design (°F)	Outdoor DB (°F)	Outdoor WB (°F)
Summer (0.4%)	75	89.7	73.5
Winter (99.6%)	72	12.8	-

Table 6 - Interior and Interior Design Conditions

Design Ventilation Requirements

ASHRAE Standard 62.1-2007 is the typical source for the minimum ventilation requirements for conditioned spaces. However, the Life Sciences Building is located on Long Island, New York, which makes the New York State Mechanical Code of 2007 is the governing ventilation code. Table 403.3 in Chapter 4 provides minimum required outdoor air ventilation rates for specific occupancy classifications, similar to that of Table 6-1 in ASHRAE Standard 62.1-2007. The air handling unit serving the laboratory spaces is a one hundred percent outdoor air unit, in which the ventilation requirements will be exceeded by the cooling load requirements.

The requirements specified in Table 403.3 in the New York State Mechanical Code were input into TRACE for the load and energy analysis for all three air handling units. Table 7 compares the designed and the calculated ventilation airflow rates for two of the air handling units. The 100% outdoor air unit was left out of the comparison because of its nature. The designed airflow rates far exceed those calculated. The calculated airflow rates hover around the industry average of 20% of design load airflow, but the designed airflows are upwards of 50% of the design load airflow. The high design ventilation airflows can be attributed to the use of a variable air volume system. When a VAV box is turned down to its minimum position with a fully occupied space, the minimum ventilation requirements must still be met. This causes an increase in the outdoor airflow percentage.

Unit	Designed (CFM)	Calculated (CFM)
AHU-1	12,775	5,358
AHU-2	12,775	7,632

Table 7 - Designed and Calculated Ventilation Rates

Design Load Estimates

To evaluate the heating, cooling loads of the Nassau Community College Life Sciences Building, Trane TRACE 700 was used along with Autodesk Revit Architecture. Revit was used to create a 3-dimensional model of the Life Sciences Building, which was exported as a gbxml file. The gbxml allows for the translation of geometries from the model to TRACE. TRACE was then used to develop an 8,760 hour to determine the design heating and cooling loads. More information about the heating and cooling loads can be found in Technical Report Two.

Table 8 below provides various engineering checks from the heating and cooling design load results. Engineering check values for the designed Life Sciences Building were not provided by the mechanical engineer, nor were they provided by the outside consultant WSP Flack + Kurtz who developed a preliminary energy model using eQuest v3.6 building simulation software. Therefore, the calculated cooling and heating loads were compared to the ASHRAE 2009 Pocket Guide. A comparison between the calculated and designed energy use of the Life Sciences Building can be seen in the next section of this report.

Air Handler Zone	Cooling (ft^2/ton)	Heating (Btu/h-ft^2)	Supply Air (CFM/ft^2)
East AHU	294.1	29.76	1.35
West AHU	245.9	28.55	1.44
Lab AHU	208.7	34.84	1.25
ASHRAE Guide	185	-	1.60

Table 8 - Design Load Engineering Checks

Design Energy Usage Estimate

Trane TRACE 700 was also used to calculate a full year energy simulation of the Life Sciences Building. The energy model was created using the proposed equipment from the mechanical construction documents. Assumptions were made regarding the laboratory electrical loads as well as other miscellaneous loads throughout the building. These assumptions can be viewed in Technical Report Two. The cooling and heating equipment are supplied from a campus chilled water and high temperature hot water system. Electricity is also supplied from the same central utility plant that produces the high temperature hot water and chilled water.

The electrical consumers are the source that uses the most energy at 62.3% of the total Life Sciences Building's yearly energy consumption. Over one half of the building's yearly energy consumption use is due to the receptacle loads throughout the building, which incorporates the chemistry laboratories and nursing skill teaching laboratories, which were estimated at a high electrical equipment power density. The receptacle loads also include the office equipment and computer labs. The energy used for heating is at a measly 7.8% of the total building energy, which can be attributed to the use of high temperature hot water through heating coils in two of the three air handling units as well as a heat recovery run-around loop utilized in the 100% outdoor air unit. A summary of the Life Sciences Building's yearly energy consumption can be viewed in Figure 2.

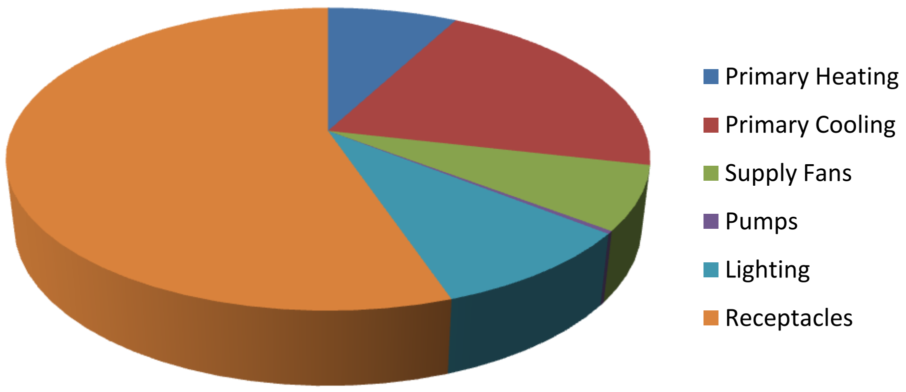

Figure 2 - System Energy Consumption

The consultant recorded results from their energy analysis of the Life Sciences Building in the units of kBtu per square foot per year, where one bBtu equals 1,000 Btu's for each of the purchased utilities; electricity, high temperature hot water and chilled water. The results are compared in Table 9. The yearly energy consumption determined by the designed energy analysis is 9.96 MBtu per year and the yearly energy consumption according to the calculated energy analysis is 9.79 MBtu per year. The designed energy consumption is 1% larger than the calculated energy consumption.

Analysis	Life Sciences Building Energy Usage (kBtu/ft^2-yr)			
	Electricity	Purchased Hot Water	Purchased Chilled Water	Total Building
Calculated Values	96.5	10.6	28.1	135.2
Designed Values	40.6	50.0[1]	46.0	136.6

Table 9 - Calculated and Design Energy Consumption

There are several justifications that can account for the differences between the calculated and designed energy usage values. The designed energy model was created using assembly heat transfer coefficients and solar heat gain coefficients from ASHRAE Standard 90.1-2004 rather than the actual coefficients provided by the architect. Furthermore, the designed energy analysis did not incorporate equipment and lighting schedules into the system. However, night setback temperatures and occupancy schedules were used. Also, the designed energy analysis used a lighting power density on a whole building spectrum, 1.2 Watts per square foot rather than on a space-by-space basis. A more detail comparison of the differences between the calculated and designed energy analyses can be found in Technical Report Two.

According to ASHRAE, a typical educational building uses 71.0 kBtu/ft^2-year of total energy. The calculated energy analysis concluded a total of 135.2 kBtu/ft^2-year, which is 190% larger than the typical ASHRAE educational building. The designed energy analysis found a total of 136.6 kBtu/ft^2-year, which is nearly twice the value for a typical educational building. The designed energy analysis is 1% larger than the calculated, which is a much closer margin than when compared to the typical ASHRAE educational building. The differences between the calculated and designed model and the ASHRAE educational building can be attributed to the Life Sciences Building being a laboratory facility. The requirements of fume hoods and high equipment loads cause the electrical consumption to be significantly larger than an educational building that consists of simply classrooms and lecture halls.

The similarity between the calculated and designed energy consumptions provide a reasonable idea as to the expected energy consumption of the Life Sciences Building. Furthermore, the large margin between the ASHRAE typical educational building and the projected energy

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[1] The designed energy and load analysis used purchased campus steam as the heating utility.

consumptions provide opportunities for a redesign that reduces the building's overall energy consumption.

Mechanical Equipment Summary

The mechanical systems that serve the Life Sciences Building are segregated into two mechanical rooms. The basement mechanical room is the location of the service entrance for the high temperature hot water and the chilled water as well as eight pumps and three heat exchangers. The mechanical penthouse is the location of the three air handling units and the laboratory exhaust fans.

The series of pumps located in the basement mechanical room are those that serve the building's heating and cooling distribution. Chilled water pumps P-1 and P-2 serve as booster pumps to the central plant's chilled water campus system in the event that the loop loses pressure. Pumps P-6A, B are small inline pumps that circulate the high temperature hot water through the heating coils in air handlers AHU-1 and AHU-2. Due to the configuration of the penthouse, the glycol hot water pump is also an inline model. A summary of the Life Sciences Building's pumps can be found in Table 10.

Unit No.	System	Location	Capacity (GPM)	Head (ft)	Motor Size (HP)
P-1,2	Chilled Water Booster	Basement	600	50	15
P-3,4	Chilled Water Distribution	Basement	600	60	15
P-5	Glycol HW	Penthouse	90	30	1½
P-6A, B	AHU-1,2 Coil Pumps	Penthouse	55	20	¾
P-7,8	Radiation HW	Basement	115	65	5
P-9,10	Re-Heat HW	Basement	75	50	3
P-11	Heat Recovery	Penthouse	100	40	2

Table 10 - Pump Schedule

The campus high temperature hot water system from the central utility plant provides water at 270°F. However, Nassau Energy Corporation has stated that there is potential for temperature fluctuations in the system. Therefore, the heat exchangers have been designed with a 240°F entering water temperature on the shell side. The heat exchangers knock the temperature down to a usable 180°F for local re-heat, radiation and a glycol pre-heat system for one air handler. There is no booster pump for the campus high temperature hot water because of the assurance from Nassau Energy Corporation that there is sufficient pressure to circulate the high temperature hot water through the Life Sciences Building. All four heat exchangers are described in Table 11.

Unit No.	System	Location	Capacity (MBH)	Tube Side		Shell Side	
				EWT (°F)	LWT (°F)	EWT (°F)	LWT (°F)
HX-1	Glycol/HW	Penthouse	1,169	150	180	240	210
HX-2	Radiation/HW	Basement	1,124	160	180	240	210
HX-3	Re-Heat/HW	Basement	1,100	150	180	240	210
HX-4	Re-Heat/HW	Basement	1,100	150	180	240	210

Table 11 - Heat Exchanger Schedule

There are three air handling units that serve the Life Sciences Building. The air handling unit that serves that laboratory and chemical storage spaces is a 100% outdoor air unit. Air handling units AHU-1 and AHU-2, which serve the classroom spaces, receive high temperature hot water directly from the central utility plant modulated to 240°F. The one hundred percent outdoor air unit, AHU-3, uses a 40% propylene glycol solution for the main heating coil. AHU-3 also utilizes a heat recovery run-around loop to pre-heat the outdoor air with waste heat from the laboratory exhaust fans. All air handling units are connected to VAV boxes, which are configured with reheat coils. All supply and return fans are controlled with a variable speed drive to accommodate the changes in load requirements. Details on the air handling units and the laboratory exhaust fans can be found in Table 12.

Unit No.	Area Served	Total CFM	Min OA CFM	Supply Fan HP	Cooling Capacity (MBH)	Heating Capacity (MBH)	Return Fan HP
AHU-1	Classrooms - East	25,550	12,775	40	1,136	733	15
AHU-2	Classrooms - West	25,550	12,775	40	1,136	733	15
AHU-3	Laboratories	24,000	-	30	1,523	1,296	-

Table 12 - Air Handler Schedule

There are chemistry laboratories located on the second floor of the Life Sciences Building, which contain fume hoods that exhaust hazardous chemical vapors to the exterior. A series of three laboratory exhaust fans are located on the roof pull the dangerous fumes from the second floor up through the building. The three fans are used as a standby system with one fan producing most of the work. The laboratory fans are required to exhaust the air as a plume into the atmosphere, away from the building. Information on the laboratory exhaust fans is located in Table 13.

Unit No.	Location	Total CFM	Fan Power (HP)	Stack Height (ft)[2]
E/F-9 A,B,C	Roof	24,050	20	52

Table 13 - Laboratory Exhaust Fan Schedule

Mechanical System Cost

The total cost for the mechanical system for the Life Sciences Building is $5,320,000. The price includes all mechanical equipment and distribution material and labor for both the hydronic and air systems. The equipment for the plumbing and fire protection systems are excluded. A breakdown of the mechanical systems in terms of equipment and distribution can be found in Table 14. Mechanical system testing and balancing as well as site utilities costs are not included in Table 14.

System	Cost ($)
Hydronic Equipment	262,000
Air Equipment	894,000
Terminal Equipment	689,000
Hydronic Distribution	1,500,000
Air Distribution	944,000
Controls	706,000

Table 14 - Mechanical Costs

The total of $5,320,000 broken down equates to $73.50 per square foot. As seen in Table 14, the hydronic distribution is the largest cost followed by the air distribution. The distributions systems include the large ducts that carry the significant amounts of air to the laboratories and big general classrooms. The air equipment is high due to the several fume hoods located in each chemistry laboratory and the sophisticated laboratory exhaust fans. Figure 3 provides a visual of the impact of each system towards to total cost.

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[2] The stack height for the laboratory exhaust fan is with a wind at 10 mph.

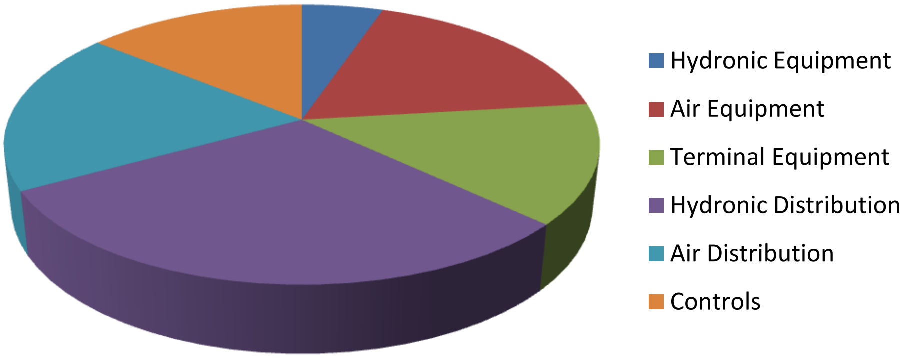


Figure 3 - Mechanical Equipment Cost

A computerized energy analysis was run in order to determine the Life Sciences Building's annual energy consumption. The rates in Table 1, Table 2 and Table 3 were used in the calculated energy analysis by created schedules for each of the utility costs. The utility costs were used in the energy analysis in order to develop the total monthly energy consumption for an entire year broken down by individual energy source. The monthly utility cost for a full year for the Life Sciences Building can be viewed in Figure 4.

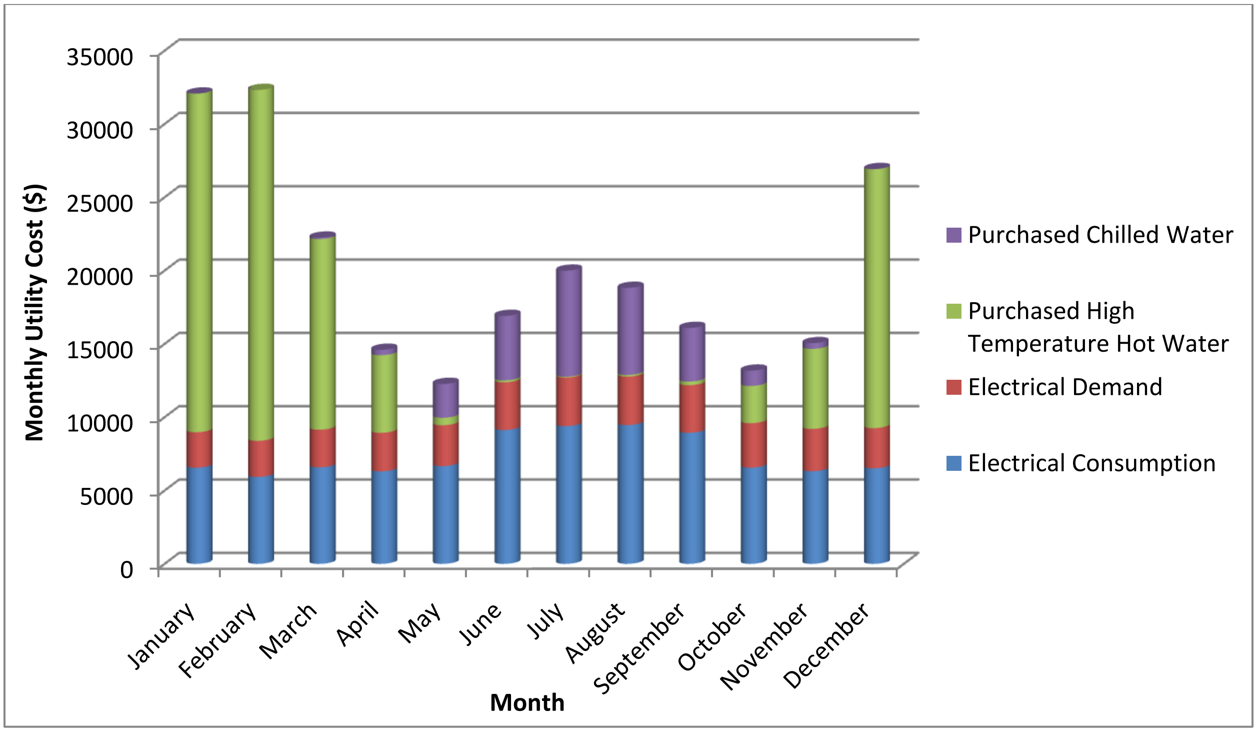


Figure 4 - Monthly Utility Cost

The total utility cost for an entire year was calculated to be $241,000 with the highest month being February with a cost of $32,327. Purchased high temperature hot water is the most expensive utility per unit and therefore is most costly. With a yearly cost of about $241,000, the utility cost per area equates to $3.33 per square foot.

Mechanical Space Requirements

Mechanical system equipment from air handling units to pumps and ductwork are essential to the operation of the mechanical system, but nevertheless they are space occupiers. Summarized in Table 15 are the areas that are taken up by the mechanical system. Included in the summary are the mechanical equipment rooms in the basement and penthouse and shaft spaces located on all floors. The total floor area occupied by the mechanical system is about 8.5% of the total building area.

Table 15 does not include spaces used for plumbing and electrical systems. There are several chases located throughout the Life Sciences Building the contain drain, waste, vent, laboratory gas and domestic hot and cold water systems. Furthermore, the electrical rooms located throughout the building, which contain the step-down transformers as well as the switchgear rooms for normal and emergency power spaces are not included. Also, the generator room is not included in the summary. The spaces should be included if a more accurate account of the area lost to the building systems.

Level	Area (ft^2)
Basement	1,140
First	170
Second	184
Third	209
Penthouse	4,427
Total	6,130

Table 15 - Mechanical Space Requirements

System Operations and Schematics

The Life Sciences Building was specified with a detailed sequence of operations due to the complexity of the air and water systems. The laboratory exhaust fan system needs to be properly interlocked with the one hundred percent outdoor air laboratory unit in order to assure proper building pressurization and adequate ventilation air. Furthermore, the high temperature hot water and chilled water that are supplied to the Life Sciences Building needs to be under constant monitoring in order to assure adequate pressure to properly condition the building.

Air-side Operations

Air Handling Units 1 and 2

Air handling units AHU-1 and AHU-2 are controlled identically since they serve similar spaces in the Life Sciences Building. AHU-1 and AHU-2 are both variable air volume systems, which serve terminal units with reheat coils throughout the building. The supply and return fans are equipped with variable speed drives to accommodate the change in system volume. The initial start sequence begins with the opening of the return air damper and activating the return fan. The energizing of the supply fan occurs after the opening if the supply air damper. Both air handling units are equipped with economizer settings, which are dependent on the outdoor air dry bulb temperature. The outdoor air, return air and relief air dampers are each controlled individually but are interlocked in order to provide adequate economizer control. The outdoor air dampers are to be at their minimum setting when the outdoor air temperature is above 55°F. Refer to Figure 5 for a schematic of air handling units AHU-1 and AHU-2

Air Handling Unit 3

Air handling unit AHU-3 is one hundred percent outdoor air, variable air volume system with a heat recovery run-around loop. The supply fan is equipped with a variable speed drive, but the laboratory exhaust fans do not modulate. The start sequence is similar to air handling units AHU-1 and AHU-2. The sequence begins with the confirmation of the operation of the laboratory exhaust fans. After the outside air damper is open, the supply fan is energized. The heat recovery run-around system contains a 30% glycol solution as the fluid that circulates between the laboratory exhaust fans and the pre-heat coil in AHU-3. The pump for the heat recovery system is to operate continuously when the outdoor air temperature is below 55°F or 80°F, which allows for the pre-heating or pre-cooling of the outdoor air. Figure 6 is a schematic of AHU-3.

Laboratory Exhaust System

The laboratory exhaust fan system consists of three exhaust fans connected to a common plenum. A series of make-up air dampers are connected to the intake plenum to ensure proper volume to allow for the required discharge velocity at 4,000 feet per minute. The three exhaust fans provide a degree of redundancy in the laboratory exhaust system. Figure 6 is a schematic of the laboratory exhaust system incorporated with air handling unit AHU-3.

Variable Air Volume Terminal Units

The variable air volume (VAV) terminal units are controlled by the local space temperature sensor to adjust the terminal unit supply air damper along with the reheat coil. The VAV terminal unit supply air damper, reheat coil control valve and local radiation control valve are all interlocked in order to maintain space temperature. The terminal units will modulate to its minimum airflow position before the opening of the radiation control valve during the winter mode. The reheat coil will be used for supplementary heat if necessary. During the summer mode, the reheat coil is used to adjust the supply air temperature if the supply air damper is inadequate. The radiation control valve will be closed. The winter and summer operating modes are determined by the outdoor air temperature. When the outdoor air temperature is above 50°F, the system will operate in the summer mode. If the outdoor temperature is below 50°F and the system is calling for heat, the system will operate in the winter mode.

Water-side Operations

Hot Water System

The hot water system for the Life Sciences Building consists of four shell and tube heat exchangers that convert campus high temperature hot water to hot water used throughout the building. The heat exchangers convert the 270°F water to 180°F water, which is used for re-heat coils, perimeter radiation and to heat a 30% glycol solution for the 100% outdoor air unit. As mentioned in the mechanical equipment section, the heat exchangers have been sized for an entering high temperature hot water temperature of 240°F due to fluctuations that may occur in the high temperature hot water system. The 270°F water is also directly piped to the two classroom air handling unit pre-heat coils. The high temperature hot water system pressure is sufficient enough to distribute the water throughout the building without the need of booster pumps. The entering and leaving pressures are measured at the service entrance as well as an energy metering station in order to determine the energy consumption of the Life Sciences Building.

On the discharge of the heating hot water heat exchangers is 180°F hot water. Both heating hot water heat exchangers are controlled by control valves that modulate in order to maintain a hot water supply temperature of 180°F. The standby heat exchanger for the re-heat coils will be changed over by manual isolation values. The re-heat coils and perimeter radiation systems each have a lead/lag series of pumps with variable speed drives for distribution. The lead pump will run continuously. If the lead pump cannot maintain the minimum pressure differential sensed by pressure differential sensors throughout the system, the lag pump will start. The lag pump will turn off when the lead pump can deliver reduced flow. The lag pump will also start in the event of a failure of the lead pump. Both the lead and lag pumps will alternate based on accumulated run time determined by the building operator.

On the discharge side glycol system heat exchanger is an inline pump to circulate the solution through the pre-heat coil for the one hundred percent outdoor air unit, AHU-3. The glycol heat exchanger is control with a control valve that modulates to maintain at 180°F glycol solution supply temperature. The glycol pump will run continuously when the outdoor air dry bulb temperature is below 60°F.

Figure 7 below provides an illustration of the hot water system in the Life Sciences Building.

Chilled Water System

The chilled water system for the Life Sciences Building consists of four pumps. Two pumps serve as a lead/lag set of booster pumps to the campus system in the event of a loss in system pressure. The second set of pumps are configured as a lead/lag system for chilled water distribution. The chilled water from the central utility plant is distributed at a constant 42°F in a constant flow system. However, the central utility plant has stated that there may not be sufficient pressure to accommodate the peak cooling load requirements. Furthermore, to accommodate fluctuations in chilled water supply temperature, the cooling coils in the building have been sized at an entering water temperature of 44°F. Therefore, the piping arrangement in the Life Sciences Building is organized such that the booster pumps are bypassed unless there is a decrease in the campus system pressure. In the event of a drop in system pressure, the booster lead pump will energize.

The Life Sciences Building's chilled water distribution pumps are variable speed pumps in a lead/lag configuration. The lead pump is to provide flow to maintain a preset pressure differential in the distribution system in order to provide adequate flow through each cooling coil. In the event that the lead pump cannot provide sufficient flow to satisfy the pressure differential, the lag pump will start. Furthermore, in the event of a failure of the lead pump, the lag pump will start.

Figure 8 below provides an illustration of the chilled water system in the Life Sciences Building.

