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ANDREW KOFFKE
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Reviewed and approved* by the following:

Donghyun Rim
Assistant Professor
Thesis Supervisor

Richard G. Mistrick
Associate Professor of Architectural Engineering
Honors Adviser

* Signatures are on file in the Schreyer Honors College.

ABSTRACT

This report analyzes the Northeast Education Building, which is a new university building project consisting of office space as well as several lecture halls. As a new icon on this university's campus, the building was originally designed with energy in mind striving for a LEED Silver rating. From a mechanical perspective, this thesis report studies the current design to see where potential improvements could be made, ultimately providing an alternative solution to the original project. Overall, the alternative design proposal is analyzed to see whether there are potential benefits to the new system and to understand why the design team may have chosen the original system. For this report, the main study revolves around an analysis of the building's heating and cooling system in the office spaces on the upper levels. As designed, the offices are conditioned utilizing a standard air-driven system with VAV terminal units. While this system is fully capable of conditioning the rooms appropriately, the newly proposed design involves two different hydronic systems – active chilled beams and fan coil units. In general, the main study of this report analyzes whether an air or water driven system operates more effectively and efficiently to heat and cool each space. As stated, the original engineers designed this building with energy in mind; therefore, one of the main goals of the redesign system was to enhance this project with an energy efficient system that would offer future payback in both utility costs and energy usage.

The other main component of this thesis report was to analyze the potential daylighting benefits in conjunction with the proposed mechanical design. Currently, the architecture of the Northeast Education Building is underutilized with respect to daylighting. As one system, the mechanical and electrical designs should utilize more natural light in the building to improve the

cost reduction benefits and provide a more aesthetically pleasing environment for the students and professors alike. By implementing a photocell design in the circulation spaces in addition to providing new LED luminaires, the building realizes potential energy benefits with this newly specified equipment. Given the analysis provided by both the mechanical and electrical system redesigns, this report also shows the difference in upfront capital costs in addition to potential pay back periods. While saving energy is a beneficial part of new building designs, owners will not realistically consider the more expensive technology if it does not prove to be cost effective. This report shows how each redesign compares when new equipment is specified as well as the potential cost savings on downsized equipment and materials. Ultimately, between all three major studies, the Northeast Education Building is redesigned in a logical, energy efficient manner. And while some of the hypothesized studies did not prove to be as beneficial as originally thought, there are several design considerations and further studies that would benefit the original design.

This report shows the following information:

Hydronic System Study		Mechanical | Construction
Option A: Chilled Beams	*Option B: Chilled Beams*	*Option C: Fan Coils*
78% air savings	62% air savings	32% air savings
Annual energy savings: $7,800	Annual energy savings: $6,500	Annual energy savings: $1,100
Capital Costs: $282,000 (14 yrs.)	Capital Costs: $270,000 (18 yrs.)	Capital Costs: $268,000 (N/A)
Electrical System Study		**Electrical Breadth**
Photocells w/ Dimming Ballasts		*T8 LED Luminaire*
Energy savings: 32.15%		Energy savings: 15%

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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Chapter 1 | Existing Systems Overview

Equipment

Heating Equipment

Campus Central Heating Plant

This campus consists of five central heating plants to maintain all of the buildings at the appropriate condition during the winter months. Of the five heating plants, the one that supplies the hot water for the Northeast Education Building has the capacity to produce 85 million BTU/hour.

Heat Exchanger

With the newly implemented high temperature hot water distribution piping, the central plant is able to deliver the appropriate water to the Northeast Education Building. Located within the building in the Lower Level Mechanical Room, there is a water-water heat exchanger. This particular heat exchanger supplies all of the hot water for the entire building and is piped into the building through 6-inch pipes. Overall, this heat exchanger (HE-1) consists of four tube passes with the capacity to handle 325°F water at 215 GPM. Piping in this high temperature hot water allows the water-water heat exchanger to produce a minimum of 8,000 MBH for use throughout the building.