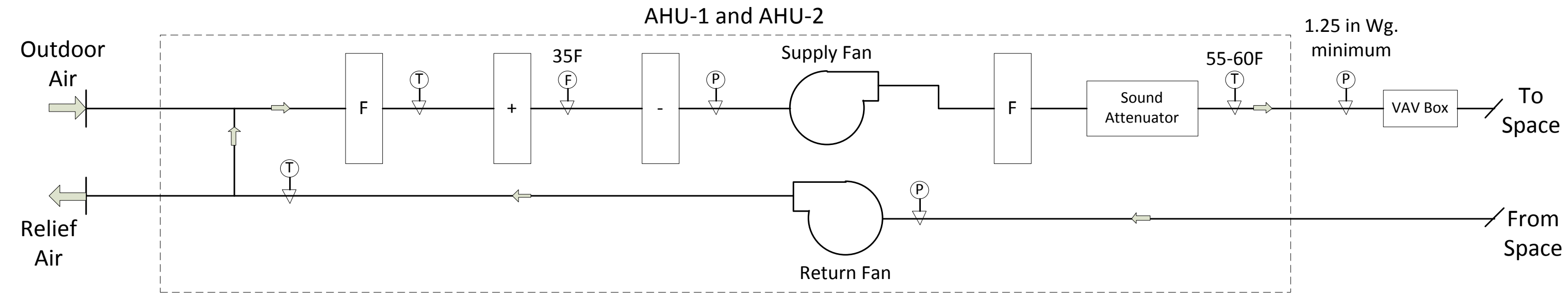


Figure 5 - AHU-1 and AHU-2 Schematic

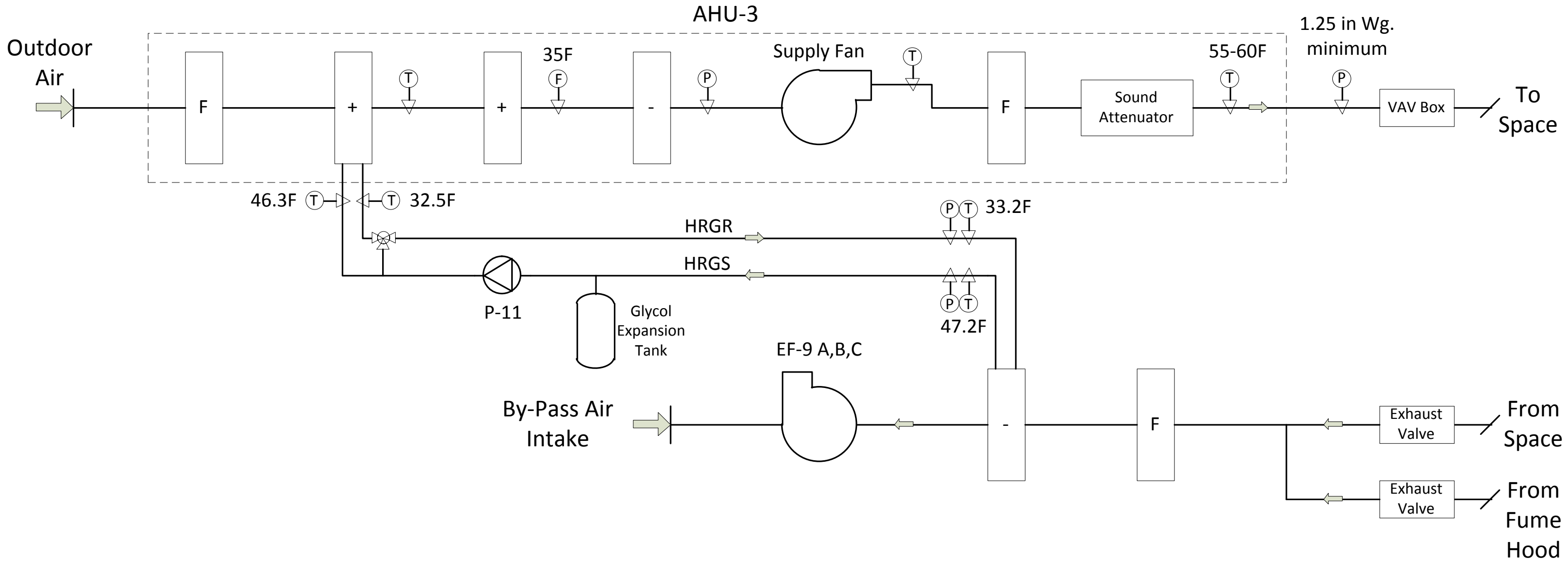


Figure 6 - AHU-3 Schematic

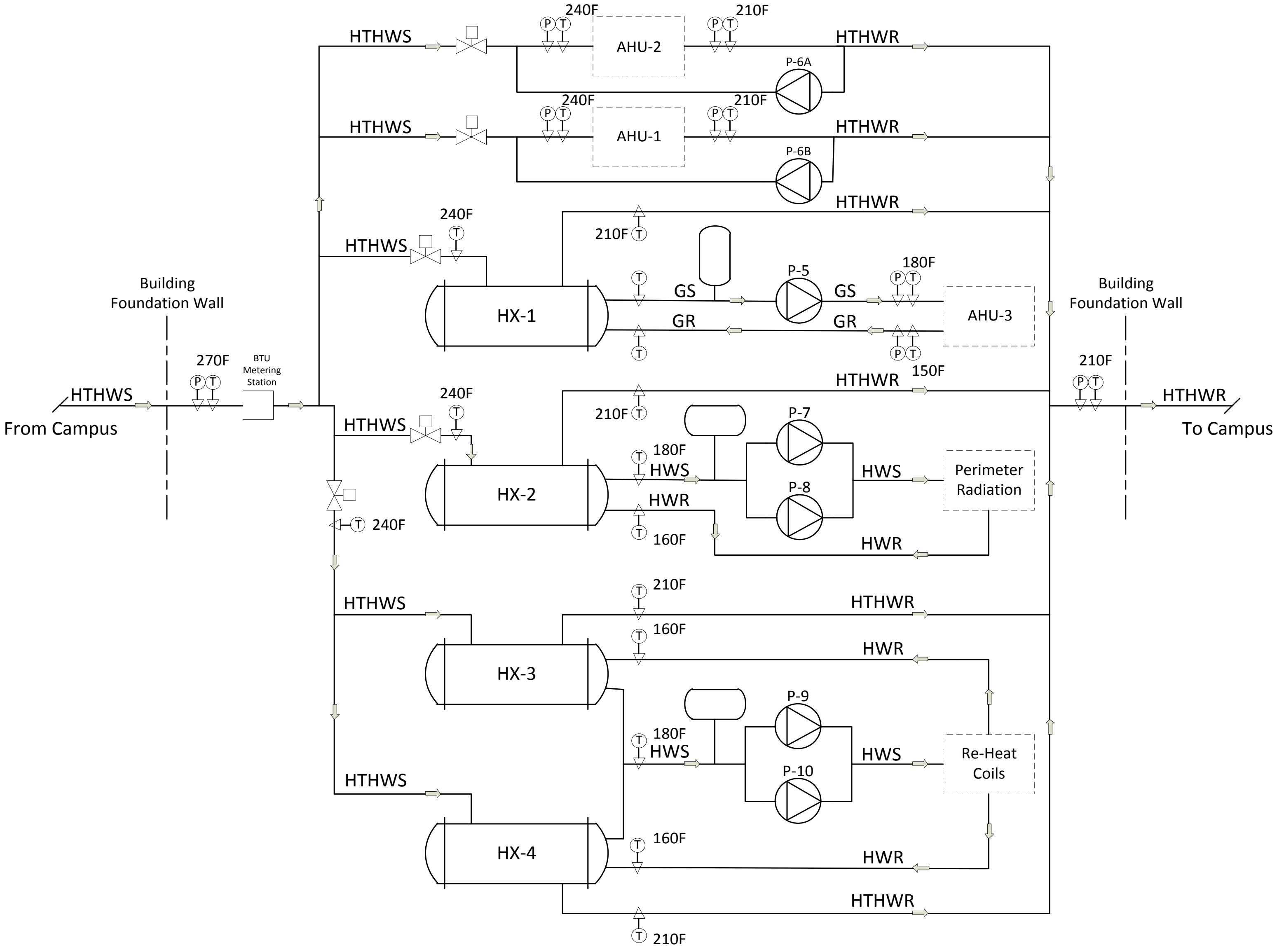


Figure 7 – Hot Water Schematic

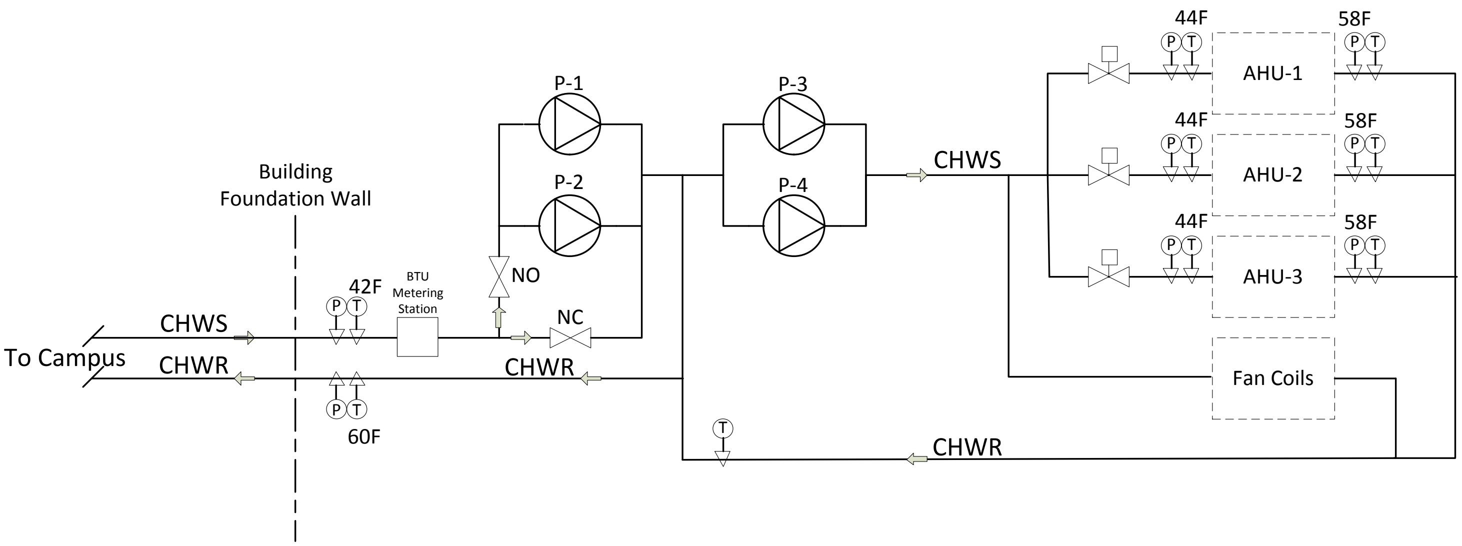


Figure 8 - Chilled Water Schematic

ASHRAE Standard 62.1-2007 Analysis

Section 5 Analysis

Section 5.1 Natural Ventilation

Exterior spaces have operable windows but all spaces are ventilated mechanically. Therefore, natural ventilation is not a method of ventilation for this building.

Section 5.2 Ventilation Air Distribution

The Life Sciences Building is able to meet the minimum ventilation requirement under and load condition. The construction documents specify explicitly a minimum airflow rate through each VAV terminal unit that complies with Section 6 of Standard 62.1. The discussion of Section 6 is discussed later in this report.

Section 5.3 Exhaust Duct Location

Chemistry laboratories, hazardous chemical storage, hazardous waste storage as well as general chemical storage rooms are all ducted and negatively pressurized relative to its surroundings and exhausted through laboratory exhaust fans located in the penthouse. General exhaust ducts are specified to be negatively pressurized to 2 in. Wg. relative to the surroundings and laboratory exhaust ducts are to be 3 in. Wg. relative to the surroundings. The laboratory exhaust fans are specified to maintain an exhaust intake velocity of 4,000 FPM through the stack in order to provide the proper clearance plume.

Section 5.4 Ventilation System Controls

The mechanical ventilation controls are designed to allow reduction in airflow when the spaces within each zone are unoccupied. Being that the Life Sciences Building is partly a VAV system, the VAV terminal units have been specified on the drawings to turn down to a minimum ventilation airflow rate that is greater than the minimum requirement given in Section 6 of Standard 62.1. Therefore, the Life Sciences Building complies with this section.

Section 5.5 Airstream Surfaces

Duct liners exposed to airstreams are specified to comply with ASTM C 1071 and UL 181. ASTM C 1071 incorporates ASTM C 1338. Therefore, the Life Sciences Building complies with this section.

Section 5.6 Outdoor Air Intakes

Noxious or dangerous exhausts are more than 30'. Therefore all outdoor air intakes are more than the minimum distance apart as per Table 5-1 in Standard 62.1. The main concern is the laboratory exhausts fans, which are a minimum of 48 feet from an outdoor air intake louver. All louvers are specified to provide the appropriate rain entrainment resistance and contain a ½" bird screen mounted flush with the louver. Therefore, all outdoor air intakes comply with this section.

Section 5.7 Local Capture of Contaminants

The exhaust from spaces where contaminants could be an issue of indoor air quality in spaces such as the hazardous chemical storage or the chemical laboratory rooms are exhausted through the roof by dedicated laboratory exhaust fans.

Section 5.8 Combustion Air

The emergency generator exhaust flue is ducted and sized with the appropriate CFM through and exhaust vent on located on the roof. An adequate amount of outdoor air to ensure a complete combustion process is ducted into the emergency generator room directly from the exterior. Therefore, the Life Sciences Building complies with this section.

Section 5.9 Particulate Matter Removal

The filters located in the air handlers are specified to comply with ASHRAE Standard 52.2 and therefore comply with this section.

Section 5.10 Dehumidification Systems

The Life Sciences Building is specified to maintain a maximum relative humidity ratio of 60%. Therefore, the Life Sciences Building complies with this section. The volume of return air is specified to be less than the volume of outdoor air in order to assure a positive building pressurization.

Section 5.11 Drain Pans

Drain pans are specified to be of doubled-wall construction with the interior wall being stainless steel. The pan shall be pitched positively in two directions with a 2" minimum drain connection. Stacked cooling coils are specified to have intermediate drain pans or troughs to channel to main pan. The Life Sciences Building specifies that the drain pans to comply with ASHRAE Standard 62.1 and therefore complies with this section.

Section 5.12 Finned-Tube Coils and Heat Exchangers

Drain pans are provided beneath each cooling coil assembly as per Section 5.11. No specification has been stated regarding the minimum 18 in. access space for the perimeter finned-tube radiation.

Section 5.13 Humidifiers and Water-Spray Systems

The Life Sciences Building does not use humidifiers or water-spray systems. This section does not apply.

Section 5.14 Access for Inspection, Cleaning and Maintenance

Access doors for each air handler are specified to be at least 24” by 60” located in the proper sections to allow access to each element of the unit. Appropriate clearances have been designated on the drawings for the removal and maintenance of the coils in each air handler. Access doors have been located for variable air volume box re-heat coils. The Life Science Building complies with this section.

Section 5.15 Building Envelope and Interior Surfaces

A continuous moisture barrier is located behind exterior copper panels. For below grade walls, a continuous waterproof membrane will be used. Internal piping and ductwork that has the ability to fall below the local dew point temperature will be provided with preventative insulation. The Life Science Building complies with this section.

Section 5.16 Buildings with Attached Parking Garages

No parking structure is attached to the Life Sciences Building. This section does not apply.

Section 5.17 Air Classification and Recirculation

Part of the Life Sciences Building is Class 1 air, which is returned via plenum return from the offices, lecture rooms and general classrooms. This air can be re-circulated back into the building. Class 2 air from the restrooms and janitor’s closets are ducted separately from other systems through a dedicated general exhaust system up through the roof. The chemistry laboratory, hazardous chemical storage, hazardous waste storage spaces contain Class 4 air by design and are isolated through a laboratory exhaust system up through the roof.

Section 5.18 Requirements for Buildings Containing ETS Areas and ETS-Free Areas

The Life Science Building is applying for LEED certification and therefore is a non-smoking facility. This section does not apply.

Section 6 Analysis

For the purpose of verifying the ventilation and exhaust requirements of ASHRAE Standard 62.1 Section 6, all air handlers (AHU-1, AHU-2 and AHU-3) were selected for the analysis. Each air handler is not restricted to one floor of the building, and due to the variety of different spaces it was beneficial to analyze all spaces requiring ventilation. The following are the sets of equations based on ASHRAE Standard 62.1-2007 Section 6 that are required for this analysis.

Ventilation Rate Procedure

Note: All tables and equations in this section refer to those found in ASHRAE Standard 62.1-2007

Breathing Zone Outdoor Airflow (V_{bz}):

$$V_{bz} = R_{p+} \cdot P_z + R_a \cdot A_z \qquad \text{(Eq. 6-1)}$$

where,

A_z = zone floor area (ft^2)

P_z = zone population, the largest number of people expected to occupy the zone during typical usage. (Estimated values found in Table 6-1)

R_p = outdoor airflow rate per person (CFM/person) (Values found in Table 6.1)

R_a = outdoor airflow rate per unit area (CFM/ft^2) (Values found in Table 6.1)

Zone Air Distribution Effectiveness (E_z):

$$E_z = 1 \qquad \text{(Determined from Table 6-2)}$$

Zone Outdoor Airflow (V_{oz}):

$$V_{oz} = V_{bz} / E_z \qquad \text{(Eq. 6-2)}$$

Primary Outdoor Air Fraction (Z_p):

$$Z_p = V_{oz} / V_{pz} \qquad \text{(Eq. 6-5)}$$

System Ventilation Efficiency (E_v):

E_v is found in Table 6-3based on the maximum Z_p value

Uncorrected Outdoor Air Intake (V_{ou}):

$$V_{ou} = D \cdot \Sigma_{\text{all zones}}(R_p \cdot P_z) + \Sigma_{\text{all zones}}(R_a \cdot A_z) \qquad \text{(Eq. 6-6)}$$

Occupant Diversity (D):

$$D = P_s / \Sigma_{\text{all zones}} P_z \qquad \text{(Eq. 6-7)}$$

where,
P_s = system population

Outdoor Air Intake (V_{ot}):

$$V_{ot} = V_{ou} / E_v \qquad \text{(Eq. 6-8)}$$

For the majority of spaces occupancies were not calculated based on ASHRAE Standard 62.1 Table 6-1. Rather the design assumptions for occupancies were used when known. Furthermore, restrooms were categorized as janitor closets for the purpose of the spreadsheet because of the high airflow rate per square foot that would be necessary for ventilation. The vending area was categorized as a coffee station based on the assumptions put forth by the design team.

As specified by the drawings, air handlers AHU-1 and AHU-2 are to supply a minimum of 12,775 CFM of outdoor air, which equates to 40 percent of the total supply airflow at the design condition. The ventilation rate procedure of Section 6 requires a minimum of 9,700 and 4,850 CFM of outdoor air for air handlers AHU-1 and AHU-2 respectively. Air handler AHU-3 is a 100 percent outdoor air unit, which supplies the laboratory spaces. The ventilation requirements for these spaces are far surpassed by the quantity supply air that has been designed. This calculation illustrates that the cooling design load quantity of supply air id the determining factor for the amount of airflow delivered to each space being served by AHU-3.

ASHRAE Standard 62.1-2007 Summary

The HVAC design of the Life Sciences Building surpasses the requirements of Section 5 where the Section is applicable. The Life Sciences Building is applying for LEED certification, which effects the design considerations from the beginning.

The minimum ventilation requirements of Section 6 are exceeded in the design of Life Sciences Building. Two of the air handlers provide 40 percent of the supply air as outdoor at the design condition, which is more than the required ratio mandated by Section 6. The third air handler is a 100 percent outdoor air unit, which is designed to meet both the ventilation requirements and the room cooling loads. The 100 percent outdoor air unit will provide the laboratory and hazardous storages spaces with a safer environment.

ASHRAE Standard 90.1-2007 Analysis

Section 5 – Building Envelope

5.1.4 Climate Zone

The climate zone for Nassau Community College Life Sciences Building is located in Garden City, NY on Long Island, which corresponds to zone 4A. Zone 4A is defined by having mixed weather conditions as well as experiencing periods of high humidity. The climate zone was determined using Table B-1 in ASHRAE Standard 90.1-2007 or by viewing Figure 9 below.

Figure 9 - United States Climate Regions

5.4 Mandatory Provisions

The exterior envelope of the Life Sciences Building is specified on the drawings to be sealed where exterior door frames, fenestration and the copper rain screen panels join in order to prevent infiltration of unconditioned air.

The two building entrance to the Life Sciences Building contain vestibules that provide a barrier between the interior conditioned space and the exterior. The smallest of the vestibules has a distance of 10 feet between the exterior and interior doors, which is greater than the mandated 7 feet.

5.5 Prescriptive Building Envelope

The prescriptive building envelope method was used to determine the Life Sciences Building's compliance with Standard 90.1's building envelope requirements. Located in Table 5.5-4 in Standard 90.1 are values corresponding to maximum U-values, R-values, C-values, F-values and SHGC for the appropriate assemblies. Standard 90.1 mandates that no more than 40% of a building's façade may be comprised of vertical fenestration as compared to exterior wall area. The summary of Standard 90.1's requirements and the Life Sciences Building's design can be viewed in Table 16, Table 17, Table 18 and Table 19 below.

	Glazing Area (ft^2)	Wall Area (ft^2)	Percent Glazing	Standard 90.1 Compliance (Y/N)
Life Science Building	16,901	42,084	40.16%	N

Table 16 – Total Building Glazing Area

The Life Sciences Building does not comply with Standard 90.1. This is due to the large storefront windows on the first floor that increase the aesthetic appeal of the building. Furthermore, the courtyard side of the building that houses the faculty offices contains a glass curtain wall that stretches from the ground to the third floor. This is to accommodate the faculty who contribute to the operations and education of the campus. The Life Sciences Building would only need a small adjustment in the windows for the smaller teaching classrooms in order to meet Standard 90.1 requirements

Exterior Materials		Prescribed Nonresidential		Actual Design Assembly		Standard 90.1 Compliance (Y/N)
Element	Element Construction	Assembly Maximum	Insulation Minimum	Assembly Maximum	Insulation Minimum	
Roof	Insulation Entirely above Deck	U-0.048	R-20.0 c.i.	U-0.06811	R-14.7	Y
Walls, Above Grade	Steel-Framed	U-0.064	R-9.5 c.i.	U-0.04678	R-21.4	N
Walls, Below Grade	Below-Grade Wall	C-1.140	NR	C-1.33	NR	N
Slab-On-Grade Floors	Unheated	F-0.730	NR	F-0.36	NR	Y

Table 17 - Building Material Properties

Two of the exterior façade elements do not meet the requirements of Standard 90.1. The walls above grade as well as the walls below grade do not have the resistance required. The walls below grade to not pass because of the lack of insulation required. The above grade walls do not meet Standard 90.1 because the composition was selected based on aesthetics rather than function. In order to compensate for the thermal loss through the above grade walls, the curtain walls and windows far surpass the requirements for maximum U-value and maximum SHGC as seen in Table 19 below.

Fenestration	Prescribed Nonresidential		Actual Design Assembly		Standard 90.1 Compliance (Y/N)
	Maximum U-Value	Maximum SHGC	Maximum U-Value	Maximum SHGC	
Metal Framing	U-0.50	SHGC-0.40	U-0.28	SHGC-0.27	Y

Table 18 - Building Fenestration Properties

Section 6 – Heating, Ventilating, and Air Conditioning

6.2 Compliance Path

Two methods are described in Standard 90.1 in order to evaluate the efficiency of the overall building mechanical system – the Simplified Approach Option or the Mandatory Provisions method.

6.3 The Simplified Approach Option for HVAC Systems

The Simplified Approach Option can be used if the building is two stories or fewer in height and in the gross floor area is less than 25,000 square feet. Since the Life Sciences Building does not meet either of those conditions, the Mandatory Provisions method will be used in this analysis.

6.4 Mandatory Provisions

The Life Science building is has zone thermostats to control both the heating and cooling space temperature. The thermostatic controls respond with an accuracy ranging from ±2°F to ±5°F. In order to prevent setpoint overlap, the thermostat will call for heat when the outdoor air temperature falls below 50°F. An outdoor air temperature below 50°F will activate the perimeter finned tube radiation and decrease the quantity of CFM supplied from the air handler to the zone.

The thermostat is also controlled by periods of occupancy based on a carbon dioxide sensor. During occupied hours the space is to maintain a temperature of 72°F. When unoccupied, the setpoint is between 68°F and 76°F to keep the space occupant ready. When the air handler is off, the space temperature will be maintained at a 55°F minimum

In the event of a fire alarm emergency, the ventilation dampers at the top of the elevator shaft are programmed to open. During all other operating modes, the elevator shaft vent is normally closed. The air handlers will shut down upon receiving a fire alarm signal. In a smoke purge situation, the air handlers operate both the return and supply fan at full capacity in full exhaust, which draws in 100 percent outdoor air to purge smoke.

Insulation for supply and return ductwork is dependent on location and use. All exterior ductwork must be insulated regardless of its use. Return ductwork is insulated in mechanical equipment rooms. Supply ductwork is insulated between the fan discharge and terminal outlet. The outdoor air intake ductwork between the air entrance and fan inlet shall be insulated. The emergency generator exhaust will be insulated for safety due to the extremely hot temperatures of combustion. Sizes for ductwork insulation can be viewed in Table 5. All piping supply and return lines are insulated regardless of service. Make-up water and condensate drain piping is also insulated. A summary of the Life Sciences Building's piping insulation thickness can be seen in Table 20.

Ductwork Insulation Thickness		
Duct Location	Insulation Material	
	Rigid Fiberglass	Flexible Fiberglass
Interior	2"	2"
Exterior	3"	N/A

Table 19 - Ductwork Insulation Thickness

Pipe Insulation Thickness				
Service	Material	<1"	1" – 1¼"	1½" – 6"
Chilled Water (40°F - Ambient)	Fiberglass	1"	2"	2"
	Cellular Glass	1"	2"	2"
Hot Water (<250°F)	Fiberglass	1"	2"	2"

Table 20 – Pipe Insulation Thickness

Duct seam and joint sealing is specified as per the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) and is also designed to meet the requirements of Standard 90.1.

6.5 Prescriptive Path

Of the three air handlers serving the Life Sciences Building, one is a 100% outdoor air unit. The two remaining air handlers have the capability to provide up to 100% of the design supply air quantity as outdoor air for cooling. Outdoor air dampers are specified to return to minimum outdoor air position when the outside air is 55°F, which is not among the acceptable control types for high-limit shutoff. The normal outdoor air fraction of supply air is 50%.

Based on the Motor Nameplate Horsepower method of calculating fan system power limitations, Table 21 provides a summary of which fans in the Life Sciences Building comply with the maximum allowable motor horsepower for a given airflow rate. It is worth noting that E/F-9 A, B, C complies with Standard 90.1 even though it is a laboratory exhaust fan serving fume hoods on the second floor. Furthermore, E/F-9 A, B, C contains a heat recovery run-around loop that recovers sensible heat, which preconditions make-up air entering the air handler.

Unit	HP	CFM	CFMx0.0015	90.1 Compliance
AHU-1 Supply	40	25,550	38.32	N
AHU-2 Supply	40	25,550	38.32	N
AHU-3 Supply	30	24,000	36	Y
AHU-1 Return	15	25,550	38.32	Y
AHU-2 Return	15	25,550	38.32	Y
E/F-1	¼	1,367	2.05	Y
E/F-3	¼	1,367	2.05	Y
E/F-4	1/6	1,095	1.64	Y
E/F-5	1/6	1,095	1.64	Y
E/F-6	2	4,500	6.75	Y
E/F-7	3	6,500	9.75	Y
E/F-8	1½	4,050	6.08	Y
E/F-9 A,B,C	20	24,050	36.08	Y

Table 21 - Life Sciences Building Fans

6.7 Submittals

A complete set of construction documents including operating manuals and sequence of operation will be handed to Nassau Community College upon completion of the Life Sciences Building. There will also be a balancing report of both the air and hydronic systems. The Life Sciences Building has submitted an application for LEED certification, therefore commissioning will we completed at the end of construction.

Section 7 – Service Water Heating

The Life Sciences Building does not contain combustion equipment for service water heating. Hot water that is supplied to the air handlers, perimeter radiation and to other various hydronic heating equipment is produced via heat exchanger by campus provided high temperature hot water. The sole combustion element of the mechanical system is the emergency generator that does not produce hot water in the event of an emergency.

Section 8 – Power

The Life Sciences Building electrical system is specified to comply with the National Electric Code (NEC), which states that feeder conductors are to have a maximum voltage drop of 2% and a maximum branch voltage drop of 3% at the design load condition. Therefore, the Life Sciences Building complies with this section. Furthermore, the construction drawings, including the single-line diagrams of the building electrical distribution as well as the floor plans, along with operating and maintenance manuals will be turned over to Nassau Community College at the completion of construction.

Section 9 – Lighting

9.2 Compliance Path

In Standard 90.1 there are two different methods to determine the compliance of the Life Sciences Building with the maximum lighting power density: the Building Area Method or the Space-by-Space Method. The Building Area Method involves totaling up the power consumed by all lighting fixtures used in the building during normal operating hours and dividing by the total building area. The Building Area Method will be used for this analysis.

9.4 Mandatory Provisions

The Life Sciences Building contains occupancy sensors in all spaces. The sensors are combined with locally controlled switches for each space.

9.5 Building Area Method Compliance Path

The Life Sciences Building falls into the category of school/university on ASHRAE Standard 90.1 Table 9.5.1. The Lighting Power Density (LPD) is designated to be no higher than 1.2 W/ft^2 for this category. Table 22 below gives a summary of the breakdown of the lighting density for the Life Sciences Building by providing the number of each fixture per floor and the number of Watts per each fixture. The calculated W/ft^2 is 0.90, which is well below the mandated maximum of 1.2 W/ft^2.

Lighting Density Compliance							
Fixture	Basement	1st	2nd	3rd	Penthouse	W/fixt.	Total W
FK1	-	29	32	32	-	63	5859
FK2	-	46	62	85	-	63	12159
FK3	-	-	-	101	-	63	6363
FL2	1	-	-	-	-	79	79
FL3	-	1	-	-	-	79	79
FL4	3	10	7	7	2	79	2291
FL5	-	-	-	-	1	63	63
FN1	-	22	22	22	-	63	4158
FN2	-	4	4	4	-	63	756
FN3	-	19	12	12	-	63	2709
FP1	-	30	-	-	-	63	1890
FP2	-	-	25	-	-	63	1575
FP5	-	24	-	-	-	63	1512
FP6	-	24	-	-	-	63	1512
FP7	-	-	26	-	-	63	1638
FP8	-	-	24	-	-	63	1512
FR4	15	-	-	-	-	79	1185
FR5	62	4	4	4	40	79	9006
FR6	-	4	-	-	-	79	316
FT6	-	-	7	-	-	117	819
PB1	-	36	38	20	-	26	2444
PU2	2	-	-	-	-	26	52
PU3	6	-	-	-	-	42	252
			Total=				58229
			Building Area =				64,563
			W/SF =				0.90
			Standard 90.1 Compliant (Y/N)				Y

Table 22 – Life Sciences Building Power Density

Section 10 – Other Equipment

All other pieces of mechanical equipment that have electrical motors are subject to this section, which defines minimum efficiencies for motors based upon rated horsepower and motor speed. There are a series of pumps used in the Life Sciences Building, none of which comply with the required minimum efficiencies of this section. Of the motors listed in Table 23, all utilize variable frequency drives (VFD) except pumps P-5, P-6A, B and P-11. Heat recovery pump P-11 does not have a VFD due to the nature of its operation. Pump P-11 is specified to operate continuously at a constant speed whenever the outside air temperature is below 55°F or above

80°F. Furthermore, all pumps serving air hander pre-heat coils operate in the same manner; when the outside air temperature is below 55°F, they run at constant speed.

Pump Motor Efficiency Compliance						
Pump	Service	HP	Efficiency (%)	RPM	Min. Efficiency (%)	Standard 90.1 Compliance
P-1, 2	CHW Booster	15	82.4	1750	91	N
P-3, 4	CHW Service	15	82.8	1750	91	N
P-5	Glycol	1.5	66.5	1750	84	N
P-6A, B	AHU-Circulation	3/4	62.4	1750	-	N
P-7, 8	Radiation	5	65.8	1750	87.5	N
P-9, 10	Re-heat	3	62.6	1750	86.5	N
P-11	Heat Recovery	2	69.2	1750	84	N

Table 23 – Life Sciences Building Pump Motor Efficiency Compliance

ASHRAE 90.1-2007 Summary

In order to determine compliance with ASHRAE Standard 90.1-2007, the prescriptive performance evaluation method was used for all sections. All things considered, the Life Sciences Building complies with this standard with some minor exceptions. The two major failures, according to Standard 90.1, are the overall glazing percentage of exterior wall area and exterior wall U-values and fan power usage.

The overall glazing percentage is over the acceptable limit by only a fraction of a percent and could be corrected with a slight sacrifice to aesthetics. The exterior walls, both above and below grade, have U-values that fall below the maximum. The walls above grade are constructed of copper rain screen panels and metal studs with a layer of insulation. This construction serves as a more aesthetic appeal rather than a functional thermal boundary. However, the large glazing areas have U-values and SHGC's that far surpass the requirements of this standard. The increase in thermal properties for the exterior glazing is to compensate for the below minimum requirements of the walls.

The supply fans for air handlers AHU-1 and AHU-2 are the only two fans that do not comply with this standard. These fans have a high external static pressure to overcome due to the long runs of ductwork to the building's extremities. A small adjustment in ductwork sizing and routing would allow for the supply fan to overcome a smaller external pressure drop. The return fans for these respective units are used for a plenum return, which is why their power requirements are much less.

The Life Sciences Building has submitted is application for LEED certification with a maximum of 69 potential points, which would yield a LEED Platinum rating. As a result, energy efficiency was a major design consideration where the majority of ASHRAE Standard 90.1 was followed. With a few minor adjustments, the Life Science Building would be compliant in all aspects of ASHRAE Standard 90.1.

LEED Analysis

The United States Green Building Council (USGBC) has created the Leadership in Energy and Environmental Design (LEED) certification system in order to implement more energy efficient designs in the building industry. Two of the LEED criteria directly affect the mechanical design – Energy and Atmosphere and Indoor Environmental Quality.

The Life Sciences Building has submitted a checklist to the USGBC totaling 50 potential points, which would achieve a LEED Gold rating. Nassau Community College is striving for a LEED Gold rating for the new Life Sciences Building.

Furthermore, LIPA provides a credit for LEED certification and a credit for every LEED point related to the mechanical system, either Energy and Atmosphere or Indoor Environmental Quality, up to $25,000. This provides a further incentive for achieving LEED certification. A summary of all the projected credits pertaining to the mechanical systems to be earned by the Life Sciences Building are summarized in this section.

Energy and Atmosphere

In the Energy and Atmosphere category, there are three prerequisites that are required in order to be considered for any points within the category. The Life Science Building meets the prerequisites and is estimated to receive 5 points.

Prerequisite 1: Fundamental Commissioning of the Building Energy System

This prerequisite is required in order to verify that the Life Sciences Building's energy-related systems are installed and calibrated properly to perform according to the design and construction documents. A commissioning company has been brought onboard the design and construction team in order to provide the assurance that the designed system will operated as designed. Furthermore, the commissioning company has been contracted to provide enhanced commissioning in accordance with one credit within this category.

Prerequisite 2: Minimum Energy Performance

The purpose of this prerequisite is to establish a minimum level of energy efficiency for the Life Sciences Building. A consultant was contracted to provide a baseline energy simulation of the Life Sciences Building in order to meet the requirements of this prerequisite. The Life Sciences Building is designed to perform above the 10% improvement in the designed performance rating.

Prerequisite 3: Fundamental Refrigerant Management

The purpose of Prerequisite 3 is to reduce the stratospheric ozone depletion caused by the refrigerants used in the HVAC industry. There is no designed use of chlorofluorocarbon-based refrigerants in the Life Sciences Building, which complies with the requirements of the prerequisite.

Credit 1: Optimize Energy Performance – 2 Points

The purpose of Credit 1 is to achieve higher levels of energy performance beyond the minimum requirements of Prerequisite 2. The design engineers chose the Option 1 compliance path for the whole building energy simulation. It was determined that the Life Sciences Building will perform 14% above the baseline building performance rating determined by the outside consultant. The baseline energy consumption for the Life Sciences Building was determined to be 9.96 MBtu per year.

Credit 2: On-Site Renewable Energy – 1 Point

Credit 2 is designed to provide a reward to the engineers who make use of new technology and utilize on-site renewable energy to offset the environmental impact of fossil fuel combustion. Even though the Life Science Building does not have any onsite combustion, the high temperature hot water and chilled water it receives from the campus are produced by a fossil fuel-burning power plant. However, Nassau Community College is investigating as to the cost and benefits of installing solar photovoltaic cells on the Life Sciences Building. This 1 point is not a certainty, rather a potential point depending on NCC.

Credit 3: Enhanced Commissioning – 1 Point

The purpose of Credit 3 is to incorporate the commissioning process early in the design. Nassau Community College has contracted a commissioning company to comply with Prerequisite 1 and has extended the contract to include the enhancement called for in Credit 3.

Credit 4: Enhanced Refrigeration Management – 1 Point

The purpose of Credit 4 is to reduce the ozone depletion further than Prerequisite 3 by complying with the Montreal Protocol. The Life Sciences Building complies with option 1 of the requirements by not using refrigerants in the mechanical system.

Credit 6: Green Power – 1 Point

Credit 6 encourages the building owner and the design team to explore the use of grid-source, renewable energy. LIPA provides voluntary programs that allow customers to purchase green power from two individual marketers, Community Energy and Sterling Planet. Nassau Community College is investigating the potential for green power for the Life Sciences Building to receive the point for Credit 6.

Indoor Environmental Quality

The Indoor Environmental Quality category contains two mandatory prerequisites that must be met in order to receive points in this category. The Life Sciences building complies with the prerequisites and is estimating to total of 13 points.

Prerequisite 1: Minimum IAQ Performance

The purpose of Prerequisite 1 is to establish a minimum indoor air quality performance, which provides a comfortable environment and contributes to the well-being of the occupants. Prerequisite 1 requires the building to comply with Section 4 through 7 of ASHRAE Standard 62.1-2007. The Life Sciences Building is mechanically ventilated. However, the Life Sciences Building complies with both ASHRAE Standard 62.1-2007 and the New York State Mechanical Code of 2007 and therefore complies with the requirements of this prerequisite.

Prerequisite 2: Environmental Tobacco Smoke (ETS)

The purpose of Prerequisite 2 is to prevent the exposure of the building occupants, indoor surfaces and ventilation system to environmental tobacco smoke (ETS). There are two options to comply with this prerequisite – either prohibit smoking in the building or prohibit smoking except in designated smoking areas. The Life Sciences Building prohibits smoking inside the building and within 25 feet of entries, outdoor air intakes and operable windows, which complies with the requirements of this prerequisite.

Credit 1: Outdoor Air Delivery Monitoring – 1 Point

Credit 1 is designed to assure the proper ventilation is being provided for occupant comfort and well being. The Life Sciences Building has specified monitors to guarantee the minimum amount of ventilation is supplied and has tied the monitors into the building automation system for air handling units AHU-1 and AHU-2. Air handling unit AHU-3 is a one hundred percent outdoor air unit and therefore does not require monitoring for minimum ventilation.

Credit 2: Increased Ventilation – 1 Point

Credit 2 is intended to improve indoor air quality and promote occupant comfort through the additional supply of outdoor air above the minimum requirements. The Life Science building provides one hundred percent outdoor air through air handling unit AHU-3 to the laboratories and 50% outdoor air to the remaining areas of the building. The excess amount of outdoor ventilation air is attributed to the nature of the variable air volume boxes ability to turn down but still provide adequate ventilation air during full occupancy. However, Credit 2 requires ventilation rates to be increased by 30% above the minimum rates provided by ASHRAE Standard 62.1-2007 for mechanically ventilated spaces. Due to the 30% increase above the minimum ventilation rate requirement for Credit 2, the one point is a potential point rather than a certainty.

The excess ventilation air that has been designed into the Life Sciences Building is due to the functionality of the variable air volume boxes, not to achieve a point for Credit 2. The point will be awarded if the excess air coincidently above the 30% increase above the minimum rates.

Credit 3.1: Construction IAQ Management Plan, During Construction – 1 Point

The purpose of Credit 3.1 is to reduce indoor air quality problems due to construction or renovation. The Life Sciences Building has been included in the specifications of its air handling units to comply with Credit 3.1 during construction. Furthermore, the ductwork has been specified to comply with the Sheet Metal and Air Conditioning National Contractors Association (SMACNA) guidelines in order to meet the requirements of Credit 3.1.

Credit 3.2: Construction IAQ Management Plan, Before Occupancy – 1 Point

The purpose of Credit 3.2 is to reduce indoor air quality problems due to construction or renovation. Credit 3.2 is similar to Credit 3.1. However, Credit 3.2 aims at purging the building from harmful substances that may have accrued during construction. Two approached can be taken to satisfy the requirements of this credit. One option is to perform a building flush-out after all finishes have been installed and before occupancy. The second option is to test the air using protocols from the EPA Compendium of Methods for the Determination of Air Pollutants in Indoor air.

The Life Sciences Building is specified to conduct a two-week building air flush-out after the commencement of construction and prior to the building occupation. There will be an indoor air quality test that complies with the EPA protocol provided by Nassau Community College. This procedure complies with the first option for compliance with Credit 3.2. The Life Sciences Building will receive one point.

Credit 4.1: Low-Emitting Materials, Adhesives & Sealants – 1 Point

The purpose of Credit 4.1 is to reduce the quantity of indoor air contaminants that are odorous, irritating and potentially harmful to the occupants due to interior adhesives and sealants. The adhesives and sealants used on the interior of the building are to comply with the requirements according to the South Coast Air Quality Management District (SCAQMD) Rule #1168. Rule #1168 limits volatile organic compounds (VOC's) that are used as adhesives and sealants inside a building. Table 24 summarizes the VOC limitations as specified for the Life Sciences Building, which meets the requirements of Credit 4.1 and will receive one point.

Adhesive/Sealant	VOC Limit (g/L)
Wood Glues	30
Metal to Metal Adhesives	30
Adhesives for Porous Materials (Except Wood)	50
Subfloor Adhesives	50
Plastic Foam Adhesives	50
Carpet Adhesives	50
Cove Base Adhesives	50
Gypsum Board and Panel Adhesives	50
Ceramic Tile Adhesives	65
Multipurpose Construction Adhesives	70
Structural Glazing Adhesives	100
Contact Adhesive	250
Plastic Cement Welding Compounds	350
ABS Welding Compounds	400
CPVC Welding Compounds	490
PVC Welding Compounds	510
Adhesive Primer for Plastic	650
Sealants	250
Sealant Primers for Nonporous Substrates	250
Sealant Primers for Porous Substrates	775

Table 24 - VOC Limitations for Adhesives and Sealants

Credit 4.2: Low-Emitting Materials, Paints & Coatings – 1 Point

The purpose of Credit 4.2 is to reduce the quantity of indoor air contaminants that are odorous, irritating and potentially harmful to the occupants due to interior paints and coatings. Architectural paints and coatings used on the interior are not to exceed VOC content limits according to Green Seal Standard GS-11, Paints. Anti-Corrosive and anti-rust paints applied to ferrous materials are not to exceed a VOC limit of 250 g/L established in Green Steal Standard GC-03, Anti-Corrosive Paints. Clear finishes such as coatings, stains, primers and shellacs used on interior elements are not to exceed VOC limits according to the South Coast Air Quality Management District (SCAQMD) Rule #1113.

The Life Sciences Building has specified acceptable VOC limits for paintings and coatings that can be used on interior surfaces that comply with the requirements of Credit 4.2. Therefore, one point is achieved through Credit 4.2

Paint/Coating	VOC Limit (g/L)
Flat Paints and Coatings	50
Non-Flat Paints and Coatings	150
Anti-Corrosive Coatings	250
Varnishes and Sanding Sealers	350
Stains	250
Aromatic Compounds	<1% by weight, total aromatic compounds

Table 25 - VOC Limitations for Paints and Coatings

Credit 4.3: Low-Emitting Materials, Carpet Systems – 1 Point

The purpose of Credit 4.3 is to reduce the quantity of indoor air contaminants that are odorous, irritating and potentially harmful to the occupants due to flooring systems. There are two options that allow for the compliance of Credit 4.3. The first option provides a list of codes that different flooring materials must meet if they are applicable to the project scope. The second option requires compliance of the California Department of Health Services Standard for Testing of Volatile Organic Emissions from Various Sources using Small-Scale Environmental Chambers including 2004 Addenda. The Life Sciences Building's carpets have been specified to comply with the Carpet and Rug Institute Green Label Plus program. The carpets have also been specified to use adhesives that comply with Credit 4.1. One point will be awarded for Credit 4.3

Credit 4.4: Low-Emitting Materials, Composite Systems – 1 Point

The purpose of Credit 4.4 is to reduce the quantity of indoor air contaminants that are odorous, irritating and potentially harmful to the occupants due to composite wood systems. Credit 4.4 requires that the composite wood and agrifiber products used on the interior of the building must not contain urea-formaldehyde resins. The Life Sciences Building has specified the medium density fiberboard used in the building to contain no urea-formaldehyde. However, on the LEED Checklist, the point associated with Credit 4.4 is not a guarantee.

Credit 5: Indoor Chemical & Pollutant Source Control – 1 Point

Credit 5 is designed to limit occupant exposure to potentially hazardous particulates and chemical pollutants. Credit 5 requires disconnects between the interior spaces and the exterior at major entryways via vestibules at least 10 feet long in the direction of travel. There also must be sufficient exhaust is spaces that contain hazardous gases or chemicals as well as provided a MERV 13 filter or higher in the ventilation system.

The Life Sciences Building complies with Credit 5 by provided vestibules at the major building entrances with the required dimensions and grates in order to capture dirt and particulates that may enter the building. Furthermore, fume hoods provide a safe environment for the handling of hazardous chemicals in the laboratory setting and provide negatively pressurized storage spaces for the chemicals in the basement. The filtration system will contain at least a MERV 13 filter to process both the return and outdoor air streams. One point will be received for Credit 5.

Credit 6.1: Controllability of Systems, Lighting – 1 Point

The purpose of Credit 6.1 is to provide a lighting system control that promotes productivity and comfort for the occupants. The lighting system is required by Credit 6.1 to provide individual controls for 90% of the building occupants that can accommodate adjustments to suit individual task needs. A lighting system for shared spaces is required to meet the group needs.

The Life Sciences Building provides a lighting control system for the different spaces in the building. The classrooms have the dimming capability for enhanced teaching. The offices contain individual lighting controls per spaces in order to accommodate individual preferences. One point will be received for Credit 6.1.

Credit 6.2: Thermal Comfort – 1 Point

Credit 6.2 aims at providing the occupants with a higher level of thermal comfort control by providing controls on an individual basis or by multi-occupant space basis to promote productivity and comfort. To receive a point for Credit 6.2, at least 50% of the occupants must have individual comfort controls to allow for adjustments for individual preferences. Multi-occupant spaces are required to have controls to allow adjustments as the group prefers.

The Life Sciences Building has been designed with thermostats in each laboratory and classroom to provide group settings to each space. Offices are combined into small groups in order to tie together spaces with similar load profiles as well as to allow at least 50% of individual occupants to control the thermal comfort settings as required by Credit 6.2. One point will be awarded for Credit 6.2.

Credit 7.1: Thermal Comfort, Design – 1 Point

Credit 7.1 is designed to provide a comfortable indoor thermal environment for the occupants. Credit 7.1 requires the designed HVAC system and the building envelope to comply with ASHRAE Standard 55-2004. The Life Sciences Building has been designed according to requirements set forth by ASHRAE Standard 55-2004 and will receive one point.

Credit 7.2: Thermal Comfort Verification – 1 Point

The purpose of Credit 7.2 is to provide an assessment of the building occupant thermal comfort over time. Credit 7.2 provides a possible extra one point on top of Credit 7.1 if a permanent monitoring system is incorporated into the design to ensure that the building performance maintains the comfort criteria specified in ASHRAE Standard 55-2004. The Life Sciences Building will conduct a survey within 6 to 18 months after occupancy as mandated by Credit 7.2. The survey will determine if more than 20% of the occupants are dissatisfied. In the event that more than 20% of the occupants are dissatisfied, corrective measures will been taken in order to correct the thermal comfort issues. One point will be awarded for Credit 7.2.

Credit 8.1: Daylight & Views, Daylight 75% of Spaces – 1 Point

Credit 8.1 is designed to connect the indoor and outdoor spaces through the use of daylighting and views in the spaces that are regularly occupied. The requirement of Credit 8.1 is that at least 75% of the regularly occupied spaces in the building are to achieve a minimum level of 25 footcandles (fc) and a maximum of 500 fc in a clear sky condition. Those spaces with illuminance levels outside the range do not meet the requirements of Credit 8.1.

There are a few different methods using either geometry or computer modeling programs that help the designers determine if Credit 8.1 is achievable. The designers of the Life Sciences Building have not provided information as to their analysis and time has not permitted a new analysis. However, the designers have assured that Credit 8.1 will be achieved.

Credit 8.2: Daylight & Views, Views for 90% of Spaces – 1 Pont

Credit 8.2 is similar in purpose to Credit 8.1 but the requirements have changed. Credit 8.2 requires that 90% of the regularly occupied spaces in the building are to achieve a minimum level of 25 fc and a maximum of 500 fc in a clear sky condition. The Life Sciences Building designers have not provided an analysis of Credit 8.2 and time has not permitted a new analysis. However, the designers have assured that Credit 8.2 will be achieved.

Mechanical System Evaluation

The Life Sciences Building resides on the campus of Nassau Community College. Typically educational buildings are mechanically designed as a variable air volume (VAV) system due to the fluctuations in occupancy and scheduling capabilities with offices and classrooms. A VAV configuration usually saves energy through the throttling of fans and control valves. However, the Life Sciences Building is also a laboratory facility that requires a dedicated exhaust system coupled with the large airflow requirements of the fume hoods. There is also a higher air change rate in chemistry laboratories due to the need of ventilation to dilute hazardous chemicals that may be present in the breathing zone. While a VAV design may be typical for an educational building, the energy savings is not as available in a laboratory building as it would be in an office and classroom only facility.

The Life Sciences Building's mechanical system has been estimated to cost a total of $5,320,000, which is approximately 17% of the total building cost. Typically, the mechanical system cost ranges from 15% to 20% of the total estimated budget. Therefore, the mechanical system serving this building falls within the typical range at $73.50 per square foot. However, while the mechanical system first cost is average, the annual energy cost is high. The total utility cost, including electricity, high temperature hot water and chilled water, is calculated to be $241,000. The total cost equates to $3.33 per square foot, which is above the average range from $2 to $3 per square foot. The above average energy cost can be due to the one hundred percent outdoor air handling unit used for the laboratories. Even with heat recovery, there are large quantities flowing through the unit, which require both heating and cooling conditioning. Furthermore, the high annual energy cost can be attributed to inaccurate utility costs determined during the computerized analysis.

The large equipment components of the mechanical system are located either in the basement mechanical equipment room or the penthouse on the roof. The basement mechanical room contains the majority of the water-side equipment such as the heat exchangers and pumps along with the campus high temperature hot water and chilled water service entrances. The penthouse contains the three air handling units as well as the laboratory exhaust fans. While a small 8.5% of the Life Sciences Building floor area occupied by the mechanical system, there is also space in the ceiling plenum that is displaced by mechanical equipment such as ductwork, variable air volume boxes and exhaust valves. The first and third floors of the building utilize a plenum return system, which decreases the need for ducted returns throughout the floor. However, the second floor has a dedicated ducted exhaust to both the fume hoods as well as the chemistry laboratories in order to prevent contamination of other spaces. The laboratories also require large quantities of supply air, which need large ducts to bring air to the spaces. Both of the supply and exhaust systems utilize a large majority of the ceiling plenum. There may be a potential ceiling height decrease as well as energy savings if a decentralized system is used for the laboratory spaces.

The laboratory floor of the Life Sciences Building is served by the one hundred percent outdoor air unit. While the system may use more energy, the abundant amounts of ventilation air provide for a higher indoor air quality. No recirculation of the air from the laboratories assures the hazardous contaminants from the laboratories will not be spread from zone to zone. The offices and classrooms are served by a variable air volume air handling system, which have a higher filter MERV rating than the code minimum due to LEED certification requirements. Furthermore, higher amounts of outdoor air are introduced into the ventilation system due to the nature of the variable air volume system. While the higher amounts of outdoor air cause higher heating and cooling costs, the increased ventilation allows for a higher indoor air quality.

Zones for the Life Sciences Building are organized based on small groups of spaces which contain similar load profiles. It is typical to have three or four offices on the same façade to be grouped into one zone. On the other hand, classrooms are each their own zone. Each zone is provided with an adjustable environmental control. The perimeter radiation and the VAV boxes are coupled and controlled by one device in order to provide the proper environmental settings as preferred by the occupants. There are sufficient controls throughout the building in order to satisfy the requirements for LEED certification.

The VAV design of the Life Sciences Building is adequate for providing conditioned air and ventilation to each space. However, a decentralized system may provide higher energy savings to the overall mechanical system as well as reduce the mechanical space requirements in the ceiling plenums. A decentralized system may be advantageous based on the availability of water to transfer more energy in a smaller area than air. Furthermore, for the one hundred percent outdoor air system, there appears to be a higher energy saving potential with a advanced engineered heat recovery system between the laboratory exhaust and outdoor air streams. There are areas of the designed mechanical system that may benefit from a redesign. Future reports will address redesign ideas.

Proposed Alternatives

The Life Sciences Building was designed as a variable air volume system due to industry norms found in educational facilities. The designed mechanical system meets the requirements of governing codes and satisfies the needs of Nassau Community College. However, several alternatives to the designed system may prove to help reduce the initial cost of the building while decreasing the Life Sciences Building's annual energy consumption and occupy less space. The redesign alternatives will require an extensive analysis as to their feasibility.

Alternatives Considered

Several aspects of the Life Sciences Building have the potential for an upgrade. Certain redesign ideas have the potential for space savings, while others are geared at energy savings and others aim at decreasing the first cost of the mechanical system. Below is a list of options that were considered for the Life Sciences Building redesign. Due to time restrictions, only a few of these options could be further investigated.

- Fume hood redesign
- Decentralized air system
- Decouple high temperature hot water from plant
- Convert high temperature hot water to hot water at the building entrance
- Heat recovery system redesign
- New chiller plant for the Life Sciences Building
- Convert high temperature hot water to steam at the building entrance

Two items from the list above have been chosen to be studied further. The topics were chosen based on consultant input, intellectual reasoning and educational value. Each redesign alternative will have an impact on the building as well as the associated mechanical system components. Therefore, the redesign will also incorporate the effect on the associated mechanical system. Each of the three redesign alternatives is detailed further in the following sections.

Decentralized Air System

The current air side system design consists of a variable air volume (VAV) system for each of the three air handling unit. While, this system configuration may be great in conceptual design, it appears to consume more energy than is necessary. The two classroom/office air handling units are designed as VAV systems because of the fluctuations in occupancies in each of the spaces. However, due to the nature of the VAV boxes, the airflow cannot turn down more than 30% of the design airflow. This causes an issue in spaces with high occupancies and low loads, such as a lecture hall during a moderate weather condition where cooling is not necessary. The VAV box will turn down to its lowest setting, which is 30% of the design condition. However, in a lecture hall, there is large ventilation load, which causes the lowest setting on the VAV box to still have airflows near 1,000 CFM. Because of these high airflows, the total system design outdoor air requirements are 50% of the total supply airflow. This is 30% greater than the code required minimum, which causes an increase in energy consumption to heat and cool the outdoor air.

There are several advantages of a decentralized airside system rather than a single air handling unit that serves as the space load and ventilation requirements. One of which is that the decentralized airside system only provides the ventilation air at a constant volume. The remaining heating and cooling load will be satisfied at the space with a fan coil, chilled beam or radiant system. The use of water to distribute energy is more advantageous than air because of the heat capacity properties of water versus air. Water has the availability to transport much more energy per pound than air. Therefore, by using pipes to move energy throughout the building, ceiling space will become more available due to the decrease in duct size.

Another advantage of a decentralized system is the availability of the supply fan to run at the design point for longer periods. If the air handling unit's main objective is to supply the ventilation air to the space, then there is a constant volume of air moving through the fan during each hour of the day. The constant volume of air allows the fan to run at maximum power at its highest efficiency point during occupied hours. Furthermore, there can be a binary control logic that modulates the fan to a decreased flow rate during the scheduled unoccupied hours. The decrease in flow rate will save energy as the electrical input varies proportionally to the cube of the flow rate.

A study will be completed to determine if there is a decreased initial first cost with a decentralized system, if there is an increase in available space with the reduction in ductwork size and if there is energy savings with heating and cooling being provided directly in the space. The study will demonstrate the effect of a decentralized system in the Life Sciences Building.

New Chiller Plant

The Life Sciences Building is receives chilled water and high temperature hot water from a local Central Utility Plant (CUP) operated by Nassau Energy Corporation. In a report produced by Parsons Brinckerhoff, it has been determined that the CUP is near its chilled water capacity. Therefore, a chiller plant located within the Life Sciences Building is being proposed as an alternative to the campus chilled water in order to remediate potential issues in chilled water capacity that may arise during the summer months. This alternative is also serves an educational purpose.

A new chiller plant located in the Life Sciences Building will significantly increase the first cost of the mechanical system. However, there are four existing chilled water pumps on-site as well as a network of chilled water piping. Therefore, any new major cost will arise from the addition of chillers and supporting equipment.

An electricity-driven chiller and cooling tower will be selected in order to provide chiller and cooling tower information for the purposes of the study. New innovative chilled water system designs are to be explored as a method of energy savings or as initial cost savings for the Life Sciences Building. Variable primary flow systems versus primary/secondary pumping arrangements will be the focus of this study.

The feasibility study of a new chiller plant serves as educational function as well as a study as to the optimization of a new chiller plant. This study will demonstrate the effect of a new chilled water plant on the Life Sciences Building.

Breadth Topics

Daylighting

The Life Sciences Building is applying for LEED certification and it has been predicted to receive both LEED points for providing a minimum of 25 footcandles to 90% of regularly occupied spaces through daylight. However, no mathematical, geometrical or computerized model conclusions have driven this prediction. Therefore, a daylighting breadth will involve the investigation of the LEED points. If the Life Sciences Building does not meet the requirements for the daylighting LEED points, adjustments will be made in an attempt to receive the credit.

The daylighting study will be completed using AutoCAD to create a three-dimensional model of the Life Sciences Building. The model will be imported into AGI32, which will be used to determine the illuminance levels in exterior spaces. The daylighting study will be coupled with the architecture study if there is a need for adjustments in the exterior façade.

Architecture

The architecture breadth is involved both in the daylighting breadth and new chiller plant depth studies. If adjustments are needed to the Life Sciences Building in order to meet the requirements of LEED for daylighting credits, the architectural façade will be changed to do so. These changes may involve the addition or relocation of fenestration or potentially shading devices.

The architecture will also need to be adjusted to allow for the addition of the new chiller plant. If the chiller plant is to be located in the basement, a new mechanical room will be necessary, which will entail an addition to the basement floor plan. If the chiller plant is to be water-cooled, then addition of cooling towers will call for adjustments to the penthouse configuration. Furthermore, there will need to be adjustments in the first floor to allow for the removal and replacement of chillers in the event of a failure.

MAE Course Relation

The requirement for the Master of Architectural Engineering program is the direct relation of the redesigns to 500-level course studies. AE 557, Centralized Cooling Production and Distribution Systems, will be related to the chiller plant design. Discussions and assignments have centered on the comparison between primary/secondary pumping and variable primary flow arrangements as well as the benefits and downfalls of each system.

Tools for Analysis

In order to complete the analyses involved in the depth and breadth studies several programs will be needed. These programs will range from building a three-dimensional model of the Life Sciences Building to complex mathematical equation solving to codes and standards that specify minimum requirements. Each of these programs plays an essential part in the completion of the studies.

Load/Energy Modeling

Trane Trace 700 will be used to determine the Life Sciences Building's annual energy consumption as well as the associated life cycle costs. Trace will be used to compare the new redesign systems to the existing systems in order to determine performance benefits or losses.

Engineering Equation Solver (EES)

EES is a complex equation solving program with built-in material properties that allows for accurate solving of various processes that occur in mechanical systems. EES, coupled with Microsoft Excel, will aid in the determination of the pumping and chiller configurations in the new chiller plant.

AutoCAD

AutoCAD will be used to develop a three-dimensional model of the Life Sciences Building. The 3-d model is essential to the completion of the daylighting breadth. The model will be imported into the program Daysim in order to evaluate the illuminance levels in the exterior spaces.

AGI32

AGI32 is a program used to evaluate daylight levels in a building. Coupled with AutoCAD, a model will be created and imported for the analysis. AGI32 will produce illuminance levels in each exterior space, which allows for a compliance check of LEED credits. AGI32 will also be used for the architecture breadth to determine new illuminance levels with the exterior shades.

Codes/Standards

Codes and standards such as the 2007 New York State Mechanical Code, ASHRAE Standard 90.1-2007 and the LEED checklist will be used during these studies in order to assure the Life Sciences Building's local compliance as well as to meet certain objectives of the studies.

Depth 1: Decentralized Air System – Chilled Beam Study

Chilled beams are a new innovative technology that originated across the Atlantic in Europe. The technology in an 'active' chilled beam induces air from the space through the unit with supply air from a central air handling unit. Chilled beams are manufactured as either a 2-pipe or 4-pipe system – meaning they can either provide only cooling to a space or both heating and cooling through heat transfer coils located within the unit. Figure 10 below provides a visual image of the airflow pattern through the units.

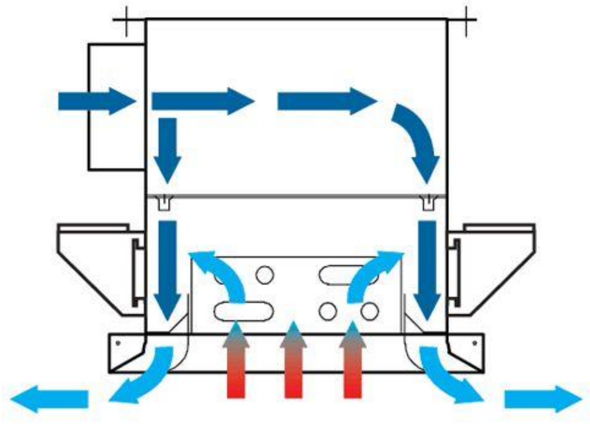


Figure 10 - Airflow Diagram of an Active Chilled beam from Price Industries

There are several advantages to chilled beam systems. One simple advantage is that the unit is space saving. Chilled beams have been actively designed and built in the Washington D.C. metropolitan area because of the tight ceiling cavities available. D.C. has a restriction on the height of the buildings within the city limits, unlike New York City where the buildings can rise sky-high. Due to this restriction, lower floor-to-floor heights are designed in order to incorporate the maximum amount of available floor area, which creates a tight squeeze for the mechanical system above the ceiling. The chilled beams are an available solution for this dilemma.

Another advantage of chilled beams is the reduction in primary airflow. Standard VAV systems provide air to a space to cool. The amount of cooling air needed to condition a space is significantly higher than the code-mandated air for ventilation. Chilled beams are typically coupled with a dedicated outdoor air system (DOAS), which provides enough air for ventilation. A DOAS system will provide a considerably less amount of primary air to a space, which greatly reduces energy usage – energy is related to the cube of the airflow.

While primary airflow to a space will decrease, chilled water pumping energy is likely to increase. However, the increase in pumping energy will not outweigh the energy saved by the reduction in primary airflow.

Analysis Procedure

The Life Sciences Building is a teaching laboratory building that contains fume hoods. There are strict airflow requirements when fume hoods are present. Therefore, the decentralized air system analysis will be performed on the classrooms, both general and nursing, and the office spaces. To save time, an analysis was performed on one classroom and one office and applied to similar spaces.

Office Space

The office spaces are spread around the courtyard of the Life Sciences Building. There are a total of 75 offices in the building each approximately one hundred square feet with a 9'-1" ceiling height. The offices are reserved for faculty in either the chemistry or nursing departments. All office spaces have a floor to ceiling glass curtain wall that overlooks the courtyard in the 'J' shaped structure. Figure 11 below provides an illustration of a typical office space in the Life Sciences Building.

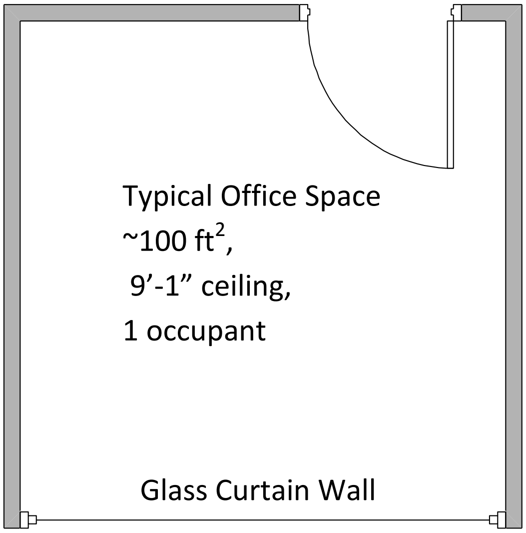


Figure 11 - Typical Office Space in the Life Sciences Buiding

Because the offices surround the courtyard, they do not all have the same orientation. The offices can face either the north, east or west directions causing the northern facing offices to have a significantly different cooling load than the eastern or western facing offices. The eastern and western offices were designed with a supply airflow quantity of 325 CFM per office while the northern offices were designed with a supply airflow of 150 CFM. The first step in the analysis is to determine the design cooling load of the space. Using the equation below, the design room sensible load can be determined from the design supply airflow rate.

$$\dot{Q}_{Sensible} = 1.08\ x\ CFM\ x\ \Delta T$$

$$\dot{Q}_{Sensible} = 1.08\ x\ 325\ x\ (75 - 55)$$

$$\dot{Q}_{Sensible} = 7{,}020 \frac{Btu}{h}$$

7,020 Btu/h of sensible cooling load is an overestimate of the actual calculated loads due to rounding of supply airflow quantities but will be used for the purpose of this analysis. The next step is to determine how much ventilation load is required for a one hundred square foot office space. According to the 2007 New York State Mechanical Code, 20 CFM per person is required for an office space. The new supply airflow of ventilation air (VA) at 55°F will condition a percentage of the room sensible load.

$$\dot{Q}_{S,VA} = 1.08\ x\ 20\ x\ (75 - 55)$$

$$\dot{Q}_{S,VA} = 432 \frac{Btu}{h}$$

432 Btu/hr is conditioned by the ventilation air to the space. The chilled beam will have to be sized to have adequate capacity to make up the difference in the room sensible load.

$$\dot{Q}_{S,CB} = 7{,}020 - 432 \frac{Btu}{h}$$

$$\dot{Q}_{S,CB} = 6{,}588 \frac{Btu}{h}$$

Based on the simple equation above, the necessary chilled beam capacity to sensibly cool the office is 6,588 Btu/h. The latent cooling capacity must be taken care of by the ventilation air supplied to the space. The latent load in the office is assumed to be 200 Btu/h per person, which is typical for a sedentary human. The supply air is design to be delivered at a temperature of 55°F and 0.006 lbm H_2O/lbm DA and the room conditions are design to be at a temperature of 75 °F and 0.0102 lbm H_2O/lbm DA.

$$\dot{Q}_{L,VA} = 4840\ x\ CFM\ x\ \Delta W$$

$$\dot{Q}_{L,VA} = 4840\ x\ 20\ x\ (0.0102 - 0.006)$$

$$\dot{Q}_{L,VA} = 407 \frac{Btu}{h} > 200 \frac{Btu}{hr \cdot person}$$

The supply ventilation air delivered to the office contains adequate latent cooling capacity required to condition the moisture load in the space. Therefore, the chilled beam total cooling capacity needs to be at least 6,588 Btu/h. According to Price Industries chilled beam catalog for a 2-way chilled beam, a 20 CFM unit will only condition 1,465 Btu/h. Therefore a larger unit will be necessary. A spreadsheet was set up to find the optimal supply ventilation air to produce adequate cooling load for the office. In Table 26, the supply air (SA) sensible load is calculated using the procedure from above with the temperature difference between the supply air and room air and the primary airflow. The chilled beam (CB) sensible load is calculated from the difference between the room sensible load and the supply air sensible load. The primary airflows and chilled beams sensible loads were compared to the Price catalog to find a unit that met the requirements. Highlighted in red in Table 26 is the unit that provided adequate total cooling capacity at the lowest primary airflow.

Room Sensible Load (BTUH)	Primary Air (CFM)	T_{SA} (°F)	T_{RA} (°F)	SA Sensible Load (Btu/h)	CB Sensible Load (Btu/h)
7,020	20	55	75	432	6,588
7,020	30	55	75	648	6,372
7,020	40	55	75	864	6,156
7,020	50	55	75	1,080	5,940
7,020	60	55	75	1,296	5,724
7,020	70	55	75	1,512	5,508
7,020	80	55	75	1,728	5,292
7,020	90	55	75	1,944	5,076
7,020	100	55	75	2,160	4,860
7,020	110	55	75	2,376	4,644
7,020	120	55	75	2,592	4,428
7,020	130	55	75	2,808	4,212
7,020	140	55	75	3,024	3,996

Table 26 - Required CB Cooling Load for Different Primary Airflows

Even though the 100 CFM primary supply air selected for the chilled beam is greater than the required ventilation air of 20 CFM, there is still a 31% reduction in supply airflow to the eastern and western facing offices. The same process is applied to the northern facing offices with 150 CFM of supply air in the VAV system. It is determined that with 20 CFM of ventilation air in the northern facing offices would required a 2,808 Btu/h total cooling capacity chilled beam. The same spreadsheet in Table 26 is used to discover that a 40 CFM unit with a cooling capacity of 2,376 Btu/h would be adequate. Table 27 provides a summary of the equipment selected from Price Industries for both office spaces with their actual cooling capacities and chilled water flow rates.

Space	Primary Airflow (CFM)	Nozzle Diameter (in)	Cooling Capacity (Btu/h)	CHW Flow Rate (GPM)
E/W Offices	100	0.31	5,086	1.55
N Offices	40	0.31	2,424	0.82

Table 27 - Summary of Price Chilled Beams Selected for the Office Analysis

The cooling loads, supply airflow and chilled beam capacities are designed for the 1% design day condition. On the off-design day, when the weather is not so severe, 100 CFM of 55°F air can overcool the office. In order to prevent overcooling in the offices the chilled beams selected are 4-pipe units, which allow hot water as well as chilled water to flow through the heat exchanger, although not simultaneously. In the overcooling situation, the chilled beam will act as a reheat coil found on typical variable air volume terminal units.

There is the availability to reset the supply air temperature at the air handling unit. However, the air handling unit serves classrooms as well as the offices. Therefore, there may be a high load in the classrooms, which contain nearly 40 people and requires 55 °F supply air while the weather conditions are on the off-design day. This is the condition when the chilled beam will act as a reheat to temper the air supplied to the offices.

Classrooms

The classrooms in the Life Sciences Building, for this analysis, are located on the first and third floors and are facing east and west. There are a total of thirteen classrooms consisting of general classrooms, nursing skill rooms, group study rooms and computer rooms. The general classrooms can be either 24 or 36 person classrooms. All of these rooms are approximately 1,100 square feet with a 9'-1" ceiling. The first floor classrooms have a floor-to-ceiling glass curtain wall while the third floor classrooms have six foot high windows spread throughout the exterior wall. Figure 12 below is an illustration of a typical classroom.

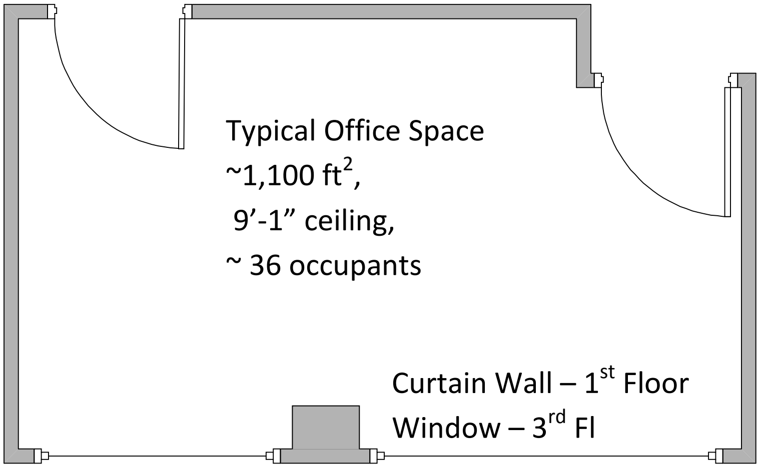


Figure 12 - Typical Classroom in the Life Sciences Building

Since the classrooms surround the exterior of the 'J' shape, they do not have the same orientation. Depending on the side of the building, they are facing either west or east. Because the classrooms are all facing either east or west, they have similar loads and therefore similar airflows at 1,600 CFM per classroom. Just like the offices, the classroom analysis was performed in the same manner. First, the design room sensible load was calculated from the design supply airflow rate.

$$\dot{Q}_{Sensible} = 1.08\ x\ CFM\ x\ \Delta T$$

$$\dot{Q}_{Sensible} = 1.08\ x\ 1600\ x\ (75 - 55)$$

$$\dot{Q}_{Sensible} = 34{,}560 \frac{Btu}{h}$$

Although this is an overestimate of the actual load calculations, 34,560 Btu/h will be used for this analysis. The New York State ventilation requirements for a classroom were found in the 2007 Mechanical Code to be 15 CFM per person. With 15 CFM per person and 36 people in the classroom, the new ventilation airflow can be calculated and the percentage of the room sensible load taken care of by the ventilation air can be determined.

$$\dot{Q}_{S,VA} = 1.08\ x\ (36\ x\ 15) x\ (75 - 55)$$

$$\dot{Q}_{S,VA} = 11{,}664 \frac{Btu}{h}$$

$$\dot{Q}_{S,CB} = 34{,}560 - 11{,}664\ \frac{Btu}{h}$$

$$\dot{Q}_{S,CB} = 22{,}896\ \frac{Btu}{h}$$

The ventilation air supplied to the classrooms has the capacity to condition 11,664 Btu/h of the total 34,560 Btu/h. Therefore the chilled beam must condition the remaining 22,896 Btu/h. Chilled beams are sensible cooling units only. Therefore the latent conditioning must be taken care of by the central air handling unit supplying the ventilation air. The latent load in the classroom is assumed to be 200 Btu/h per person. The latent capacity of the ventilation air is checked against the latent load of the classroom with the same assumptions from the office.

$$\dot{Q}_{L,VA} = 4840\ x\ CFM\ x\ \Delta W$$

$$\dot{Q}_{L,VA} = 4840\ x\ (15\ x\ 36) x\ (0.0102 - 0.006)$$

$$\dot{Q}_{L,VA} = 10{,}977 \frac{Btu}{h} > 7{,}200 \frac{Btu}{hr}$$

The supply ventilation air contains adequate latent cooling capacity to condition the latent load of the classroom. Therefore, the chilled beam needs to have a sensible capacity of at least 22,896 Btu/h. Chilled beams are not manufactured for this high of a cooling capacity so the classrooms will need an array of units unlike the offices. A spreadsheet was not required to determine the capacities and airflows of the classroom units. Rather, it was determined that nine-60 CFM units will serve the largest classrooms and four-90 CFM units would have adequate cooling for the smaller classrooms. Table 28 below provides a summary of the chilled beams from Price Industries that were selected for the classrooms for this analysis.

Space	Primary Airflow (CFM)	Nozzle Diameter (in)	Cooling Capacity (Btu/h)	CHW Flow Rate (GPM)
36-Person Classroom	60	0.31	3,311	1.06
24-Person Classroom	90	0.28	4,574	1.39

Table 28 - Summary of Price Chilled Beams Selected for the Classroom Analysis

Overcooling is not as much of an issue for the classrooms as for the offices. The classrooms are the spaces with the highest occupancies and the highest internal loads, which governs the capability of the central air handling unit to reset the supply air temperature. In other words, if the classroom is being overcooled, the load in the space is not at as high as the air handler is reading and therefore the air handler can raise the supply air temperature. However, because the offices receive ventilation air from the same central air handling units, it is possible for the offices to have a much lower cooling load than the classrooms but still receive high quantities of 55°F air, which can overcool the space. For the sake of simplicity though, the chilled beams in the classroom will also be 4-pipe units. This allows for consistency for the maintenance team as well as the installation team and provides the classrooms with the potential for reheat if necessary.

Dedicated Outdoor Air System (DOAS)

The dedicated outdoor air systems (DOAS) are to replace the existing 25,550 CFM air handling units AHU-2 and AHU-3. The new DOAS units have over one half of the supply air quantity, which will allow for a smaller unit size in the penthouse. First the outdoor design conditions were found for the 1% condition using ASHRAE data for the JFK International Airport weather station in Queens, NY. Table 29 summarizes the outdoor air weather conditions used for sizing the DOAS unit.

Peak WB (°F)	MCDB (°F)	HR (gr/lbm)	Enthalpy (Btu/lbm)
75.8	81.9	125.7	39.1

Table 29 - 1% Design Conditions at JFK Int'l Airport based on Peak WB

Next, the space conditions were determined. Typical indoor conditions in the New York metropolitan area for the summer months are 75 °F with 55% relative humidity. This translates to a humidity ratio of 71.2 grains per pound of dry air. The supply air (SA) conditions are based off of the ventilation air requirements or chilled beam primary air requirements and the critical room latent load. The latent load is a primary driver of the size of the DOAS unit because the unit is the sole location of dehumidification in the system. The equation below was used to determine the lowest supply air humidity ratio between the classroom and the office spaces.

$$W_{SA} = W_{Space} - \frac{\dot{Q}_{Latent}}{0.68\dot{V_{SA}}}$$

$$W_{SA,Classroom} = 71.2\frac{gr}{lbm} - \frac{7{,}200\frac{Btu}{h}}{0.68(540\ CFM)} = 51.6\frac{gr}{lbm}$$

$$W_{SA,Office} = 71.2\frac{gr}{lbm} - \frac{\frac{200Btu}{h}}{0.68(100\ CFM)} = 68.3\frac{gr}{lbm}$$

Therefore, the classrooms have the critical latent load of 51.6 grains of moisture per pound of dry air. Since the DOAS units contain both desiccant and sensible wheels for energy recovery, their effectiveness values are used to determine the air properties at the remaining states of the air handling unit. The equations below are used to determine the temperature and humidity ratio leaving the desiccant wheel.

$$T_2 = T_1 - \varepsilon_S \frac{(\dot{m}C_p)_{min}}{(\dot{m}C_p)_1}(T_1 - T_6)$$

$$W_2 = W_1 - \varepsilon_L \frac{\dot{m}_{min}}{\dot{m}_1}(W_1 - W_6)$$

The sensible and latent effectiveness values were 85.6% and 83.5%, respectively. These values were determined for silica gel desiccant material in the ASHRAE Journal article by Jeong and Mumma. The procedure describe previously is summarized in Figure 13. Each important state point contains the dry bulb temperature, humidity ratio in grains per pound and the enthalpy of the air. States 2 and 3 are used to determine cooling coil capacity of the unit. Figure 13 is a schematic of the DOAS unit during the summer cooling months. The supply fan is located before the cooling coil in order to obtain the maximum amount of cooling possible. The supply fan is assumed to add two degrees to the airstream. The heating coil is used for reheating the air in the even the sensible wheel is not provided adequate reheating capacity.

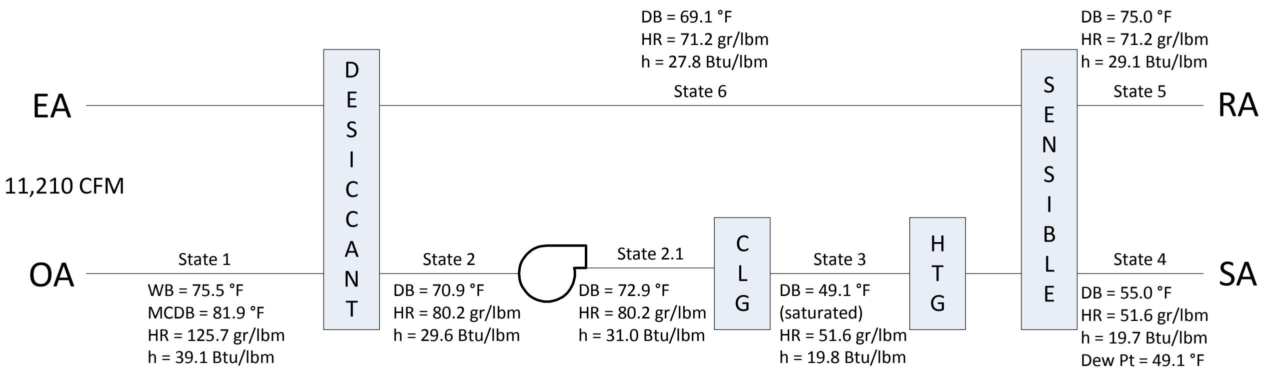


Figure 13 - Schematic of a DOAS Unit

The off-coil air temperature (State 3) is 49.1°F, which is 5.1°F above the entering chilled water temperature. The 5.1°F approach temperature is acceptable for a cooling coil design. A five degree approach temperature difference between the off-coil temperature and the entering water temperature can be achieved with a high quality copper/aluminum coils with multiple passes and rows. The cooling capacity of the coil is determined with the equation below considering the enthalpies before and after the coil and the total air passing over the coil.

$$\dot{Q}_{Cooling\ Coil} = 0.06 \cdot \rho \cdot \dot{V}_{SA} \cdot (h_2 - h_3)$$

$$\dot{Q}_{Cooling\ Coil} = 0.06 \cdot 0.074 \frac{lbm}{ft^3} \cdot 11{,}210\ CFM \ \cdot (31.0 - 19.8 \frac{Btu}{lbm})$$

$$\dot{Q}_{Cooling\ Coil} = 46.5\ tons$$

The cooling coil for this DOAS unit requires 46.5 tons of cooling, which is 50.9% less than the originally design cooling coil for the 25,550 CFM air handling unit AHU-1. The same procedure is used to size the second DOAS unit that requires 14,400 CFM and a cooling capacity of 59.7 tons of cooling. Overall, the two new DOAS units require 43.7% less cooling capacity than the original AHU-2 and AHU-3. However, with the DOAS units, cooling capacity is distributed to the chilled beams throughout the Life Sciences Building.

The operation of the DOAS units will resemble that of a constant volume air handling unit. However, rather than using VAV boxes to modulate air to each space, a 2-way motorized damper, interlocked with an occupancy sensor in the space will control the supply air delivered to the space. Therefore, ideally the system is either in an occupied or unoccupied mode. Because not all faculty and students arrive in the Life Sciences Building at one specific time, the supply fan will be controlled by a variable frequency drive (VFD), which is interlocked with static pressure sensors located approximately two-thirds of the distance down the longest run. This pressure sensor will allow the supply fan to modulate according to the amount of supply air dampers that are opened. So, while the DOAS system resembles that of a constant volume system, the supply fan has the capability of modulating based on the actual number of occupants in the Life Sciences Building.

Chilled Beam Cooling and Heating Operation

The chilled beam cooling operation will utilize its own pump to distribute the processed chilled water to each beam. This is due to the chilled beam requiring a 4°F differential across the heat exchanger. Such a small temperature difference is required in order to maintain turbulent flows through the heat exchanger. If a larger temperature difference were to be used, then the flow requirements through the chilled beams would decrease, which would begin to approach laminar flow conditions and cause the heat exchange process to significantly decrease. As it is, the chilled beams currently require approximately 1.5 GPM per unit and laminar flow conditions begin to occur at 0.5 GPM. Therefore, the design for the chilled water flow to the beams is centered about a 4°F differential. Furthermore, with a chilled water supply temperature of 50°F, the chilled water is 6°F above the dew point temperature of the primary supply air, which is an acceptable cushion to assure no condensation. Nevertheless, condensation sensors will be installed to act as a safety in the event of moisture on the piping.

Due to the need for a different chilled water supply temperature than the cooling coils in the air handling units, the chilled water pumping system is organized in a primary/secondary arrangement and utilizes a mixing valve to modulate the temperature in the processed chilled water loop for the chilled beams. Figure 14 is a schematic of the Life Sciences Building's chilled water system with the processed chilled water loop for the chilled beams.

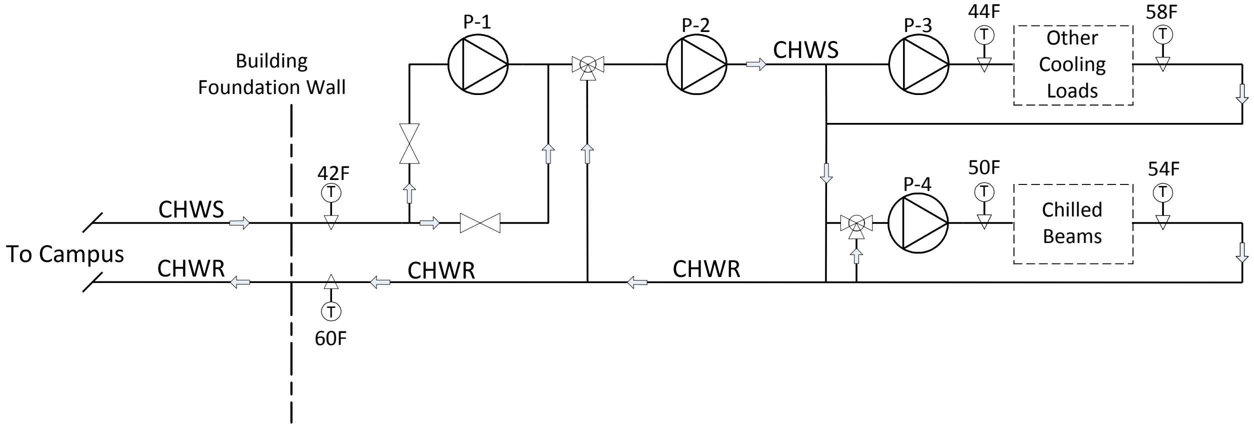


Figure 14 - Chilled Water System Schematic for the Chilled Beam/DOAS System

Pumps P-3 and P-4 are the secondary distribution pumps for the chilled water and processed chilled water loops to the different loads in the building. Pump P-2 is the primary chilled water pump and P-1 is a pressure booster utilized in the event of a pressure drop in the campus chilled water loop.

Regarding the heating operation, the chilled beams were designed for a supply air temperature of 65°F and a 4°F hot water differential. In order to maintain and 85°F off-diffuser temperature, which is recommended for a balance between thermal comfort and to avoid stratification, with a supply air of 65°F, a mean water temperature of 92°F is required. This is much lower than the typical mean water temperature of 170°F. Furthermore, the supply air temperature also has the capability of being reset to a higher temperature, but the air handling unit serves classrooms as well as offices. The high occupancies of the classrooms may prevent higher reset temperatures.

Analysis Conclusion

Energy

Energy cost and consumption are affected in a few different ways with a chilled beam and DOAS system. The quantity of ventilation air greatly reduces with a dedicated outdoor air system, but there is an increase in chilled water flow throughout the building. After adjusting the cooling coil flow rates from the existing design to the new DOAS design and accounting for the new flows from the added chilled beams, there is an 18% increase in chilled water flow in the Life Sciences Building. On the other hand, there is a 49.9% reduction in supply airflow to the Life Sciences Building with the dedicated outdoor air units. More detailed pump and fan calculations were computed in order to determine the energy costs for an entire year.

Pump

To begin the pump energy calculations, a spreadsheet was setup using the outdoor air (OA) dry bulb temperature and the cooling and heating loads from the design calculations from the engineer for 8,760 hours. The VAV pump is the originally designed pump for the chilled water system; the heating pump was not considered for this analysis. It is assumed that the hot water consumption will remain the same and the chilled beam would simply replace the finned tube radiation. The flow rate for the pump is calculated using the following equation.

$$\dot{Q} = 500 \cdot GPM \cdot \Delta T$$

The change in temperature is designed to be 14°F, with a chilled water supply at 44°F and the return at 58°F for the cooling coils in the dedicated outdoor air units and 4°F for the chilled beams with a supply of 50°F and a return of 54°F. A schedule was created within the spreadsheet stating the chilled water pump is operating between the hours of 7 am and 5pm, which is in conjunction with the design assumptions. The DOAS and CB pumps the new pump selected for the chilled beam and DOAS system. The DOAS and CB pump flow rates were determined by a relationship to the cooling load and required flow rate needed to meet the load. The VAV, DOAS and CB pump power values were calculated using Engineering Equation Solver (EES) with multivariable regressions and then imported into this spreadsheet for completeness. Table 30 is a brief segment of the spreadsheet.

Month	Day	Hour	OA DB (°F)	Cooling Load (tons)	VAV Pump Flow (GPM)	VAV Pump Power (kW)	DOAS Pump Flow (GPM)	DOAS Pump Power (kW)	CB Pump Flow (GPM)	CB Pump Power (kW)
Jul	1	6	69	1.36	0.00	0	0.00	0	0.00	0
Jul	1	7	72	3.07	5.26	2.766	4.02	2.85	14.34	1.405
Jul	1	8	75	7.77	13.32	2.732	10.18	2.835	36.28	1.377
Jul	1	9	78	11.63	19.94	2.7	15.23	2.825	54.31	1.36
Jul	1	10	78	12.28	21.05	2.694	16.08	2.823	57.34	1.357
Jul	1	11	81	11.38	19.51	2.699	14.90	2.825	53.14	1.361
Jul	1	12	79	9.34	16.01	2.686	12.23	2.82	43.61	1.36
Jul	1	13	78	9.2	15.77	2.679	12.05	2.821	42.96	1.361
Jul	1	14	80	9.95	17.06	2.674	13.03	2.818	46.46	1.357
Jul	1	15	78	10.62	18.21	2.665	13.91	2.815	49.59	1.354
Jul	1	16	76	11.18	19.17	2.656	14.64	2.813	52.21	1.352
Jul	1	17	73	10.74	18.41	2.66	14.07	2.815	50.15	1.354
Jul	1	18	72	9.55	16.37	2.672	12.51	2.819	44.60	1.359
Jul	1	19	71	6.95	0.00	0	0.00	0	0.00	0

Table 30 - Spreadsheet Pump Segment from July 1st Hours 6 – 19

The multivariable regressions created for EES stemmed from the pump curves for the selected pumps for the Life Sciences Building. Figure 15 is the pump curve for the originally designed VAV system chilled water pump.

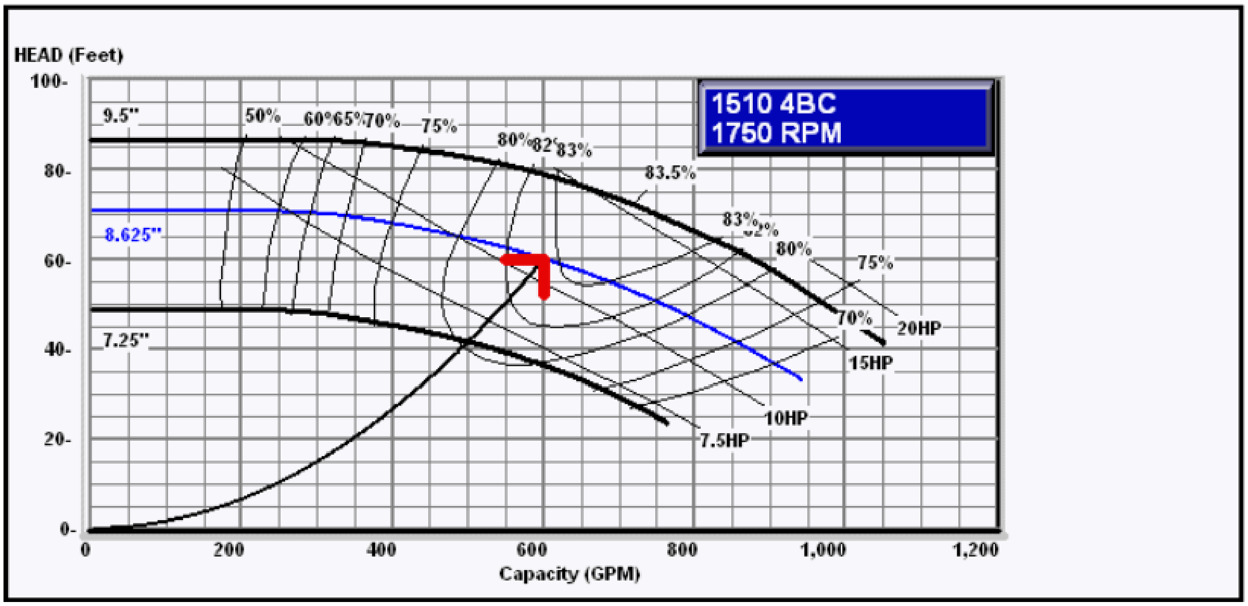


Figure 15 – 15 HP Pump Curve from Bell & Gossett

Following the system curve, pressure head was plotted as a function of flow rate because in a variable flow system, system head is equal to pump head. Next, pump efficiency along the pump curve was plotted as a function of flow rate. Both of these equations are used with the affinity laws to solve for unknown variables. The equations below with general variables illustrate the form of the functions used, where a and b are regression coefficients and N_0 is the design RPM (1750). Furthermore, the system curve is modeled using a similar equation based on known design factors.

$$H_{pump}(Q,N) = \left[a_1 + a_2\left(\frac{N_0Q}{N}\right) + a_3\left(\frac{N_0Q}{N}\right)^2 + a_4\left(\frac{N_0Q}{N}\right)^3 + a_5\left(\frac{N_0Q}{N}\right)^4\right] \cdot \left(\frac{N^2}{N_0^2}\right)$$

$$\eta_{pump}(Q,N) = b_1 + b_2\left(\frac{N_0Q}{N}\right) + b_3\left(\frac{N_0Q}{N}\right)^2 + b_4\left(\frac{N_0Q}{N}\right)^3 + b_5\left(\frac{N_0Q}{N}\right)^4$$

$$H_{system} = H_{fixed} + \left(\frac{Q}{Q_{design}}\right)^2 \cdot (H_{design} - H_{fixed})$$

Regressions were also created for motor efficiencies and variable frequency drive efficiencies and used in conjunction with pump efficiency to determine the overall pump system efficiency. The total efficiency value is used in the pump power equation to determine the total amount of energy needed to run the pump. The pump power equation is found below.

$$\eta_{total} = \eta_{pump} \cdot \eta_{motor} \cdot \eta_{drive}$$

$$P_{total}[HP] = \frac{Q \cdot H_{pump}}{3960 \cdot \eta_{total}}$$

The P_{total} equation is solved for each of the 8760 hours in the year for the flow rates determined in the spreadsheet. After calculating the total pump power for each hour of the year, the power was summed for all 8760 hours to acquire the total kilowatt-hours needed for the chilled water pump. The same procedure was followed for the new DOAS and CB pumps to determine the new power requirements. A B&G 1510 4BC model pump was selected for the DOAS pump and a B&G 1510 2-1/2BB model in order to maintain consistency in the analysis.

It is determined from this analysis that the new DOAS and CB pumps would require 6,108 kWh and 3,265 kWh of electricity respectively, which is a 46% increase from the 6,420 kWh required for the originally designed VAV pump. In terms of dollars, DOAS and CB pumps have an annual pump electricity cost of $575 and $400 respectively as opposed to the VAV pump, which cost $592 annually. This equates at a 65% increase in pump energy cost over the entire year. Figure 16 below is a chart comparing the monthly costs for VAV system and chilled beam/DOAS system pumps. While there is an increase in annual pump energy cost, the difference is in terms of hundreds of dollars. The fan cost savings will be in the thousands of dollars, which will make the increase in pump energy cost insignificant.

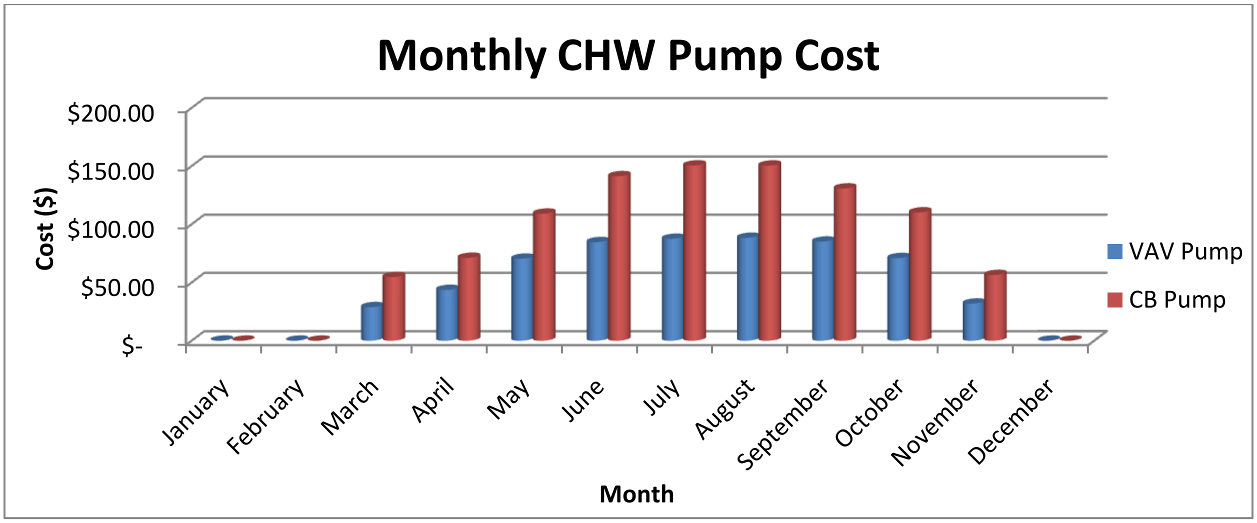


Figure 16 – Monthly Chilled Water Pump Costs Comparison Between 15 HP and 20 HP Pumps

Fan

The same spreadsheet that was used to set up the pump energy analysis was also used for fan energy. The hourly loads were used to determine the airflow quantities for each hour for the original design. The airflows for the DOAS design were treated as a constant volume system, for simplicity. The flow rate for the originally designed 32” diameter fan was calculated using the following equation:

$$\dot{Q} = 1.08 \cdot CFM \cdot \Delta T$$

The change in temperature was designed to be 20 °F, with a supply temperature of 55 °F and the return at 75 °F. A schedule was created within the spreadsheet stating the ventilation system operating between the hours of 7 am and 5pm, which is in conjunction with the design assumptions. A 22” diameter fan was selected for the DOAS unit. Both the 32” and 22” fans are the same model, just different sizes for simplicity. However, one small change was made when selecting the new 22” fan. Because of the addition of chilled beams to the system, the total static pressure of the fan will increase. Chilled beams rely on a greater pressure difference than VAV boxes to induce room air. For Price chilled beams, the pressure across a unit can be nearly 0.8 in. Wg., which increased the overall fan static from 5.68” to 6.0”. Similar to the pump analysis, multivariable regressions were created from the fan curves in order to determine the hourly power consumption values. The hourly power values were returned to the spreadsheet to determine cost differences.

Month	Day Type	Day	Hour	OA Dry Bulb (°F)	Cooling Load (tons)	Heating Load (MBH)	32” Fan SA (CFM)	32” Fan Power (kW)	22” Fan SA (CFM)	22” Fan Power (kW)
Jul	Sat	1	6	69	24.48	0	7665	1.155	0	0
Jul	Sat	1	7	72	25.34	0	7665	1.155	11210	4.999
Jul	Sat	1	8	75	39.01	0	7665	1.155	11210	4.999
Jul	Sat	1	9	78	55.37	0	10458	2.002	11210	4.999
Jul	Sat	1	10	78	59.29	0	11199	2.287	11210	4.999
Jul	Sat	1	11	81	56.12	0	10600	2.054	11210	4.999
Jul	Sat	1	12	79	46.84	0	8847	1.473	11210	4.999
Jul	Sat	1	13	78	50.71	0	9578	1.698	11210	4.999
Jul	Sat	1	14	80	53.08	0	10026	1.848	11210	4.999
Jul	Sat	1	15	78	58.4	0	11031	2.22	11210	4.999
Jul	Sat	1	16	76	64.44	0	12172	2.707	11210	4.999
Jul	Sat	1	17	73	61.63	0	11641	2.472	11210	4.999
Jul	Sat	1	18	72	54.71	0	10334	1.956	11210	4.999
Jul	Sat	1	19	71	43.89	0	8290	1.316	0	0

Table 31 – Spreadsheet Fan Segment from July 1st Hours 6 – 19

The multivariable regressions created for EES originate from the fan curves for the selected fan in AHU-1 for the Life Sciences Building. Figure 17 is the curve for the originally designed 32” fan.

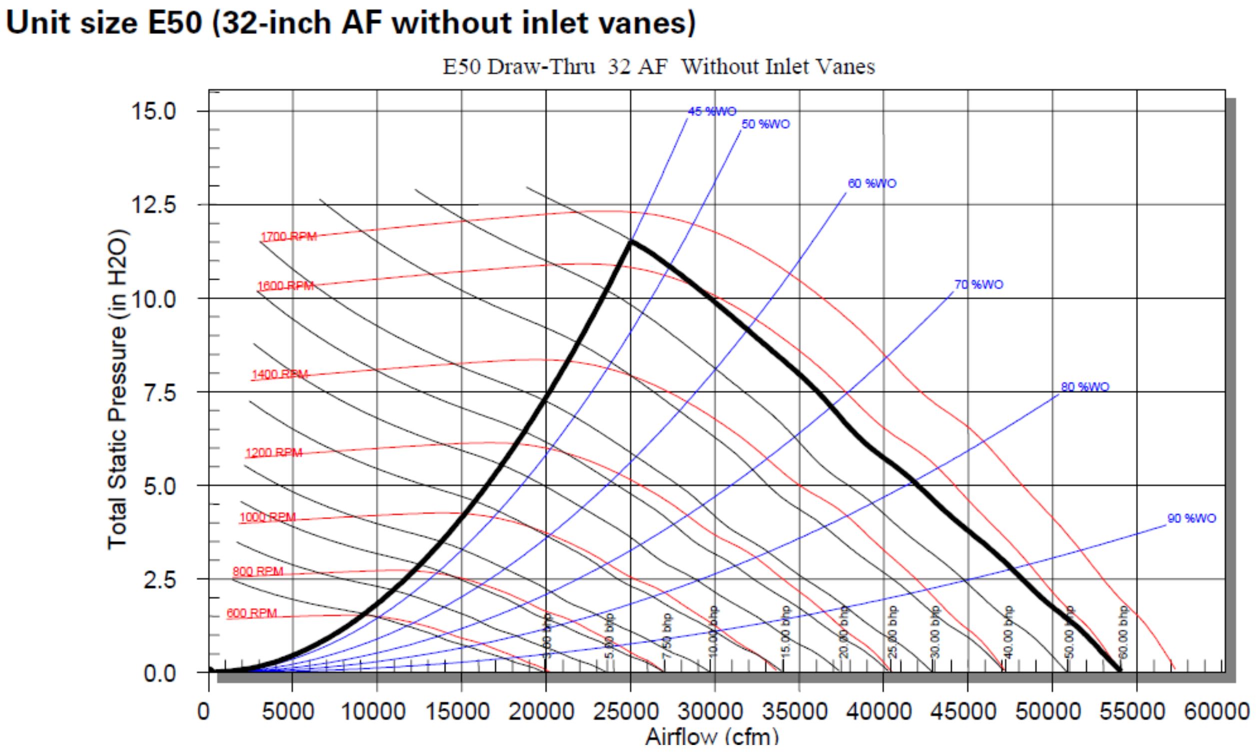


Figure 17 - Fan Curve from Trane M-Series Catalog

The equations used to model the fan energy are similar to those of the pump. However, different laws were used based on the information that was retrieved from the fan curve. First, a parabolic-shaped system curve was overlaid on the fan curve and a pressure versus flow rate regression was created. Second, following the system curve again, shaft power was plotted against flow rate. The two regressions created resembled the equations below:

$$P_{fan}[in.Wg.] = \left[c_1 + c_2\left(\frac{N_0Q}{N}\right) + c_3\left(\frac{N_0Q}{N}\right)^2 + c_4\left(\frac{N_0Q}{N}\right)^3 + c_5\left(\frac{N_0Q}{N}\right)^4\right] \cdot \left(\frac{N^2}{N_0^2}\right)$$

$$\dot{W}_{shaft}[BHP] = \left[d_1 + d_2\left(\frac{N_0Q}{N}\right) + d_3\left(\frac{N_0Q}{N}\right)^2 + d_4\left(\frac{N_0Q}{N}\right)^3 + d_5\left(\frac{N_0Q}{N}\right)^4\right] \cdot \left(\frac{N^3}{N_0^3}\right)$$

In the equations above, c and d are regression coefficients and N_0 is the design RPM. Q is determined from the spreadsheet and N is the unknown variable to be solved. Just like for the pump analysis, regressions were also created for motor efficiencies and variable frequency drive efficiencies. However, for the fan analysis, total efficiency is solved for with the use of shaft power. Total power is solved for with total efficiency and shaft power. The equations are summarized below.

$$\eta_{total} = \frac{Q \cdot \Delta P}{6350 \cdot \dot{W}_{shaft}}$$

$$\dot{W}_{total}[HP] = \dot{W}_{shaft} \cdot \eta_{total}$$

The total power equation is solved for each of the 8760 hours for each of the flow rates provided for the 32” fan. The hourly power consumption is summed to give the annual kilowatt-hour requirement of the fan. The entire procedure is then repeated for the DOAS 22” fan.

It is determined that the AHU-1, 32” fan supply fan requires 29,781 kilowatt-hours of electricity consumption per year as opposed to the 18,246 kilowatt-hours needed for the smaller DOAS fan. This equates to a 38.7% reduction in fan energy requirements. Assuming the return/exhaust fans are exactly the same as the supply fans, AHU-1 and the DOAS systems utilize 59,562 and 36,492 kilowatt-hours of energy respectively. In terms of dollars, the annual fan energy costs $4,209 and $2,580 for AHU-1 and the DOAS system respectively. This is a 38.7% reduction in fan electricity costs or a savings of $1,629 per air handling unit. Furthermore, AHU-1 and AHU-2 are replaced by two DOAS systems and therefore would save $3,258. Figure 18 below provides a visual chart for steady DOAS fan cost compared to the spiking air handling unit fan cost. Furthermore, the fan savings far outweighs the increase in pumping cost. It is also interesting to note that the fan savings is significant in spite of the 5% increase in static pressure.

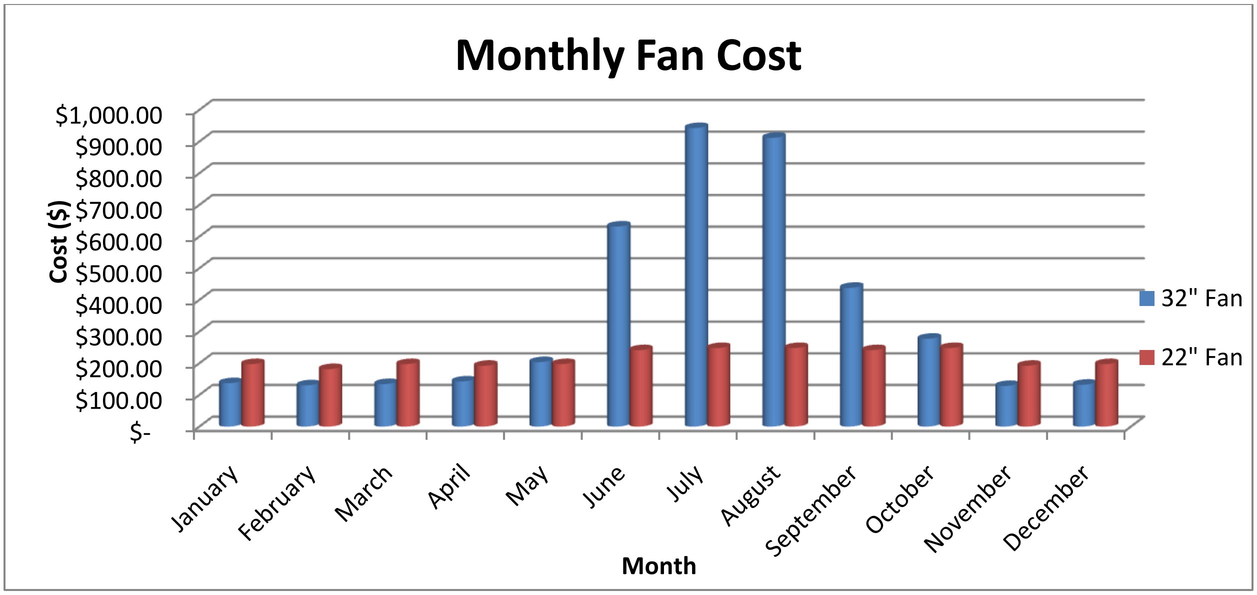


Figure 18 - Monthly Fan Costs Comparison 32” and 22” Fans

Chilled Water

On top of the adjustments to the electricity costs between the pumps and fans, there is a change in the chilled water flow and therefore a change in the annual purchased chilled water cost. Figure 19 below provides an illustration of the monthly chilled water costs between the two systems, VAV and chilled beam/DOAS. The change in chilled water flow is a significant issue because of the high cost of chilled water per therm.

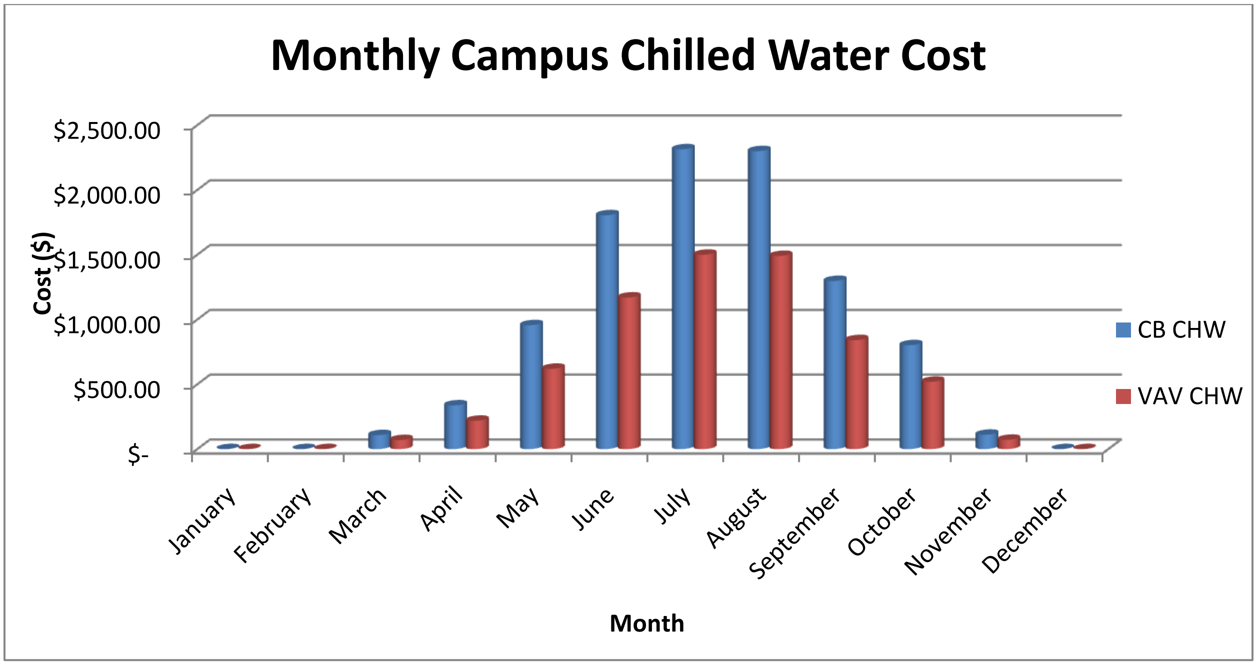


Figure 19 – Monthly Campus Chilled Water Cost

Overall, including purchased chilled water, pump and fan electricity changes, the annual energy cost for chilled beam/DOAS system is 54% more than the VAV system with terminal reheat. The need for more chilled water for the chilled beam/DOAS system causes the annual energy cost to rise above that of the VAV system.

First Cost

For a first cost comparison, only the elements from the original design that are to be affected by the chilled beam and DOAS system redesigns were included in the cost analysis. The labor and material cost data used in this analysis were provided by Cannon Design in the construction document cost estimate. For the chilled beam and dedicated outdoor air unit, cost information was provided by Price for the chilled beams and RS Means for supplementary equipment. For this analysis, it is assumed that the controls from the originally designed finned tube radiation and VAV boxes amount to the same cost as the controls for the chilled beams. Table 32 and Table 33 are summaries of first cost information for the original and new designs.

Item Description	Quantity		Total		
			Unit Cost		Amount
26,000 CFM AHU	2.00	/EA	$ 106,395.79	/EA	$ 212,792
Rectangular Supply Duct	36,585	/LB	$ 11.95	/LB	$ 437,306
Rectangular Return Duct	16,147	/LB	$ 11.95	/LB	$ 193,009
VAV Boxes w/ Reheat	59.00	/EA	$ 1,280.65	/EA	$ 75,559
Supply Air Diffuser	187.00	/EA	$ 202.27	/EA	$ 37,824
Return Air Diffuser	126.00	/EA	$ 202.27	/EA	$ 25,486
Finned Tube Radiation	1,780.00	/FT	$ 97.20	/FT	$ 173,023
Finned Tube Hook-Up	65.00	/EA	$ 715.13	/EA	$ 46,483
Finned Tube Insulation	65.00	/EA	$ 137.21	/EA	$ 8,919
15 HP Centrifugal Pumps	4.00	/EA	$ 7,276.96	/EA	$ 29,108
15 HP VFD	4.00	/EA	$ 3,617.75	/EA	$ 14,471
Total					$ 1,253,980

Table 32 – VAV Design First Cost Information

Item Description	Quantity		Total		
			Unit Cost		Amount
15,000 CFM AHU	2.00	/EA	$ 25,750.00	/EA	$ 51,500
Rectangular Supply Duct	18,293	/LB	$ 11.95	/LB	$ 218,653
Rectangular Return Duct	8,074	/LB	$ 11.95	/LB	$ 96,505
VAV Boxes w/ Reheat	14.00	/EA	$ 1,280.65	/EA	$ 17,929
Chilled Beams	203.00	/EA	$ 1,448.60	/EA	$ 294,066
3/4" Copper Type L	3,000.00	/LF	$ 29.39	/EA	$ 88,170
1" Copper Type L	1,000.00	/LF	$ 33.76	/EA	$ 33,764
Supply Air Diffuser	39.00	/EA	$ 202.27	/EA	$ 7,889
Return Air Diffuser	126.00	/EA	$ 202.27	/EA	$ 25,486
15 HP Centrifugal Pumps	2.00	/EA	$ 5,150.00	/EA	$ 20,600
15 HP VFD	2.00	/EA	$ 3,180.00	/EA	$ 12,720
7.5 HP Centrifugal Pumps	2.00	/EA	$ 10,065.00	/EA	$ 20,130
7.5 HP VFD	2.00	/EA	$ 2,753.81	/EA	$ 5,508
Desiccant Wheel	2.00	/EA	$ 24,275.00	/EA	$ 48,550
Sensible Wheel	2.00	/EA	$ 24,275.00	/EA	$ 48,550
Total					$ 1,000,278

Table 33 – Chilled Beam/DOAS First Cost Information

The first cost with the chilled beam and DOAS redesign is expected to be 20.2% less than the VAV system first cost. This equates to a savings of $253,703. The major components that allow for cost savings are the radical decrease in air handling unit size, which decreases the cost by approximately $100,000. Furthermore, there will be no finned tube radiation in the chilled beam design. The chilled beam performs heating and cooling in one single unit. The chilled beams allow for smaller ductwork, less supply diffusers and no VAV boxes where the beams are to be used.

The decrease in supply ductwork raises the concern of economizer mode capabilities. Typically, ductwork needs to be larger to handle 100% outdoor air without mechanical cooling. However, according to section 803.2.6 in the 2007 New York State Energy Conservation Code the use of an economizer capable of operating with 100% outdoor air even if mechanical cooling is required to meet the cooling load is acceptable.

Life Cycle Cost

A 30-year, life cycle cost analysis was performed in order to compare the VAV and chilled beam/DOAS system. Cost escalation factors were obtained from the National Institute of Standards and Technology (NIST) *Energy Prince Indices and Discount Factors for Life-Cycle Cost Analysis – 2010*. The NIST Supplement provides escalation factors for primary fuels and electricity but not for purchased utilities such as hot and chilled water. Therefore, since the Central Utility Plant burns natural gas to operate steam-driven, centrifugal chillers, it will be assumed for this analysis that the cost escalation of purchased chilled water will vary proportionally to the cost of natural gas. This is assumption is loosely defined because the cost of purchased chilled water also includes the cost of equipment and labor, which may not vary as drastically as natural gas with changes in inflation. However, for the purposes of this analysis, natural gas escalation factors will be used. Furthermore, electricity escalation factors will be used to adjust the costs of operating the pumps and fans. Table 34 and Table 35 summarize the initial values used to begin the life-cycle analysis.

Annual CHW Energy (MMBtu)	Annual CHW Cost ($)	Annual Elec. Energy (kWh)	Annual Elec. Cost ($)	OMB Base Discount Rate (%)
520.27	6,503	65,982	4,800	2.7

Table 34 – Input Values for VAV Life Cycle Cost Analysis

Annual CHW Energy (MMBtu)	Annual CHW Cost ($)	Annual Elec. Energy (kWh)	Annual Elec. Cost ($)	OMB Base Discount Rate (%)
802.4	10,030	45,866	3,555	2.7

Table 35 - Input Values for Chilled Beam/DOAS Life Cycle Cost Analysis

A spreadsheet was set up to calculate the total net present value (NPV) of the 30-year life cycle of each system. The 30-year life cycle includes the assumption of $1,000 per year for maintenance for both the VAV and chilled beam/DOAS systems. The analysis includes the first costs for each of the systems as the initial capital investment. Table 36 and Table 37 are the spreadsheets used to determine the total NPV of the life cycle of each system.

Analysis Year	Year	Initial Capital	Other Maint.	Nat Gas Esc.	Base CHW Cost	Elec. Esc.	Base Elec. Cost
1	2011	$ 1,253,980	$ 1,000	1.07	$ 6,958.62	0.90	$ 4,320.12
2	2012	$ -	$ 1,000	1.13	$ 7,348.83	0.92	$ 4,416.12
3	2013	$ -	$ 1,000	1.13	$ 7,348.83	0.94	$ 4,512.12
4	2014	$ -	$ 1,000	1.11	$ 7,218.76	0.93	$ 4,464.12
5	2015	$ -	$ 1,000	1.11	$ 7,218.76	0.92	$ 4,416.12
6	2016	$ -	$ 1,000	1.12	$ 7,283.79	0.93	$ 4,464.12
7	2017	$ -	$ 1,000	1.12	$ 7,283.79	0.95	$ 4,560.12
8	2018	$ -	$ 1,000	1.12	$ 7,283.79	0.95	$ 4,560.12
9	2019	$ -	$ 1,000	1.12	$ 7,283.79	0.96	$ 4,608.12
10	2020	$ -	$ 1,000	1.13	$ 7,348.83	0.97	$ 4,656.12
11	2021	$ -	$ 1,000	1.14	$ 7,413.86	0.98	$ 4,704.13
12	2022	$ -	$ 1,000	1.16	$ 7,543.93	0.99	$ 4,752.13
13	2023	$ -	$ 1,000	1.17	$ 7,608.96	1.00	$ 4,800.13
14	2024	$ -	$ 1,000	1.17	$ 7,608.96	1.01	$ 4,848.13
15	2025	$ -	$ 1,000	1.18	$ 7,674.00	1.01	$ 4,848.13
16	2026	$ -	$ 1,000	1.19	$ 7,739.03	1.01	$ 4,848.13
17	2027	$ -	$ 1,000	1.20	$ 7,804.06	1.02	$ 4,89613
18	2028	$ -	$ 1,000	1.22	$ 7,934.13	1.03	$ 4,944.13
19	2029	$ -	$ 1,000	1.25	$ 8,129.23	1.05	$ 5,040.13
20	2030	$ -	$ 1,000	1.28	$ 8,324.33	1.06	$ 5,088.14
21	2031	$ -	$ 1,000	1.31	$ 8,519.44	1.08	$ 5,184.14
22	2032	$ -	$ 1,000	1.33	$ 8,649.50	1.10	$ 5,280.14
23	2033	$ -	$ 1,000	1.33	$ 8,649.50	1.12	$ 5,376.14
24	2034	$ -	$ 1,000	1.35	$ 8,779.57	1.13	$ 5,424.14
25	2035	$ -	$ 1,000	1.36	$ 8,844.61	1.14	$ 5,472.15
26	2036	$ -	$ 1,000	1.38	$ 8,974.67	1.15	$ 5,520.15
27	2037	$ -	$ 1,000	1.39	$ 9,039.71	1.15	$ 5,520.15
28	2038	$ -	$ 1,000	1.41	$ 9,169.77	1.16	$ 5,568.15
29	2039	$ -	$ 1,000	1.43	$ 9,299.84	1.17	$ 5,616.15
30	2040	$ -	$ 1,000	1.44	$ 9,364.88	1.17	$ 5,616.15
Column Total		$ 1,253,980	$ 30,000		$ 239,649.79		$ 148,324
Column NPV		$ 1,221,013	$ 29,211		$ 233,349.36		$ 144,424
			Total NPV		**$ 1,627,998**		

Table 36- Life Cycle Cost Analysis Spreadsheet for the VAV System

Analysis Year	Year	Initial Capital	Other Maint.	Nat Gas Esc.	Base CHW Cost	Elec. Esc.	Base Elec. Cost
1	2011	$ 1,000,278	$ 1000	1.07	$ 10,732.13	0.90	$ 3,199.47
2	2012	$ -	$ 1,000	1.13	$ 11,333.94	0.92	$ 3,270.57
3	2013	$ -	$ 1,000	1.13	$ 11,333.94	0.94	$ 3,341.67
4	2014	$ -	$ 1,000	1.11	$ 11,133.34	0.93	$ 3,306.12
5	2015	$ -	$ 1,000	1.11	$ 11,133.34	0.92	$ 3,270.57
6	2016	$ -	$ 1,000	1.12	$ 11,233.64	0.93	$ 3,306.12
7	2017	$ -	$ 1,000	1.12	$ 11.233.64	0.95	$ 3,377.22
8	2018	$ -	$ 1,000	1.12	$ 11,233.64	0.95	$ 3,377.22
9	2019	$ -	$ 1,000	1.12	$ 11,233.64	0.96	$ 3,412.77
10	2020	$ -	$ 1,000	1.13	$ 11,333.94	0.97	$ 3,448.32
11	2021	$ -	$ 1,000	1.14	$ 11,434.24	0.98	$ 3,483.87
12	2022	$ -	$ 1,000	1.16	$ 11,634.84	0.99	$ 3,519.42
13	2023	$ -	$ 1,000	1.17	$ 11,735.14	1.00	$ 3,554.97
14	2024	$ -	$ 1,000	1.17	$ 11,735.14	1.01	$ 3,590.52
15	2025	$ -	$ 1,000	1.18	$ 11,835.44	1.01	$ 3,590.52
16	2026	$ -	$ 1,000	1.19	$ 11,935.74	1.01	$ 3,590.52
17	2027	$ -	$ 1,000	1.20	$ 12,036.04	1.02	$ 3,626.06
18	2028	$ -	$ 1,000	1.22	$ 12,236.04	1.03	$ 3,661.61
19	2029	$ -	$ 1,000	1.25	$ 12,537.54	1.05	$ 3,732.71
20	2030	$ -	$ 1,000	1.28	$ 12,838.44	1.06	$ 3,768.26
21	2031	$ -	$ 1,000	1.31	$ 13,139.34	1.08	$ 3,839.36
22	2032	$ -	$ 1,000	1.33	$ 13,339.94	1.10	$ 3,910.46
23	2033	$ -	$ 1,000	1.33	$ 13,339.94	1.12	$ 3,981.56
24	2034	$ -	$ 1,000	1.35	$ 13,540.54	1.13	$ 4,017.11
25	2035	$ -	$ 1,000	1.36	$ 13,640.84	1.14	$ 4,052.66
26	2036	$ -	$ 1,000	1.38	$ 13,841.44	1.15	$ 4,088.21
27	2037	$ -	$ 1,000	1.39	$ 13,941.74	1.15	$ 4,088.21
28	2038	$ -	$ 1,000	1.41	$ 14,142.34	1.16	$ 4,123.76
29	2039	$ -	$ 1,000	1.43	$ 14,342.95	1.17	$ 4,159.31
30	2040	$ -	$ 1,000	1.44	$ 14,443.25	1.17	$ 4,159.31
Column Total		$ 1,000,278	$ 30,000		$ 369,607		$ 109,848
Column NPV		$ 973,980	$ 29,211		$ 359,890		$ 106,961
			Total NPV		**$ 1,470,042**		

Table 37 - Life Cycle Cost Analysis Spreadsheet for the Chilled Beam/DOAS System

The total NPV for the VAV and chilled beam/DOAS systems are $1,627,998 and $1,470,042, respectively. This equates to a $157,957 or 9.7% savings over the life cycle of a chilled beam/DOAS system if the Life Sciences Building were to use a chilled beam/DOAS system rather than a VAV with terminal reheat system. It is interesting to note that the chilled beam/DOAS system proves to be the better option over the VAV system in spite of the fact that it consumes more energy annually.

Depth 2: Chiller Plant

Currently the Life Sciences Building utilizes Nassau County's chilled water system. The chilled water is created at the Central Utility Plant (CUP) run by Nassau Energy Corporation. However, the campus chilled water system is reaching maximum capacity. Therefore, a hypothetical chiller plant was created for the Life Sciences Building and a study was performed between two pumping arrangements: primary/secondary (P/S) configuration and variable primary flow (VPF).

Primary/secondary pumping design is the typical for chiller plants in the past. The arrangement calls for two sets of chilled water pumps. One set provides a constant volume of flow in a loop through the chiller, which allows the chiller to operate at its design efficiency. The second set of variable speed pumps delivers chilled water to the load and flow varies with demand. The P/S pumping configuration became popular because chillers did not have the technology to reduce flow through the evaporator while maintaining a respectable kilowatt per ton ratio. An alternative to the P/S arrangement is variable primary flow.

Variable primary flow is becoming popular because it solves issues with low ΔT syndrome as well as reducing energy consumption in a chiller plant. Variable primary flow is organized with one set of chilled water pumps that serve both the load and the chiller. The pumps are controlled with variable frequency drives that allow the pump to slow down chilled water flow as the demand for flow decreases. New chillers have the ability to turn down evaporator flow to as much as 10% of the design capacity. The decrease in chilled water flow saves pump energy within the plant, which, studies show, can equate to approximately 5% of total energy cost. A low-flow bypass is installed to decouple the pumps from the chiller in the event that chilled water demand is below the minimum turn down on the chiller. VPF systems also benefit in first cost due to the need for only one set of pumps.

Analysis Procedure

The analysis of the new chiller plant for the Life Sciences Building started with the selection of a chiller and cooling tower to satisfy the loads of the building. The cooling loads and chilled water flow rates used for the selection of equipment and the analysis are taken from the design documents. Carrier and Marley were consulted for the selection of the chiller and cooling tower. Table 38 and Table 39 below are schedules of the chiller and cooling tower used for this analysis.

Unit No.	Chiller Type	Capacity (Tons)	EIR (kW/Ton)	Evaporator				Condenser			
				Capacity (GPM)	EWT (°F)	LWT (°F)	ΔP (ft)	Capacity (GPM)	EWT (°F)	LWT (ºF)	ΔP (ft)
CH-1	Screw	267.4	0.709	534.8	44	56	18.5	802.1	85	95	25.1

Table 38 - Chiller Schedule

Unit No.	System	Capacity (GPM)	WB (°F)	Min LWT (°F)	Fan Power (HP)
CT-1	Chiller CH-1	810	75.8	70	25

Table 39 - Cooling Tower Schedule

New pumps were also selected for the two different chiller plant configurations. The P/S system requires a primary pump, secondary pump and condenser water pump. The VPF arrangement needs a primary pump as well as a condenser water pump. The condenser water pumps are exactly the same in both systems, and do not have an effect on the chilled water pumping system. However, they are used to gather a more accurate prediction of the energy consumption of a chiller plant in the Life Sciences Building. Table 40 below is a pump schedule for the various pumps used in this study. The schedule includes pumps for both the P/S and VPF studies as well as the standby pumps. The standby pumps were not used in the study for energy consumption, but were accounted for in the first cost analysis. All pumps were selected from Bell & Gossett's 1510 series in order to maintain consistency with the other pumps in the Life Sciences Building.

Unit No.	System	Capacity (GPM)	Head (ft)	Efficiency (%)	Pump Size		Motor	
					Suction (in)	Discharge (in)	BHP	HP
P-12	Condenser Water	810	60	82.72	5	4	14.78	20
P-13	Condenser Water	810	60	82.72	5	4	14.78	20
P-14	Primary Chilled Water	550	30	80.03	5	4	5.24	7.5
P-15	Primary Chilled Water	550	30	80.03	5	4	5.24	7.5
P-16	Secondary Chilled Water	550	60	82.01	5	4	10.18	15
P-17	Secondary Chilled Water	550	60	82.01	5	4	10.18	15
P-18	VPF Chilled Water	550	60	82.01	5	4	10.18	15
P-19	VPF Chilled Water	550	60	82.01	5	4	10.18	15

Table 40 - Chiller Plant Pump Schedule

All pumps in Table 40 are also included in the following schematics for both the primary/secondary and variable primary flow systems. Figure 20 and Figure 21 below are schematics of the P/S and VPF systems, respectively. Each schematic illustrates both the chilled water flow and condenser water flow through the pieces of equipment.

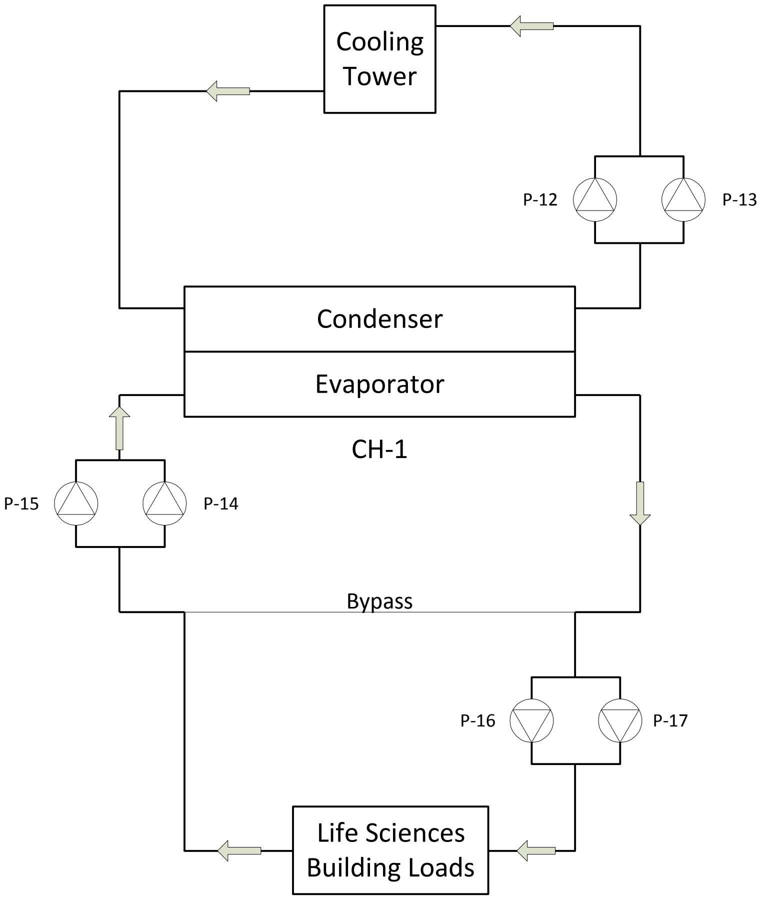


Figure 20 - Primary/Secondary Schematic

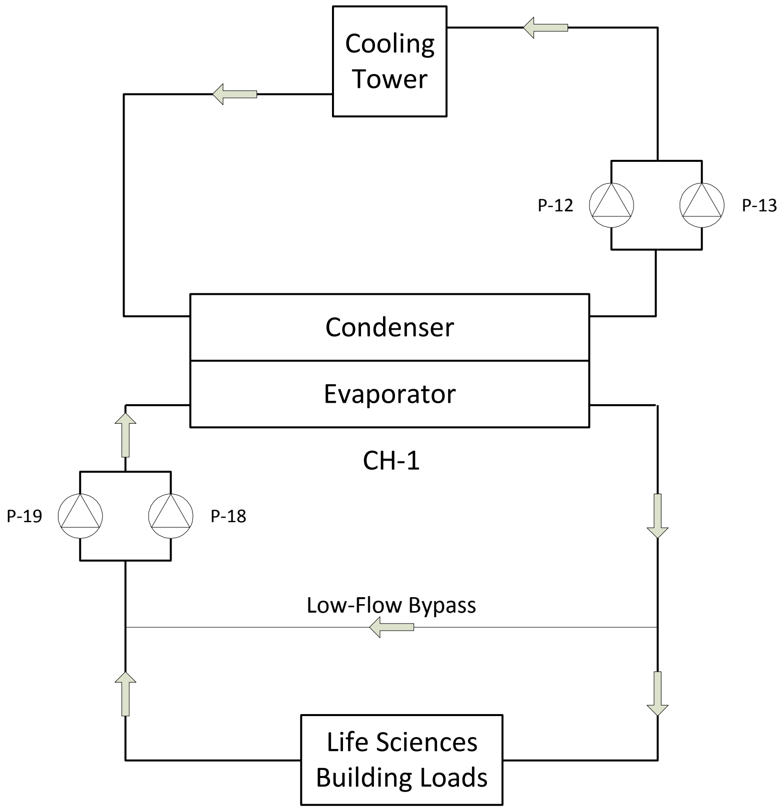


Figure 21 - Variable Primary Flow Schematic

The cooling tower, chiller and each pump were modeled in Engineering Equation Solver (EES) in order to determine the power consumption of the chiller plant. The cooling tower curves generated by Marley for operation at 100% and 50% fan power were used to create regressions to determine the condenser water temperature for a given wet bulb temperature. Figure 22 below is a cooling tower curve produced by Marley selection software for the cooling tower selected for this analysis. The curve has a design point of 75.8°F wet bulb temperature (the 1% design condition for JFK International Airport in Queens, NY) and a cold water temperature of 85°F at tower water flow of 802.1 gallons per minute and 100% of fan power. The three lines are curves for different ranges; 8°F, 10°F and 12°F for curves 1, 2 and 3 respectively. The same curve is generated for the same design conditions, but the fan speed it at 50% of full power.

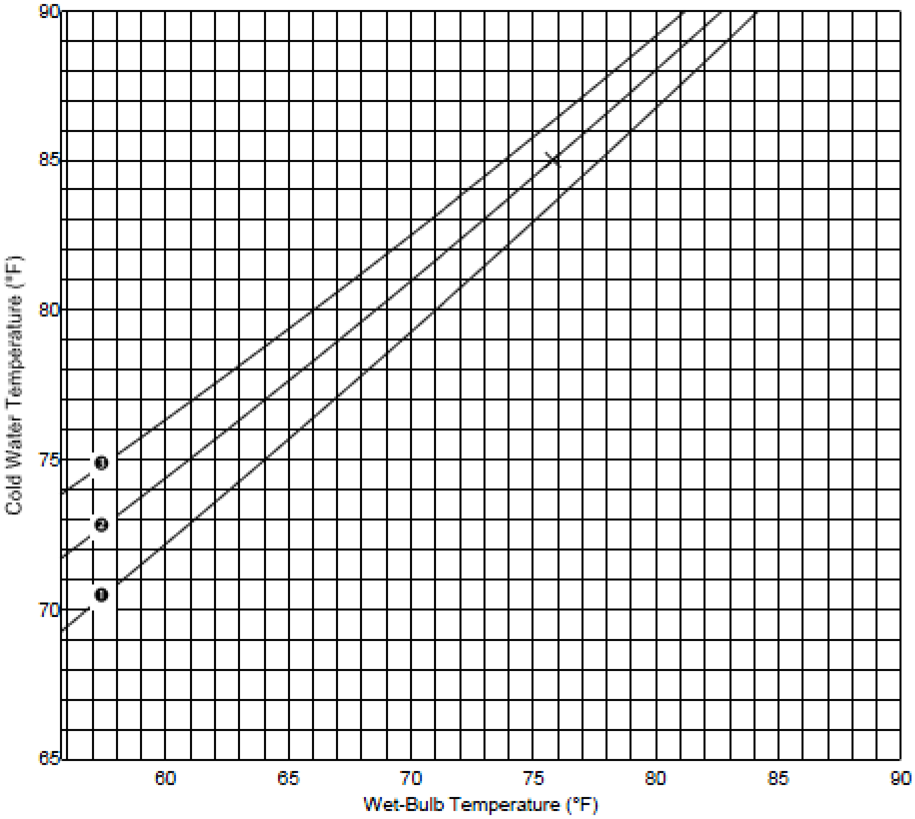


Figure 22 - Cooling Tower Curve at 100% Fan Operation From Marley

Both of the 100% and 50% fan power curves are used to create regressions. The regressions are made from plotting points along each range curve. Each range curve will generate an equation for condenser water temperature as a function of wet bulb temperature in the form of the one below:

$$T_{CW,R_1}(T_{WB}) = a_1 + b_1 \cdot T_{WB} + c_1 \cdot T_{WB}^2$$

Coefficients a_1, b_1 and c_1 are constants for range R_1. Sets of coefficients for each range can be used to develop another regression as a function of range. Constants a_1, a_2 and a_3 are used to create the following regression:

$$a(R) = d + e \cdot R + f \cdot R^2$$

Coefficients d, e and f are more, unique constants that describe a as a function of R. The same process is followed to create b(R) and c(R). Putting all of the regressions together yields the following equation, which determines condenser water temperature for a given wet bulb and Range:

$$T_{CW}(T_{WB}, R) = a(R) + b(R) \cdot T_{WB} + c(R) \cdot T^2$$

The process above is used to create equations for condenser water as a function of wet bulb temperature and range when the fan is operating at either 100% or 50%, but the cooling tower also has the ability to run while the fan is off. Curves are not generated for zero fan speed. It is assumed that the cooling tower capacity is 10% of full speed capacity when there is zero fan speed.

The cooling tower has the ability to operate in three speeds: 100%, 50% and off. Therefore, fan power can be simply calculated because the cooling tower cycles between the three speeds to produces the necessary cold water temperature. For this analysis, the motor efficiency is assumed to be 95%. Figure 23 is a plot of the fan fraction versus the actual load seen by the cooling tower at wet bulb temperature of 63.6°F, which is the average wet bulb temperature at JFK International Airport for the 2% design condition.

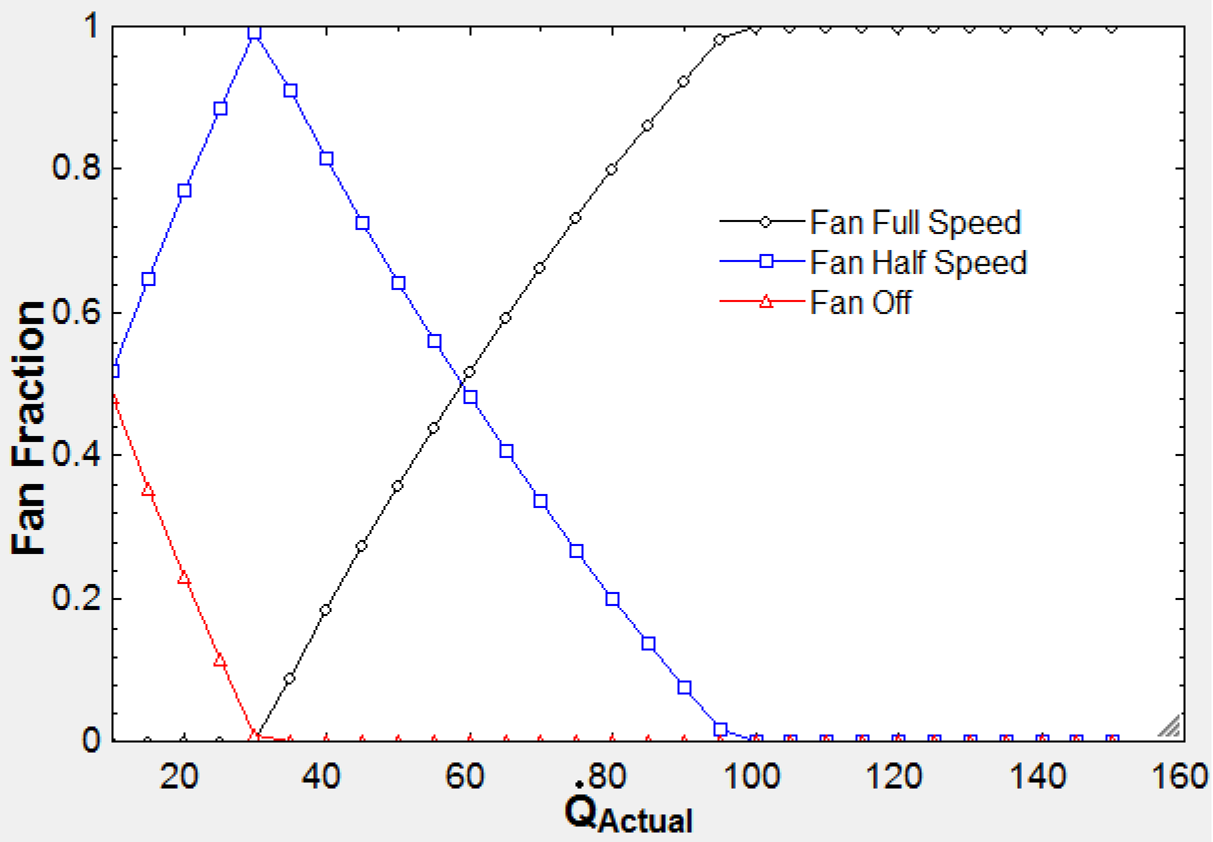
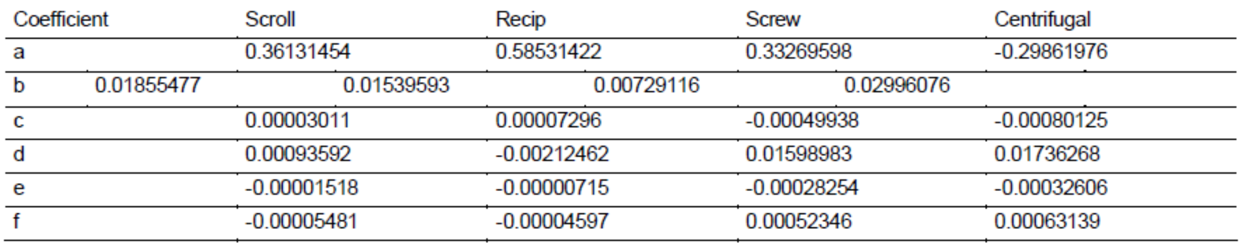


Figure 23 - Cooling Tower Fan Fraction vs. Cooling Load at 63.6°F Wet Bulb Temperature

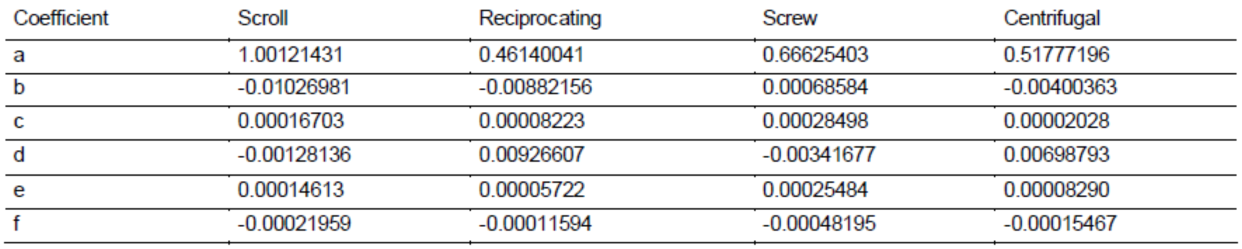
An 8760 hour parametric table was set up to calculate fan fraction with varying wet bulb temperatures from TMY data and actual loads as seen by the Life Sciences Building in order to obtain accurate hourly fan power data. The selected Marley cooling tower operates with a nominal motor power of 25 HP and 3.54 HP at full and half speed, respectively.

Similar to the cooling tower, the chiller was modeled in EES using characteristic equations in order to determine the power consumption of the chiller performing at conditions other than full load. Empirical DOE2 polynomial equations were used to equate capacity as a function of temperature, energy input ratio (EIR) as a function of temperature and EIR as a function of part load ration (PLR) using coefficients from the California Energy Commission's *Nonresidential Alternative Calculation Method Approval Manual for the 2005 Building Energy Efficiency Standards for Residential and Nonresidential Buildings*. Figure 24, Figure 25 and Figure 26 are charts from the California Energy Commission that provide coefficients for each type of water-cooled chiller for each of the empirical equations used in this analysis.



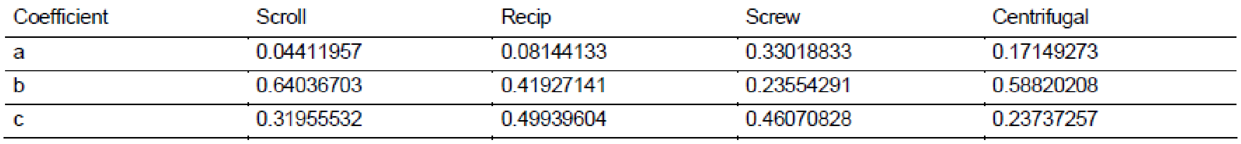
Coefficient	Scroll	Recip	Screw	Centrifugal
a	0.36131454	0.58531422	0.33269598	-0.29861976
b	0.01855477	0.01539593	0.00729116	0.02996076
c	0.00003011	0.00007296	-0.00049938	-0.00080125
d	0.00093592	-0.00212462	0.01598983	0.01736268
e	-0.00001518	-0.00000715	-0.00028254	-0.00032606
f	-0.00005481	-0.00004597	0.00052346	0.00063139

Figure 24 – Capacity Coefficients for Water-Cooled Chillers



Coefficient	Scroll	Reciprocating	Screw	Centrifugal
a	1.00121431	0.46140041	0.66625403	0.51777196
b	-0.01026981	-0.00882156	0.00068584	-0.00400363
c	0.00016703	0.00008223	0.00028498	0.00002028
d	-0.00128136	0.00926607	-0.00341677	0.00698793
e	0.00014613	0.00005722	0.00025484	0.00008290
f	-0.00021959	-0.00011594	-0.00048195	-0.00015467

Figure 25 – EIR Coefficients for Water-Cooled Chillers



Coefficient	Scroll	Recip	Screw	Centrifugal
a	0.04411957	0.08144133	0.33018833	0.17149273
b	0.64036703	0.41927141	0.23554291	0.58820208
c	0.31955532	0.49939604	0.46070828	0.23737257

Figure 26 – EIR as a Function of PLR Coefficients for Water-Cooled Chillers

The equations below for CAP_{FT}, EIR_{FT} and EIR_{FPLR} are the polynomial equations that utilize the coefficients from the charts above. The variable T_{CHWS} is 44°F, which is a design condition. T_{CW} is dependent on the cooling tower equations discussed above. Therefore, the cooling tower and chiller model equations are to be solved simultaneously. The variable PLR in the equation EIR_{FPLR} is simply the ratio of the actual cooling load to the available capacity of the chiller.

$$CAP_{FT} = a + b \cdot T_{CHWS} + c \cdot {T_{CHWS}}^2 + d \cdot T_{CW} + e \cdot {T_{CW}}^2 + f \cdot T_{CHWS} \cdot T_{CW}$$

$$EIR_{FT} = a + b \cdot T_{CHWS} + c \cdot {T_{CHWS}}^2 + d \cdot T_{CW} + e \cdot {T_{CW}}^2 + f \cdot T_{CHWS} \cdot T_{CW}$$

$$EIR_{FPLR} = a + b \cdot PLR + c \cdot PLR^2$$

$$PLR = \frac{\dot{Q}_{Actual}}{\dot{Q}_{Available}}$$

$$\dot{Q}_{Available} = CAP_{FT} \cdot \dot{Q}_{Rated}$$

After solving CAP_{FT}, EIR_{FT} and EIR_{FPLR}, the power consumed by the chiller can be solved for using the rated chiller capacity and the rated energy input ratio as provided by the manufacturer.

$$P_{Chiller} = \dot{Q}_{Rated} \cdot EIR_{Rated} \cdot EIR_{RT} \cdot CAP_{FT} \cdot EIR_{FPLR}$$

The chiller power can be solved for each of the 8760 hours in the year with the calculated hourly load profile for the Life Sciences Building. Combined with the cooling tower, a more accurate prediction of the chiller plant power consumption and electrical cost can be obtained.

Condenser water pumps, primary and secondary pumps are also included in the chiller plant power consumption. The same procedure is followed as previously described in the chilled beam study for pump power by created regressions for each pump. However, there are a few differences in this model. In the P/S configuration, the condenser water and primary pumps are constant volume pumps. Therefore, when the chiller is operating, the condenser water pump is moving a constant 810 GPM and the primary pump is moving a constant 550 GPM. The secondary pump varies as the cooling load varies.

In the VPF system, the condenser water pump is also a constant volume pump, but the chilled water pump is varying with the cooling load of the Life Sciences Building. However, the chilled water pump must pump the lowest recommended flow rate through the chiller. For the selected carrier chiller, the lowest flow rate allowable is 10% of the design capacity or 27 tons.

After obtaining the hourly power consumption for each the chiller, cooling tower and pumps, the 8760 hour power values were exported into excel where the electrical rate structures were applied in order to determine the yearly cost of each the P/S and VPF chiller plants. First cost for each configuration was calculated in order to perform a life cycle cost analysis in order to determine the optimal system for the Life Sciences Building.

Since the chiller plant is a new addition to the Life Sciences Building, a mechanical engineering room (MER) needs to be put in to the building. Fortunately, the current basement only occupies about 60% of the entire building footprint. Therefore, the proposed 2,750 square foot, chiller MER is to be attached to the existing basement in the unexcavated area. Figure 27 shows the existing basement plan. Figure 28 shows the basement plant with the proposed chiller MER.

Figure 27 - Existing Basement Plan of the Life Sciences Building

Figure 28 - Proposed Basement Plan of the Life Sciences Building

Even though the chiller MER is in the basement, the space will be accessible for equipment replacement. The white alcove that cuts into the chiller MER in Figure 28 is the inlet for deliveries on the first floor. The MER will have a concrete shaft with a steel beam supported, steel door that will be able to support the loads of the delivery trucks as well as be able to be removed to allow for equipment to be lowered into the chiller MER. Similar shafts have been designed for the emergency generator on the opposite side of the building. However, the emergency generator shaft does not support the weight of a delivery truck.

The chiller MER is proposed to be located in the basement rather than the roof for a couple of reasons. First, the basement is secured to authorized personnel only and is the located of the majority of other major mechanical and electrical equipment. Second, if the chiller MER were to be on the roof, there would be a greater vibration concern for the life sciences building. Furthermore, the addition of chillers to the rooftop penthouse would increase the overall footprint of the penthouse, which is against the design wishes of the architects.

In terms of means of egress, the 2010 New York State Building Code, Section 1017.3, Exception 2 states that occupancy classifications B and F with automatic sprinkler systems can have dead end corridors with a limit of 50 feet. The distance from the existing stairwell to the proposed MER is 35.5 feet, which is within the limit of the code mandated corridor length. Furthermore, the 2007 New York State Mechanical Code states that the chiller MER needs only one means of egress, which is based on its occupancy density. Therefore, the proposed chiller MER complies with the mandatory means of egress requirements.

The cooling tower is to be placed in the rooftop penthouse enclosed in the anodized aluminum façade. This façade allows air to penetrate through the material to allow for adequate flow through the laboratory exhaust fans without a significant increase in pressure. Therefore, it is assumed that air will pass through the façade to allow for adequate condenser water cooling while providing the desired aesthetic cover in the minimum required space as designed by the architects.

Analysis Conclusion

There are difference aspects of this study that are used to analyze each system. Energy, first cost and life cycle cost each contribute an insight into each system. Energy usage provides information into the monthly and annual consumption and cost of each system. First cost tells the owner how much capital needs to be invested into each system and life cycle cost determines which system is a better investment based on total cost over a 30 year life cycle. Energy, first cost and life cycle cost are all broken down in the next few sections for each primary/secondary and variable primary flow configurations.

Energy

Energy costs for the Life Sciences Building chiller plant are affected by each the chiller, cooling tower, condenser water pumps and chilled water pumps for each of the configurations. However, the energy savings will be found with the mainly with the chilled water. While the flow through the evaporator is slowing down in a variable primary flow system, the COP of the chiller remains the same due to the constant lift between the evaporator and condenser. Therefore, there is a negligible adjustment in energy between P/S and VPF configurations. Energy consumption for each pumping configuration is discussed in the following sections in more detail.

Primary/Secondary

In the yearly model, schedules were created to designate when the chiller and cooling tower were to operate, just as a schedule would be programmed into the sequence of operation. Therefore, the chiller and cooling tower only operated during occupied hours and days with steady loads. This means that if there was a random day where the Life Sciences Building required a small amount of cooling, the chiller and cooling tower were not turned on due to the effort needed to startup the system. Table 41 is a segment of the annual pump analysis.

Month	Day	Hour	OA DB (°F)	Chiller Cap. (Tons)	Cooling Load (Tons)	CW Flow (GPM)	CW Power (kW)	Prime. CHW Flow (GPM)	Prime. Pump Power (kW)	Sec. CHW Flow (GPM)	Sec. Pump Power (kW)
Jul	1	6	68	27	24.48	802.1	11.69	534	3.92	50.68	2.772
Jul	1	7	67	27	25.34	802.1	11.69	534	3.92	50.68	2.772
Jul	1	8	69	39.01	39.01	802.1	11.69	534	3.92	78.02	2.739
Jul	1	9	70	55.37	55.37	802.1	11.69	534	3.92	110.74	2.708
Jul	1	10	70	59.29	59.29	802.1	11.69	534	3.92	118.58	2.702
Jul	1	11	70	56.12	56.12	802.1	11.69	534	3.92	112.24	2.707
Jul	1	12	68	46.84	46.84	802.1	11.69	534	3.92	93.68	2.723
Jul	1	13	69	50.71	50.71	802.1	11.69	534	3.92	101.42	2.716
Jul	1	14	67	53.08	53.08	802.1	11.69	534	3.92	106.16	2.712
Jul	1	15	68	58.4	58.4	802.1	11.69	534	3.92	116.80	2.703
Jul	1	16	69	64.44	64.44	802.1	11.69	534	3.92	128.88	2.694
Jul	1	17	68	61.63	61.63	802.1	11.69	534	3.92	123.26	2.698
Jul	1	18	67	54.71	54.71	802.1	11.69	534	3.92	109.42	2.709

Table 41 - Segment from Annual Pump Spreadsheet for P/S system

It can be seen in Table 41 that the chiller load is greater than the Life Sciences Building cooling load during certain hours. This is because the chiller can turn down a maximum of 10% of the cooling load, which is 27 tons. Therefore, even though the cooling requirements of the building may be less than 27 tons, the chiller cannot produce less than 27 tons of cooling in order to ensure a safe operation. Furthermore, it can be seen that the condenser water (CW) and primary chilled water flows are constant. Table 42 is a segment of the annual chiller and cooling tower analysis.

Month	Day	Hour	OA DB (°F)	OA WB (°F)	Chiller Capacity (Tons)	Chiller Power (kW)	Cooling Tower Power (kW)
Jul	1	6	69	68	27	54.65	19.62
Jul	1	7	72	67	27	54.65	18.14
Jul	1	8	75	69	39.01	58.01	19.62
Jul	1	9	78	70	55.37	62.92	19.62
Jul	1	10	78	70	59.29	64.02	19.62
Jul	1	11	81	70	56.12	63.13	19.62
Jul	1	12	79	68	46.84	59.24	19.62
Jul	1	13	78	69	50.71	60.94	19.62
Jul	1	14	80	67	53.08	60.15	19.62
Jul	1	15	78	68	58.4	62.29	19.62
Jul	1	16	76	69	64.44	64.76	19.62
Jul	1	17	73	68	61.63	63.20	19.62
Jul	1	18	72	67	54.71	60.58	19.62

Table 42 - Segment from Annual Chiller/Cooling Tower Spreadsheet for P/S System

The power consumption values for the chiller, cooling tower and pumps in Table 41 and Table 42 are determined using the EES models discussed in the above sections. The electric rate structures were applied for the peak and off-peak months to determine the annual cost for each system. The chiller and cooling tower power consumptions were found to be 338,570 kWh and 43,661 kWh respectively for the entire year. This equates to an annual chiller and cooling tower electrical cost of $20,944 and $3,088 respectively. The condenser water pump, which runs at a constant volumetric flow rate, utilizes 60,765 kWh or $3,928 of electricity annually. The primary and secondary pumps use 20,376 kWh and 6,761 kWh respectively, which is a cost of $1,492 for the primary pump and $679 for the secondary pump for the entire year. The total annual chiller plant consumption with a P/S pumping configuration is $30,132. Figure 29 is a graph of the monthly electricity cost for a primary/secondary pumping configuration for a chiller plant in the Life Sciences Building.

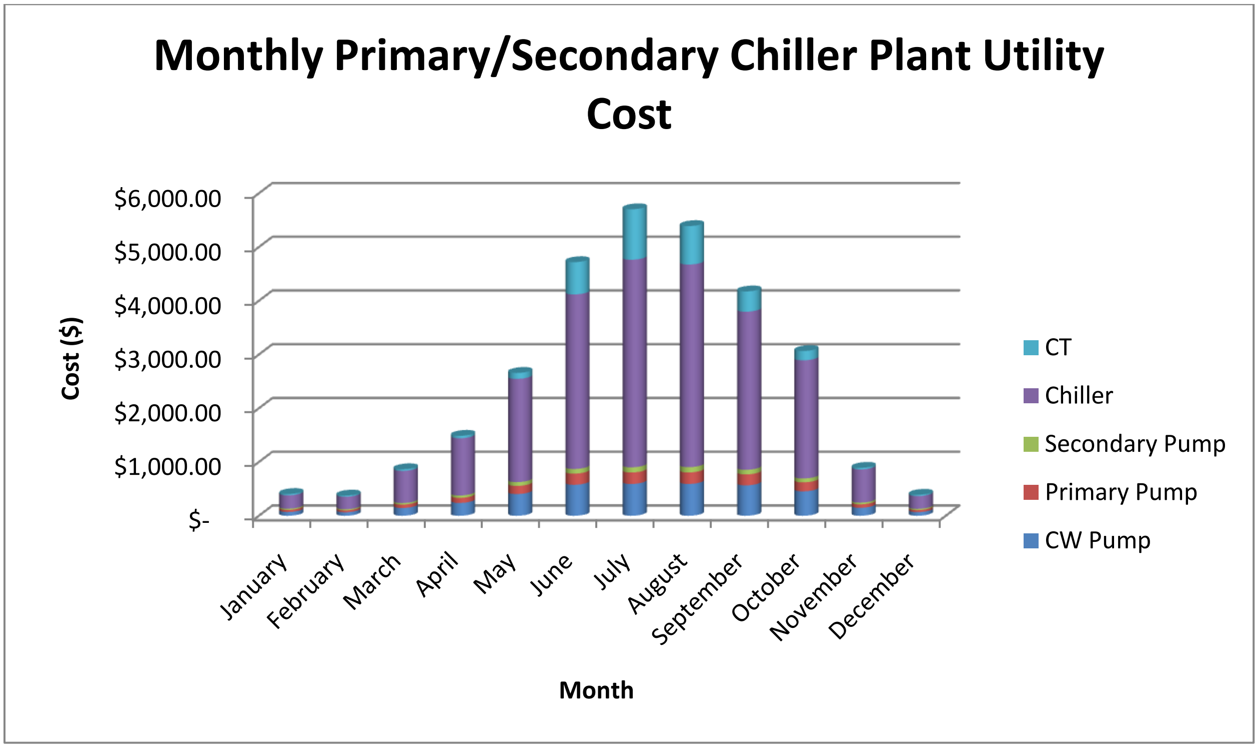


Figure 29 - Monthly Primary/Secondary Chiller Plant Utility Cost

Variable Primary Flow

The analysis for variable primary flow energy consumption was performed in the same manner as the primary/secondary. The same schedules were applied to the pumps and chiller and the same EES files were used to model the electrical consumption of the chiller plant. Table 43 is a segment from the spreadsheet analysis of the condenser and chilled water pump analysis for the variable primary flow pumping configuration.

Month	Day	Hour	OA DB (°F)	Chiller Cap. (Tons)	Cooling Load (Tons)	CHW Pump (GPM)	CHW Pump Power (kW)	CW Flow (GPM)	CW Pump Power (kW)
Jul	1	6	69	27	24.48	54	2.768	802.1	11.69
Jul	1	7	72	27	25.34	54	2.768	802.1	11.69
Jul	1	8	75	39.01	39.01	78.02	2.739	802.1	11.69
Jul	1	9	78	55.37	55.37	110.74	2.708	802.1	11.69
Jul	1	10	78	59.29	59.29	118.58	2.702	802.1	11.69
Jul	1	11	81	56.12	56.12	112.24	2.707	802.1	11.69
Jul	1	12	79	46.84	46.84	93.68	2.723	802.1	11.69
Jul	1	13	78	50.71	50.71	101.42	2.716	802.1	11.69
Jul	1	14	80	53.08	53.08	106.16	2.712	802.1	11.69
Jul	1	15	78	58.4	58.4	116.8	2.703	802.1	11.69
Jul	1	16	76	64.44	64.44	128.88	2.694	802.1	11.69
Jul	1	17	73	61.63	61.63	123.26	2.698	802.1	11.69
Jul	1	18	72	54.71	54.71	109.42	2.709	802.1	11.69

Table 43 - Segment from Annual Pump Spreadsheet for VPF System

In Table 43, it is seen that the chilled water pump operates with a variable speed drive, throttling back on power consumption when the demand for chilled water decreases. The condenser water pump remains as it did for the primary/secondary study, a constant volumetric flow pump. Table 44 is a segment from the spreadsheet analysis of the chiller and cooling tower power consumption for the variable primary flow system. The values are very similar to those of the primary/secondary analysis.

Month	Day	Hour	OA DB (°F)	OA WB (°F)	Chiller Capacity (Tons)	Chiller Power (kW)	Cooling Tower Power (kW)
Jul	1	6	69	68	27	54.65	19.62
Jul	1	7	72	67	27	54.12	18.14
Jul	1	8	75	69	39.01	58.01	19.62
Jul	1	9	78	70	55.37	62.92	19.62
Jul	1	10	78	70	59.29	64.02	19.62
Jul	1	11	81	70	56.12	63.13	19.62
Jul	1	12	79	68	46.84	59.24	19.62
Jul	1	13	78	69	50.71	60.94	19.62
Jul	1	14	80	67	53.08	60.15	19.62
Jul	1	15	78	68	58.4	62.29	19.62
Jul	1	16	76	69	64.44	64.76	19.62
Jul	1	17	73	68	61.63	63.20	19.62
Jul	1	18	72	67	54.71	60.58	19.62

Table 44 - Segment from Annual Chiller/Cooling Tower Spreadsheet for VPF System

Just like the primary/secondary analysis, the electric rate structure was applied to the power usages of the different equipment in order to determine the annual electricity cost of the chiller plant. The chiller and cooling tower annual electricity consumption is 338,570 kWh and 43,661 kWh respectively. This equates to a cost of $20,944 for the chiller and $3,088 for the cooling tower. The chilled water and condenser water pumps use 6,745 kWh and 60,765 kWh per year respectively. The annual electricity for the chilled water pump costs $678 and the electricity for the condenser water pump costs $3,928. The total chiller plant annual electricity cost for the variable primary flow configuration is $28,638. Figure 30 is a graph of the monthly electricity cost for a variable primary flow pumping configuration for a chiller plant in the Life Sciences Building.

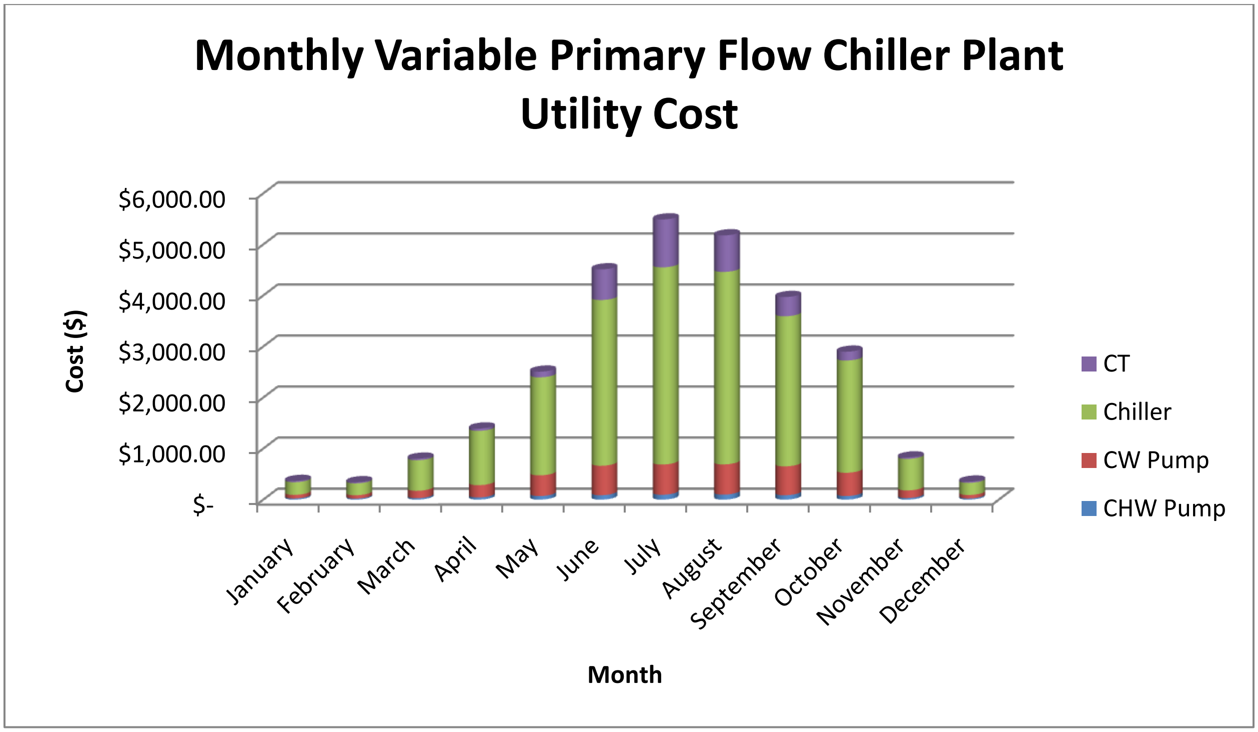


Figure 30 - Monthly Primary/Secondary Chiller Plant Utility Cost

The differences between the two different pumping configurations mainly reside with the use of the primary chilled water pump. With the loss of the primary pump and the use of a variable speed drive on the chilled water pump in the VPF system, there is a 24.5% decrease in pump energy consumption. This equates to a reduction of 5% in overall chiller plant energy with the variable primary flow system over the primary/secondary configuration. Furthermore, it is important to note that for this analysis, the chillers are assumed to have the same electrical consumption as the load varies. However, in reality, the chiller with varying flow through the evaporator will operate more efficiently than the chiller with a varying chilled water return temperature. Therefore, the variable primary flow system will have an even higher advantage over the primary/secondary system.

First Cost

For a first cost comparison between the primary/secondary and variable primary flow systems, the majority of the material and labor costs were found in RS Means. When available, data from Cannon Design cost estimates was used. Because the large pieces of equipment are used in both systems, it is not critical that the cost data for the equipment be exact. For example, Carrier was not consulted for costs for the chiller. Instead, RS Means was used to obtain a reasonable estimate for this analysis.

Item Description	Quantity		Total		
			Unit Cost		Amount
270 Ton Water-Cooled Screw Chiller	1.00	/EA	$ 95,300.00	/EA	$ 95,300
300 Ton Cooling Tower, Axial Fan	1.00	/EA	$ 35,350.00	/EA	$ 35,350
15 HP Centrifugal Pump	4.00	/EA	$ 7,276.96	/EA	$ 29,108
15 HP VFD	2.00	/EA	$ 3,617.75	/EA	$ 7,236
7.5 HP Centrifugal Pump	2.00	/EA	$ 10,065.00	/EA	$ 20,130
20 HP Centrifugal Pump	2.00	/EA	$ 5,150.00	/EA	$ 10,300
6" Schedule 40 Steel Pipe - Welded	200.00	/LF	$ 203.15	/LF	$ 40,630
6" Fiberglass Insulation	200.00	/LF	$ 25.33	/LF	$ 5,066
Total					$ 243,119

Table 45 - First Cost Data for Primary/Secondary Configuration

Item Description	Quantity		Total		
			Unit Cost		Amount
270 Ton Water-Cooled Screw Chiller	1.00	/EA	$ 95,300.00	/EA	$ 95,300
300 Ton Cooling Tower, Axial Fan	1.00	/EA	$ 35,350.00	/EA	$ 35,350
15 HP Centrifugal Pump	2.00	/EA	$ 7,276.96	/EA	$ 14,554
15 HP VFD	2.00	/EA	$ 3,617.75	/EA	$ 7,236
7.5 HP Centrifugal Pump	2.00	/EA	$ 10,065.00	/EA	$ 20,130
20 HP Centrifugal Pump	2.00	/EA	$ 5,150.00	/EA	$ 10,300
6" Schedule 40 Steel Pipe - Welded	150.00	/LF	$ 203.15	/LF	$ 30,472
6" Fiberglass Insulation	150.00	/LF	$ 25.33	/LF	$ 3,800
Total					$ 217,141

Table 46 - First Cost Data for Variable Primary Flow Configuration

The estimate of linear feet of pipe is based off of the initial estimate for welded, schedule 40 steel pipe for the originally designed chilled water system with the campus chilled water loop. The cost difference between these two first costs equates to $26,000. This is due to the two less fifteen horsepower centrifugal pumps in the variable primary flow system.

Life Cycle Cost

A 30-year, life cycle cost analysis was performed in order to compare the primary/secondary and variable primary flow pumping configurations. Cost escalation factors were obtained from the National Institute of Standards and Technology (NIST) *Energy Prince Indices and Discount Factors for Life-Cycle Cost Analysis – 2010* for electricity, which is the fuel type used in the chiller plant. The electricity escalation factors will be used to adjust the costs of operating the pumps, chiller and cooling tower. Table 47 and Table 48 summarize the initial values used to begin the life-cycle analysis.

Annual Elec. Energy (kWh)	Annual Elec. Cost ($)	OMB Base Discount Rate (%)
470,132	30,131	2.7

Table 47 - Input Values for Primary/Seconday Life Cycle Cost Analysis

Annual Elec. Energy (kWh)	Annual Elec. Cost ($)	OMB Base Discount Rate (%)
442,995	28,638	2.7

Table 48 - Input Values for Variable Primary Flow Life Cycle Cost Analysis

A spreadsheet was set up to calculate the total net present value (NPV) of the 30-year life cycle of each system. The 30-year life cycle includes the assumption of $3,000 per year for maintenance for both the P/S and VPF systems. The analysis includes the first costs for each of the systems as the initial capital investment. Table 49 and Table 50 are the spreadsheets used to determine the total NPV of the life cycle of each system.

Analysis Year	Year	Initial Capital	Other Maint.	Elec. Esc.	Base Elec Cost
1	2011	$ 243,119	$ 3,000	0.90	$ 27,118
2	2012	0	$ 3,000	0.92	$ 27,721
3	2013	0	$ 3,000	0.94	$ 28,324
4	2014	0	$ 3,000	0.93	$ 28,022
5	2015	0	$ 3,000	0.92	$ 27,721
6	2016	0	$ 3,000	0.93	$ 28,022
7	2017	0	$ 3,000	0.95	$ 28,625
8	2018	0	$ 3,000	0.95	$ 28,625
9	2019	0	$ 3,000	0.96	$ 28,926
10	2020	0	$ 3,000	0.97	$ 29,228
11	2021	0	$ 3,000	0.98	$ 29,529
12	2022	0	$ 3,000	0.99	$ 29,830
13	2023	0	$ 3,000	1.00	$ 30,131
14	2024	0	$ 3,000	1.01	$ 30,433
15	2025	0	$ 3,000	1.01	$ 30,433
16	2026	0	$ 3,000	1.01	$ 30,433
17	2027	0	$ 3,000	1.02	$ 30,734
18	2028	0	$ 3,000	1.03	$ 31,035
19	2029	0	$ 3,000	1.05	$ 31,638
20	2030	0	$ 3,000	1.06	$ 31,939
21	2031	0	$ 3,000	1.08	$ 32,542
22	2032	0	$ 3,000	1.1	$ 33,145
23	2033	0	$ 3,000	1.12	$ 33,747
24	2034	0	$ 3,000	1.13	$ 34,049
25	2035	0	$ 3,000	1.14	$ 34,350
26	2036	0	$ 3,000	1.15	$ 34,651
27	2037	0	$ 3,000	1.15	$ 34,651
28	2038	0	$ 3,000	1.16	$ 34,953
29	2039	0	$ 3,000	1.17	$ 35,254
30	2040	0	$ 3,000	1.17	$ 35,254
Total		$ 243,119	$ 90,000		$ 931,063
Column NPV		$ 236,727	$87,634		$ 906,585
			Total NPV		$ 1,230,946

Table 49 - Life Cycle Cost Analysis Spreadsheet for the Primary/Secondary System

Analysis Year	Year	Initial Capital	Other Maint.	Elec. Esc.	Base Elec Cost
1	2011	$ 217,141	$ 3,000	0.90	$ 25,774
2	2012	0	$ 3,000	0.92	$ 26,347
3	2013	0	$ 3,000	0.94	$ 26,920
4	2014	0	$ 3,000	0.93	$ 26,634
5	2015	0	$ 3,000	0.92	$ 26,347
6	2016	0	$ 3,000	0.93	$ 26,634
7	2017	0	$ 3,000	0.95	$ 27,206
8	2018	0	$ 3,000	0.95	$ 27,206
9	2019	0	$ 3,000	0.96	$ 27,493
10	2020	0	$ 3,000	0.97	$ 27,779
11	2021	0	$ 3,000	0.98	$ 28,065
12	2022	0	$ 3,000	0.99	$ 28,352
13	2023	0	$ 3,000	1.00	$ 28,638
14	2024	0	$ 3,000	1.01	$ 28,925
15	2025	0	$ 3,000	1.01	$ 28,925
16	2026	0	$ 3,000	1.01	$ 28,925
17	2027	0	$ 3,000	1.02	$ 29,211
18	2028	0	$ 3,000	1.03	$ 29,497
19	2029	0	$ 3,000	1.05	$ 30,070
20	2030	0	$ 3,000	1.06	$ 30,357
21	2031	0	$ 3,000	1.08	$ 30,929
22	2032	0	$ 3,000	1.10	$ 31,502
23	2033	0	$ 3,000	1.12	$ 32,075
24	2034	0	$ 3,000	1.13	$ 32,361
25	2035	0	$ 3,000	1.14	$ 32,648
26	2036	0	$ 3,000	1.15	$ 32,934
27	2037	0	$ 3,000	1.15	$ 32,934
28	2038	0	$ 3,000	1.16	$ 33,220
29	2039	0	$ 3,000	1.17	$ 33,507
30	2040	0	$ 3,000	1.17	$ 33,507
Total		$ 217,141	$ 3,000		$ 884,921
Column NPV		$ 211,432	$87,634		$ 861,656
			Total NPV		$ 1,160,723

Table 50 - Life Cycle Cost Analysis Spreadsheet for the Variable Primary Flow System

The total NPV for the P/S and VPF configurations are $1,230,946 and $1,160,723, respectively. This equates to a $70,224 or 5.7% savings over the life cycle of a VPF system if the Life Sciences Building were to use a variable primary flow configuration rather than a primary/secondary configuration.

Breadth 1: Daylighting – LEED Analysis

One of the design goals of the Life Sciences Building is to achieve LEED Gold certification by the United States Green Building Council (USGBC). A LEED point of particular interest is the Indoor Environmental Quality (IEQ) Credit 8.1: Daylight and Views – Daylight. As mentioned in the LEED Analysis, the designers of the Life Sciences Building believe that their structure will meet the requirements of Credit 8.1. The purpose of this analysis is to perform a simulation as desired by the USGBC to determine if 75% of the regularly occupied spaces in the building fall between the limits of 25 and 500 footcandles (fc).

Analysis Procedure

Architectural plans were used to build a three-dimensional model of the Life Sciences Building in AutoCAD. Rooms that do not contain windows to the exterior, such as restrooms and electrical rooms, were not included in the model. This allowed for a simpler model and a quicker simulation time. Three-dimensional models were created of both the first and second floors. The third floor is assumed to have similar illuminance levels as the second floor since the floor layouts are similar.

Following the creation of the three-dimensional model, the model was imported into AGI32 for a daylighting simulation. The LEED requirements are centered about a specific date and time, September 21 at both 9am and 3pm. A daylighting calculation was run for each the first and second floor at each time on September 21st. Figure 31, Figure 32, Figure 33 and Figure 34 below are images of the daylight study from AGI32 at their respective times. Contour lines have been overlaid in order to denote the location of specific illuminance levels.

The results from AGI32 were exported back to AutoCAD with the contour lines in order to calculate the floor area between the limits of 25 and 500 footcandles. The areas below 25 fc and above 500 fc do not comply with the requirements of Credit 8.1.

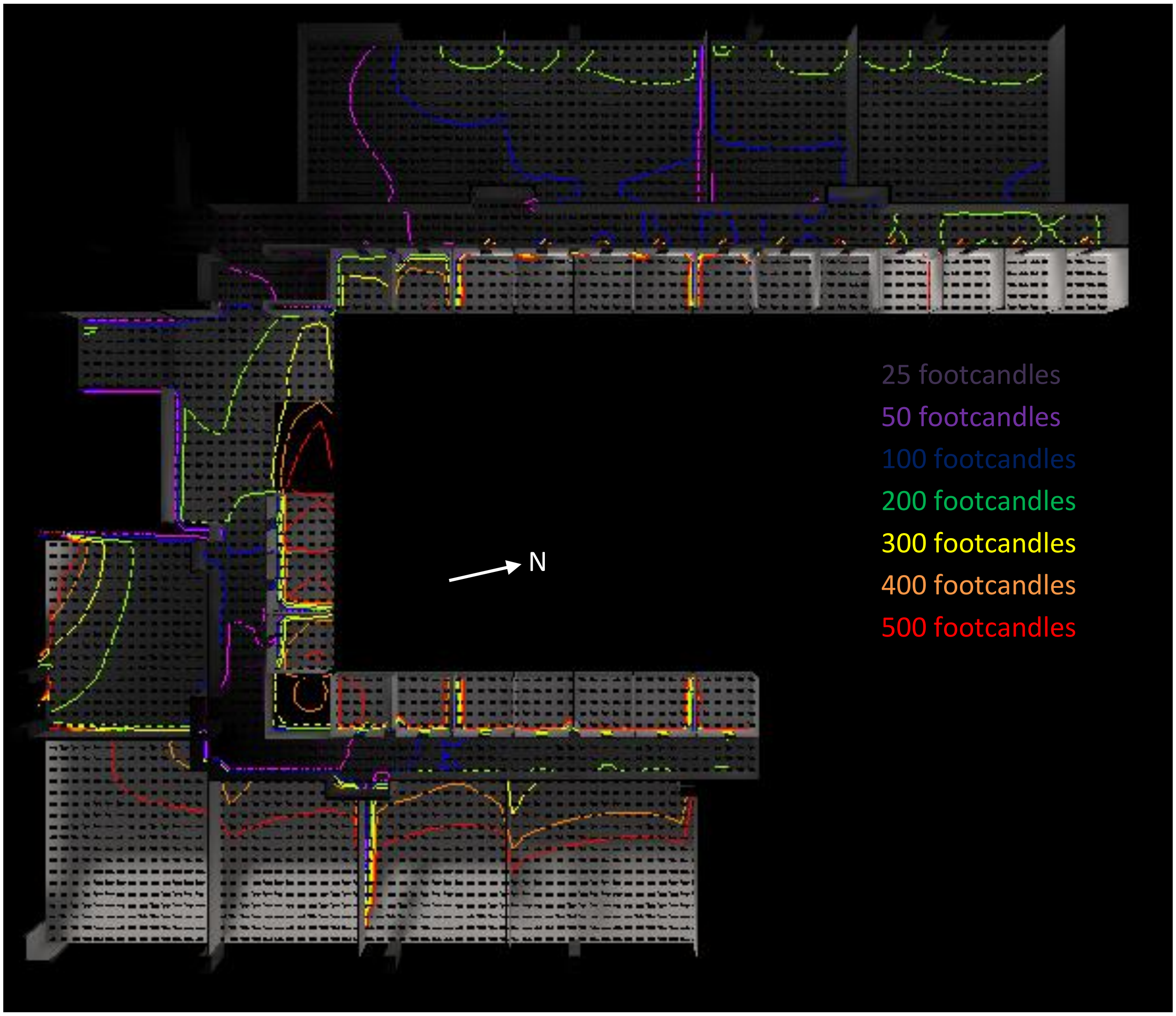


Figure 31 - 1st Floor at 9am

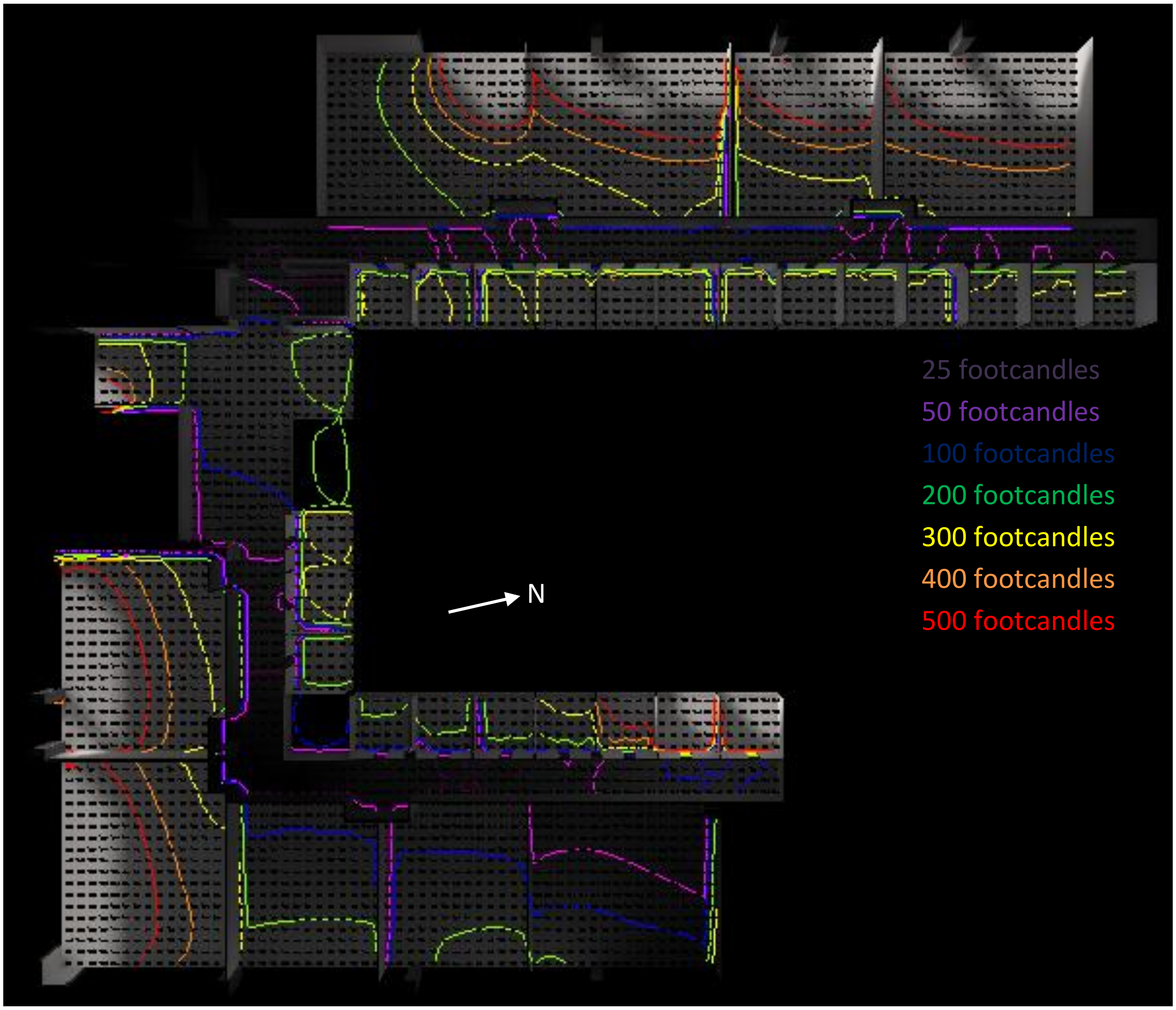


Figure 32- 1st Floor at 3pm

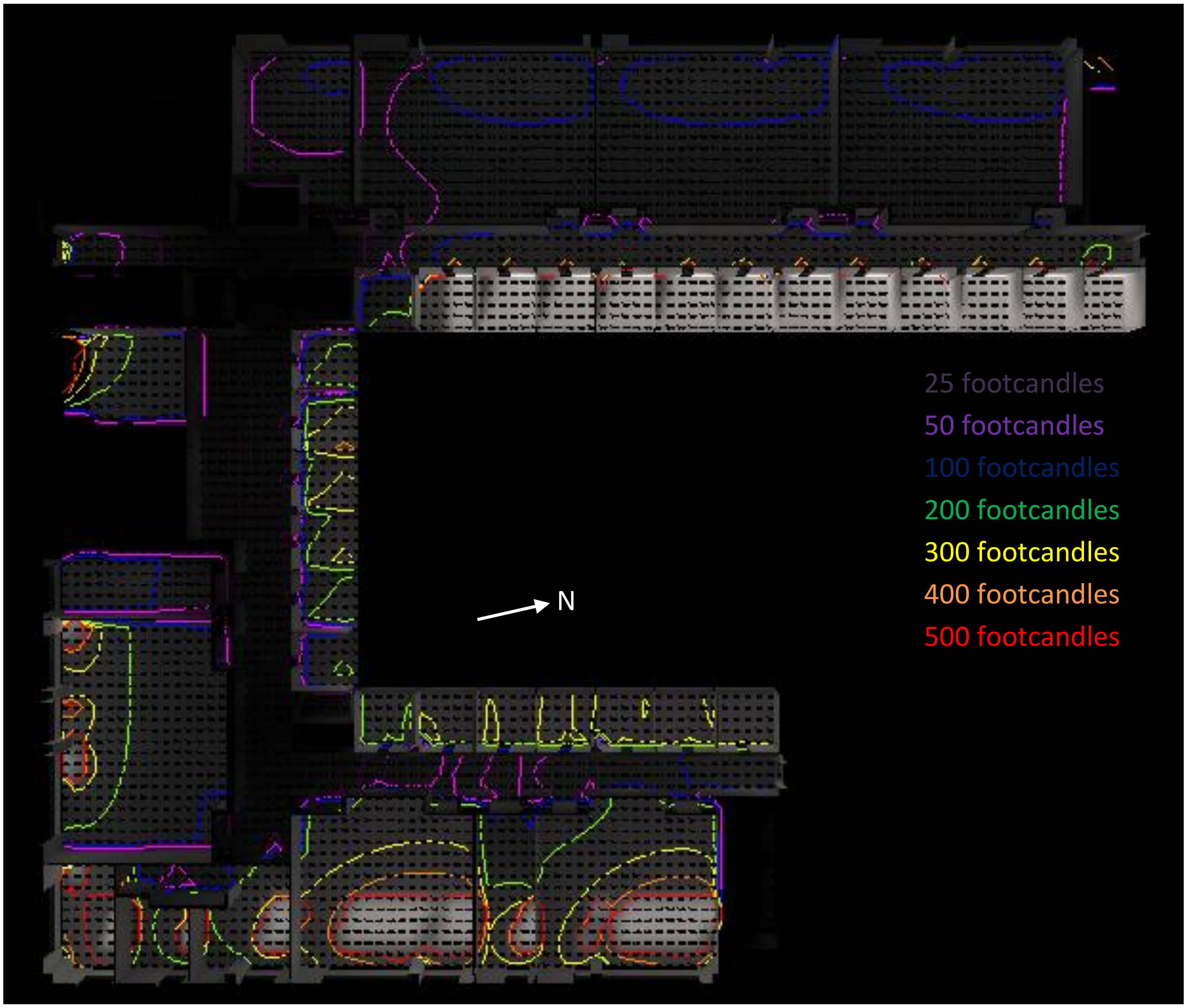


Figure 33 - 2nd Floor at 9am

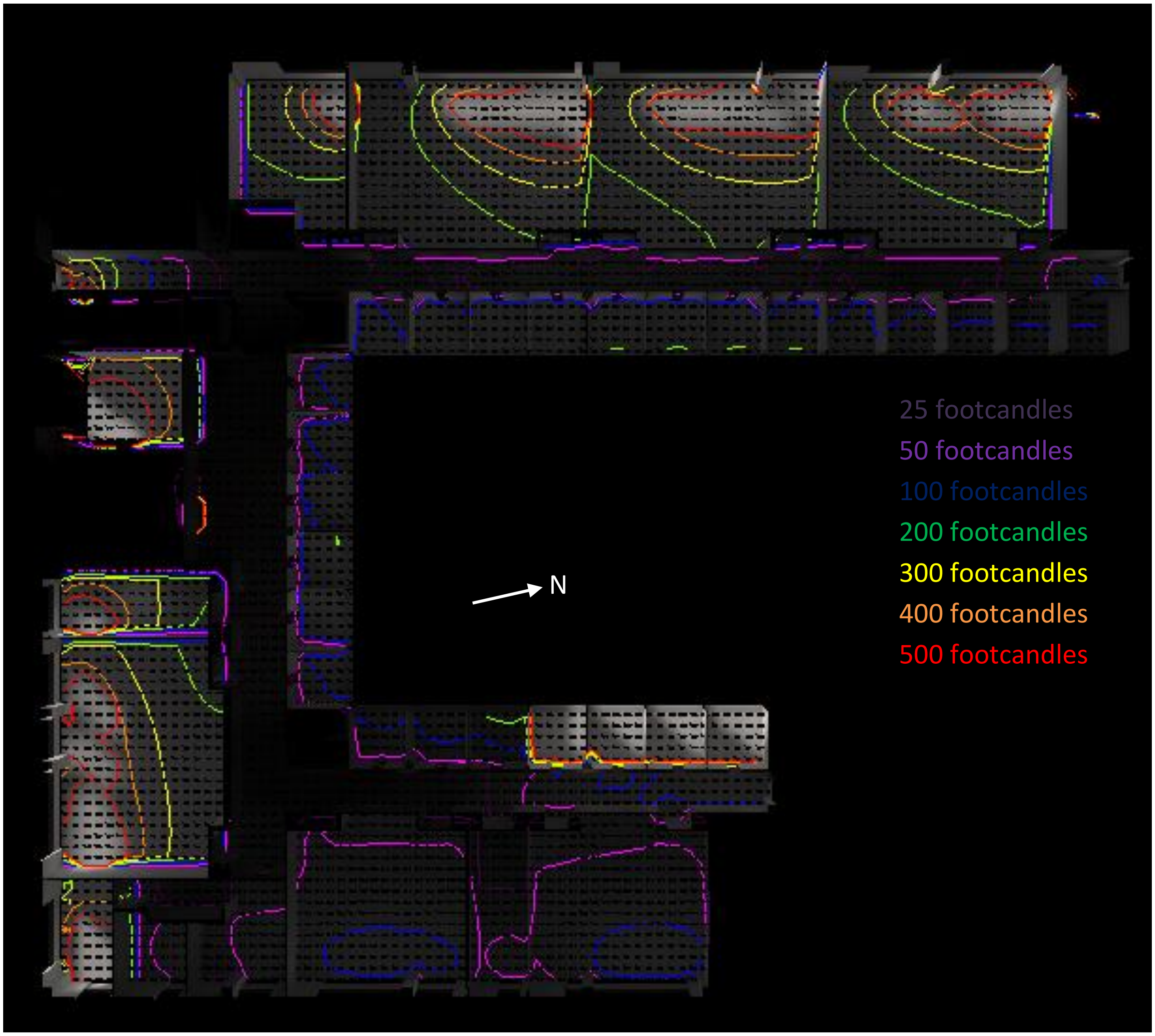


Figure 34 - 2nd Floor at 3pm

Analysis Conclusion

After calculating the areas between 25 and 500 footcandles, it was determined that the Life Sciences Building meets the requirements of Credit 8.1 at 3pm on September 21st but not at 9am. For the purpose of this analysis, regularly occupied spaces were defined as offices, lounges and classrooms – both lecture halls and laboratories. Table 51 below illustrates the floor areas on each building level that fall between the illuminance limits of Credit 8.1. Table 52 below summarizes the percent of each floor area that is between the limit of 25 and 500 fc. Table 52 also provides the total percentage of regularly occupied area that is between the limits.

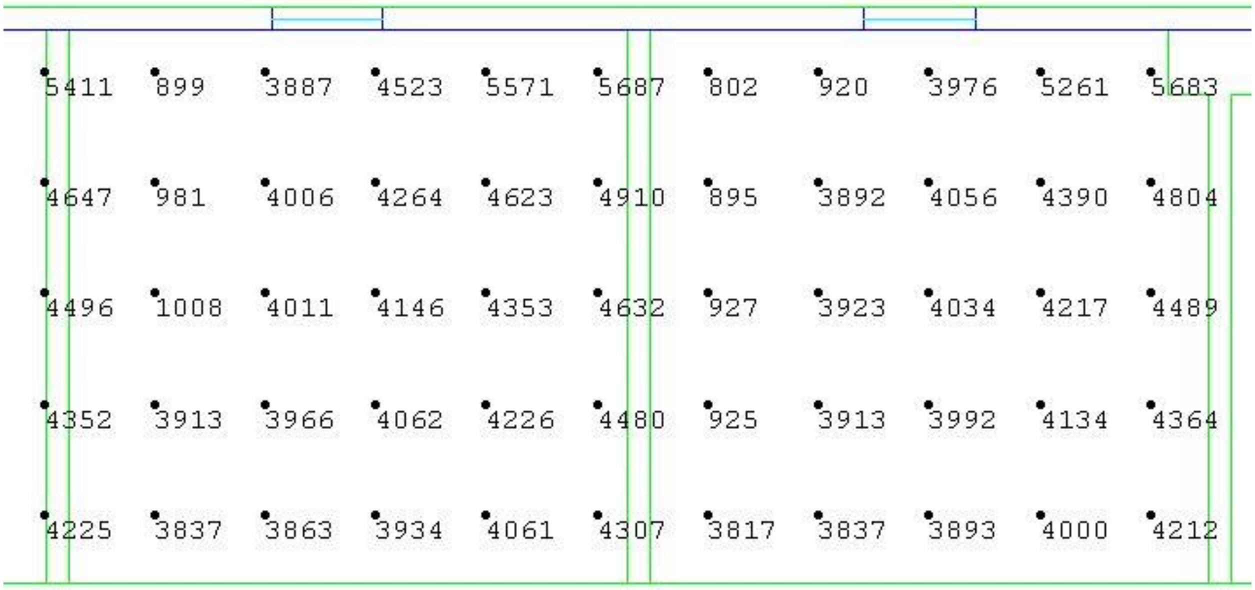
Floor	Area at 9am (ft^2)	Area at 3pm (ft^2)	Total Area (ft^2)
1st Floor	6,168	8,478	11,014
2nd Floor	9,933	10,270	12,230
3rd Floor	9,933	10,270	12,230

Table 51 - Regularly Occupied Floor Areas on September 21st between 25 and 500 fc

Floor	% at 9am	% at 3pm
1st Floor	56.0	77.0
2nd Floor	81.2	84.3
3rd Floor	81.2	84.3
Total	73.4	81.8

Table 52 - Percent of Regularly Occupied Areas on September 21st between 25 and 500 fc

In conjunction with Table 51 and Table 52, Figure 31 - 1st Floor at 9amFigure 31 and Figure 33 show that the reason for falling below the 75% floor area of regularly occupied space requirement is because there are eastern facing spaces that have significant area above the 500 fc cutoff. Entire offices in the west wing of the Life Sciences Building area well above the limit of 500 fc, which cause them to not comply with Credit 8.1. Figure 35 shows the illuminance values for two eastern-facing offices on the second floor at 9 am. It can be seen that the illuminance values are well above the 500 fc limit and completely disqualify the offices from counting towards Credit 8.1. Neighboring offices perform in the same respect as those in Figure 35.



5411	899	3887	4523	5571	5687	802	920	3976	5261	5683
4647	981	4006	4264	4623	4910	895	3892	4056	4390	4804
4496	1008	4011	4146	4353	4632	927	3923	4034	4217	4489
4352	3913	3966	4062	4226	4480	925	3913	3992	4134	4364
4225	3837	3863	3934	4061	4307	3817	3837	3893	4000	4212

Figure 35 – Illuminance Values for Eastern-Facing Offices at 9am on September 21st

Because floor areas above 500 fc area do not comply with LEED Credit 8.1, only 73.4% of the total floor area of regularly occupied spaces in the Life Sciences Building is between the required range of 25 and 500 fc at 9 am on September 21st. Therefore The Life Sciences Building will not receive one LEED point for Credit 8.1 unless adjustments are made to lower the illuminance levels at 9am.

Breadth 2: Architecture – Façade Adjustments

Daylighting improves the overall indoor environment in a building. However, when the illuminance levels are too high, the occupants can become uncomfortable. Through the daylighting study previously performed, it has been determined that there are points within various office spaces that can reach over 5,000 fc. Because of these extremely high illuminance levels, permanent shading devices were investigated for the glass curtain wall in the courtyard. Three different shading devices were explored during this study: horizontal overhang, vertical fins and rods.

Analysis Procedure

The ideas for horizontal and vertical shading devices were recommended in document sponsored by The California Institute for Energy Efficiency (CIEE), which is a research unit of the University of California. It has been suggested that for eastern and western facing façades that shading devices should be oriented vertically and horizontally for southern facing facades. The shading device orientations are based on the height of the sun and the angle at which it hits the window.

Vertical shades, fins, were explored first. The equation below determined the depth of the fins necessary to block the sun.

$$w = D \times \tan\left(solar\ azimuth - window\ azimuth\right)$$

The variable w was set to 5'-3", which is the width of the window which would be the maximum shadow needed to block the sun. The equation was solved for D, which is the depth of the fin. The depth of the fin needed to block the sun at Nassau Community College is 11 feet. 11 feet is an incredibly large fin that would be a significant eyesore to the building aesthetics. Nevertheless, the fins were modeled in AutoCAD and a daylighting simulation was run in AGI32. The results illustrated that the sunlight at 9 am on September 21st would still penetrate the office curtain walls and cause illuminance levels to be in the 5,000 fc range. The sun location at 9 am is not far enough south where the vertical fins can block the direct sunlight into the space. Therefore, the Life Sciences Building still does not comply with LEED Credit 8.1.

Even though horizontal shading devices are not recommended for eastern and western facing windows, they were explored for the purposes of this study. Using the equation below from the CIEE document, the depth of the overhang necessary to block the sunlight was determined.

$$h = \frac{D \times \tan(solar\ altitude)}{\cos(solar\ azimuth - window\ azimuth)}$$

The variable h was set to 9’-1”, which is the ceiling height for offices. After solving the equation for D, the depth of the overhang was determined to be about 5 feet. Similar to the vertical fins previously explored, a 5 foot overhang would be a poor addition to the façade of the Life Sciences Building. However, the study was completed just like the fins, with an AutoCAD model and a daylight simulation in AGI32. Similar results were found, but their causes were different. Just like the vertical fins, the daylight illuminance levels at 9 am on September 21st were well above the 500 fc limit found in the LEED Credit 8.1. However, the reason for the high illuminance levels are that the sun is at a very low altitude at 9 o’clock in the morning and therefore render the overhand ineffective. The direct sunlight penetrates the office windows below the overhang and shines brightly within the office.

The third type of shading device is inspired by the New York Times Building in New York City. The New York Times Building is decorated with ceramic rods on the exterior of the building to act as fixed shading devices to prevent strong, direct sunlight from penetrating the skin. The rods are an effective shading device for this particular application because of the specific requirements of LEED Credit 8.1. Credit 8.1 requires the illuminance levels due to daylight to be between 25 and 500 fc on September 21st at 9 am and 3 pm. As previously determined, the early sunlight at 9 am is difficult to shade with vertical fins and horizontal overhangs because of the angle of the sun. Therefore an array of rods spanning the interior courtyard provides shading from direct sunlight at all hours of the day. An AutoCAD model of the rods was modeled and daylight calculations were completed using AGI32, like the previous analyses. The results proved that the regularly occupied floor area between 25 and 500 fc increased for both the 9 am and 3 pm conditions.

Analysis Conclusion

The array of rods as shading devices provides the optimal shading for 9 am on September 21st. The rods provide adequate shading to allow over 75% of the regularly occupied floor area to be between the boundaries of 25 and 500 footcandles, which are the requirements of LEED Credit 8.1. The advantage of the rods over the horizontal overhand or vertical fins is that they will provide shading throughout the entire year when the sun is at varying angles while still providing visibility to the courtyard. Because achieving a LEED Gold certification, the horizontal and vertical shading devices would have been designed for a specific date and time in order to comply with LEED. This would cause the shading to be rather ineffective during other times during the year.

The rods allow for an increase in regularly occupied floor area between the limits of 25 and 500 fc at both 9 am and 3 pm on September 21st. Table 53 below illustrates that the shading rods have positive effects during both criteria times for Credit 8.1, particularly the first floor at 9 am.

Floor	Area at 9 am (ft^2)	% Change in Area	Area at 3 pm (ft^2)	% Change in Area
1st Floor	7,608	+23.3	8,805	+3.9
2nd Floor	11,117	+4.1	10,545	+2.7
3rd Floor	11,117	+4.1	10,545	+2.7
Total	29,842	+14.6	29,895	+3.0

Table 53 - Changes in Regularly Occupied Floor Area due to Shading

The significant increase in regularly occupied floor area between the limits of Credit 8.1 allows for the compliance of the Life Sciences Building with the requirements of this credit. Table 54 below summarizes the new percentages of regularly occupied floor areas and shows how the Life Sciences Building complies with Credit 8.1 and will receive one point for the installation of the shading devices.

Floor	% at 9am	% at 3pm
1st Floor	77.4	79.9
2nd Floor	85.1	86.2
3rd Floor	85.1	86.2
Total	84.1	84.3

Table 54 - Percent of Regularly Occupied Areas on 9/21 between 25 and 500 fc with shading

While providing shading for the Life Sciences Building, the rods maintain continuity with the original façade design. The original façade design of the Life Sciences Building is comprised of copper rain screen panels along the exterior of the ‘J’ shape that are colored like an aged penny; dark and dull. The interior courtyard of the ‘J’ is a glass curtain wall from ground level to the parapet with shadow boxes in the ceiling cavities. The shading rods match the color of the rain screen panels, which continues the façade through the glass courtyard. Figure 36 is an image of the original design for the interior courtyard.

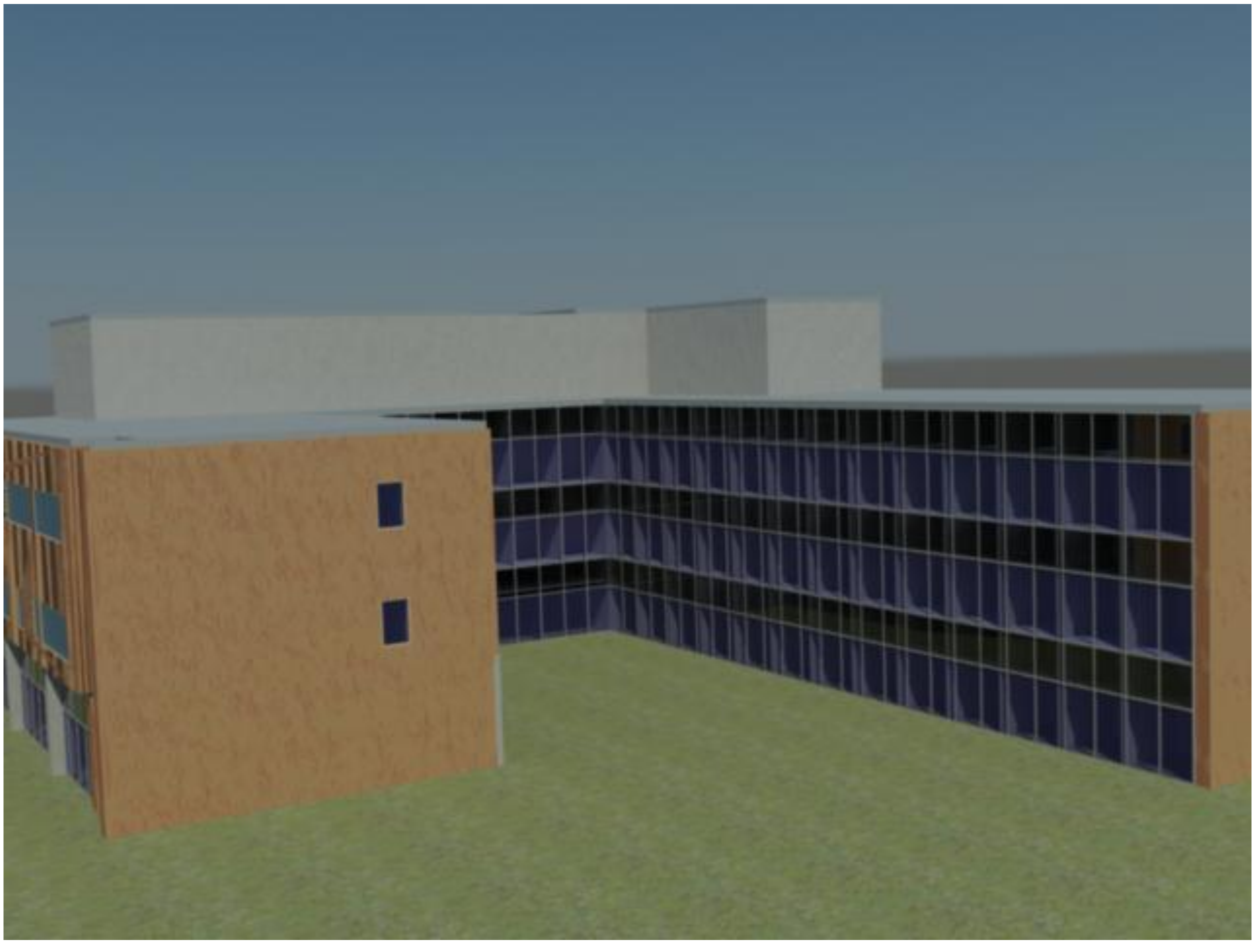


Figure 36 - Rendering of Existing Courtyard Design

Figure 37 below provides the same rendering as Figure 36 with the addition of the shading rods. It is seen that the copper color of the rods wraps the exterior ‘J’ façade around the entire building. The rods work with the existing façade design without making drastic alterations to the sensitive architectural design while adding a great degree of functionality to the solid structure.

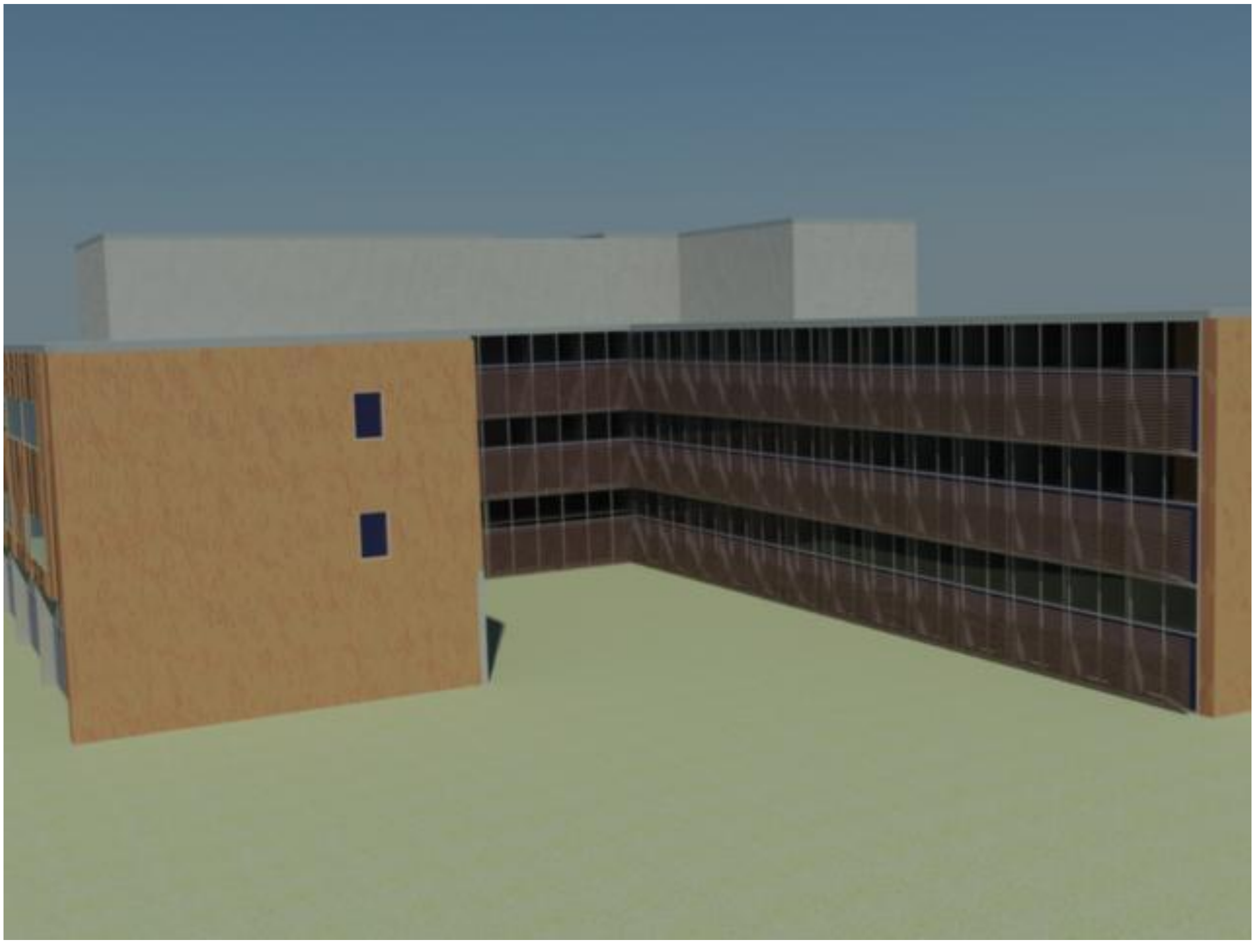


Figure 37 - Rendering of New Courtyard Design

The shading rods are design to be two inches in diameter spaced five inches apart on center. This allows for a three in gap between each rod. Furthermore, the rods are to be installed one foot away from the glass surface. These parameters maintain visibility through the courtyard windows while restricted unwanted direct sunlight. Figure 38 is a rendering of the shading rods on the façade and shows that visibility is still available. The shading rods would be supported by brackets on the end and spaced evenly throughout the span. The brackets would be connected to the mullions which are spaced evenly at 5’-3”. The rods also have a reflectivity of 0.5, which is high enough to reflect a large amount of sunlight, but low enough to provide comfort to the occupant gazing out the window. If the reflectivity were to be too high, the occupant would have the effect of looking out the window into a pile of snow on a sunny day; the view is blinding, painful and uncomfortable. The reflectivity of the rods prevents this phenomenon from occurring.

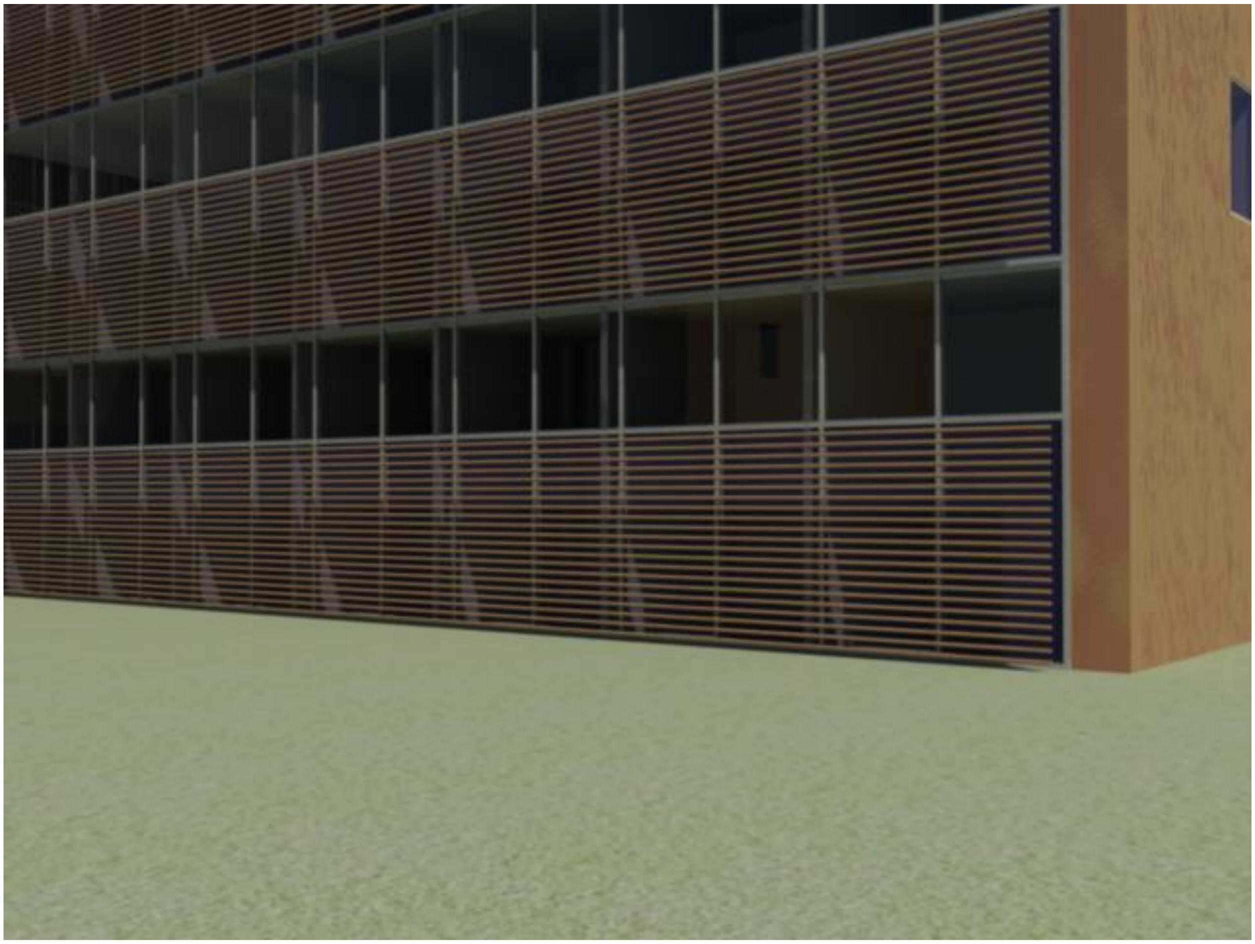


Figure 38 - Close-Up Rendering of Shading Rods on Courtyard Façade

MAE Course Relation Summary

A Masters requirement for the senior thesis report is that Masters level courses must be used within the report. Both depths have utilized Masters level coursework in the studies. 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 about the various systems and equipment found in cooling systems. A section of the course was devoted to modeling pumps and how to optimize pumping arrangements. The pump modeling techniques learned were utilized in the analysis of both depth 1 and 2. The pump model was used in depth 1 to determine the annual energy consumption of the pumps in both the VAV and chilled beam/DOAS systems. The pump model was also utilized in depth 2 when analyzing the energy differences between primary/secondary and variable primary flow pumping arrangements. Furthermore, AE 551 also devoted several classes to the differences between primary/secondary systems and variable primary flow systems. AE 551 also discussed chiller and cooling tower modeling techniques, similar to pump modeling. The chiller and cooling tower models learned in this course were used in depth 2 in order to determine the annual energy consumption of both the chiller and cooling tower.

AE 558 – Centralized Heating Production and Distribution Systems

AE 558 is a course devoted to the various heating systems utilized in the HVAC industry. However, one section among this course was the subject of life cycle cost analysis procedures. The life cycle cost analyses were used for both depth 1 and 2 in order to compare the design alternatives. The life cycle cost analysis is important to the studies because it determines the thirty year savings for each of the alternatives presented.

Conclusion

Decentralized Air System

The analysis of the VAV versus the combination chilled beam and DOAS systems proves the chilled beam/DOAS is the better option. This is due to several factors. First, the decentralized air system allows for a 49.9% reduction in supply airflow. Furthermore, even though there is a large decrease in supply airflow, the airflow is still well above the code required ventilation air. This allows for an additional LEED point, which was not obtained before. The 49.9% decrease in airflow equates to a 38.7% reduction in fan electricity consumption and a 39% decrease in annual fan energy cost. On the water side, there is an 18% increase in chilled water flow requirements due to the chilled beam. However, the increase in chilled water flow only requires a 46% increase in pump energy consumption, which equates to a 65% increase in the annual pump energy cost. In terms of dollars, the 39% reduction in fan energy cost equates to a savings of $3,258. The 46% increase in pump energy cost equals $383 more annually. The savings from the decrease in fan energy significantly outweighs the increase in pump energy cost. However, because the Life Sciences Building taps into a campus chilled water system, the chilled water cost must be evaluated as well. The increase in chilled water with the decentralized system causes a 54% increase in chilled water cost, which equates to a $3,527 increase in cost annually. Overall, the decentralized system has a 20% higher energy cost than the VAV system.

With respect to first cost, the decentralized system is $ 253,703 cheaper in material and labor costs. When the 30-year life cycle of the two systems is analyzed, the decentralized system has a 9.7% smaller net present value (NPV). Therefore, even with the higher yearly energy cost, the decentralized air system costs less over the 30-year life cycle.

After the study and analysis of the VAV and decentralized air system, it is recommended that the Life Sciences Building install the chilled beams and dedicated outdoor air units to condition the offices and classrooms. The advantages of the chilled beams and dedicated outdoor air units range from a decreased life cycle cost as well as increased indoor air quality due to the excess outdoor air delivered to the space. Furthermore, the chilled beams allow for independent user control rather than groups of users controlled by one thermostat.

Chiller Plant Design

The analysis of the primary/secondary pumping configuration versus the variable primary flow configuration proves the variable primary flow is the most cost effective option. In both systems, the same amount of cooling is required; the only variable is how the cooling is delivered to the load from the plant. The primary/secondary pumping configuration requires a set of primary pumps to maintain a constant flow through the chiller. The variable primary flow configuration allows the flow through the evaporator to modulate with the load demand of the Life Sciences Building. The overall yearly energy cost of the primary/secondary system is $30,132, while the annual energy cost of the variable primary flow is $28,638. The difference in annual cost is mainly due to the 24.5% decrease in pumping energy with VPF than P/S. Overall, there is a 5% decrease in the plant energy cost with the variable primary flow chiller plant than the primary/secondary chiller plant.

The first cost of each chiller plant is very similar. The variable primary flow chiller plant contains two less pumps than the primary/secondary plant. This equates to a first cost savings of $26,000 with the variable primary flow configuration. When the 30-year life cycle is analyzed for both plants, there is a 5.7% decrease in the NPV of the variable primary flow system than with the primary/secondary.

After the study and analysis of the primary/secondary versus variable primary flow configurations, it is recommended that the Life Sciences Building utilize a variable primary flow plant if a chiller plant is needed. The advantages of a variable primary flow chiller plant range from less first cost to a decrease in annual energy consumption and cost. However, the variable primary flow configuration will need a more complex control sequence to protect the chiller.

Daylighting

The study and analysis of the daylighting system in the Life Sciences Building according to LEED Credit 8.1 concludes that the Life Sciences Building will not meet the requirements of Credit 8.1 at 9 am on September 21st. The illuminance values are above the upper limit of 500 footcandles.

Architecture

The architectural changes were aimed at satisfying the daylighting requirements of LEED Credit 8.1. Therefore, shading rods were mounted on the exterior of the courtyard glass façade. The benefit of the shading rods over horizontal shades for vertical fins is that they provide daylight shading throughout the year rather than simply designing to the specific time requirements of

LEED. Furthermore, the rods are placed at such a distance so that they maintain visibility from the interior of the offices to the courtyard. The rods are also made of the copper material that makes up the façade in order to maintain continuity with the original façade design. Overall, the shading rods will provide the best daylight shading scenarios while maintaining visibility from the offices and continuity with the rest of the façade.

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