Equipment

Throughout the building, there are several types of equipment that are utilized to heat the spaces. More specifically, finned tube radiation is used within the two lecture halls located on the third floor. The four main lecture halls in the building were designed with a displacement ventilation or floor distribution system, which accounts for the cooling and heating of the daily occupants. Because the upper lecture halls were not designed in this fashion, but rather have a typical ceiling distribution system, there is a need for finned tube radiation on the perimeter of the building spaces. Located on the east wing, the radiant tubing is all Type A specified by BR+A. In essence, each tube has a minimum of 650 BTUH per foot with an average temperature of 170°F. Other equipment used within the building consists of hot water unit and cabinet heaters. The cabinet heaters are located within the stairwells as an easy way to displace the colder air in the winter months. These are primarily utilized to aid in the building envelope air infiltration within the stairwell shafts. On the other hand, the hot water unit heaters are connected to the air handling unit water lines. These heaters are designed to help in the preheat process of the air entering the DOAS systems; there are several of them along the pipeline into the units. For the majority of the office and classroom spaces, air terminal boxes are used to control the conditioning of the room.

Cooling Equipment

Chiller Plant

The Northeast Education Building has its own chiller plant located within the Level Four East Penthouse. This plant consists of two cooling tower cells and two centrifugal chillers. In total, this system serves 600 tons of chilled water to nine air handling units that distribute air across the building. Each chiller has a 12°F differential with a leaving water temperature of 45°F. Both centrifugal units have been specified to have a NPLV equal to 0.406 and a 188.3 kW compressor. Similarly, each cooling tower cell is designed for a 300-ton capacity with a 600 GPM rating. Both are equipped with 10MPH, VFD motors that account for the 15°F range and 7°F approach to deliver the correct water temperature to the chillers.

Airside Distribution

Air Handling Units

Shown below is a general outline of the eleven air handling units that maintain the airside distribution and temperature of the Northeast Education Building (see Table 1). The main units within the building consist of the recirculation and DOAS systems in each respective wing. Both the East and West Wing units are designed as a typical 30% OA system with a full economizer mode. These units serve the majority of the support spaces such as all corridors and restrooms in addition to the office and classroom space distributed across the building. On the other hand, each DOAS system in the two wings of the building is designed to properly ventilate the main lecture halls on the Ground Level. As mentioned above, these lecture halls consist of a displacement ventilation system below the seating in each row.

These systems are coupled with the RAHU or reheat systems located beneath each tiered lecture hall on this level. The reheat system acts as a recirculation device to maintain the proper temperatures in the space while the DOAS system ventilates based on the 300-person capacity. An additional feature to each main system in the building wings is the enthalpy wheel energy recovery system that is designated by the EAHU units in Table 1. These units have a plenum return fan that pulls air from the respective spaces and extracts the heat that is mixed with the incoming outdoor air. The last note shown below is the use of pre-filter and after-filters for the air handling units. All of the units utilize the MERV-8 and MERV-13 filters when conditioning the air except AHU-3, which is only used to condition the Main Electrical Room.

Table 1. Air Handling Unit Design Conditions

Unit	System	Total CFM	O.A. %	Energy	Preheat/Reheat	Filters	
						MERV-8	MERV-13
AHU-W-2	West Wing	75,000	30%	Full Economizer Mode	Preheat	X	X
AHU-W-1	DOAS West	25,000	100%	Enthalpy Wheel	Preheat	X	X
EAHU-W-1	Energy Recovery West	25,000	-		-	X	X
AHU-E-2	East Wing	40,000	30%	Full Economizer Mode	Preheat	X	X
AHU-E-1	DOAS East	30,000	100%	Enthalpy Wheel	Preheat	X	X
EAHU-E-1	Energy Recovery East	30,000	-		-	X	X
RAHU-1	Tiered Lecture Hall	10,000	30%	Return Air Bypass	Reheat	X	X
RAHU-2	Tiered Lecture Hall	10,000	30%	Return Air Bypass	Reheat	X	X
RAHU-3	Tiered Lecture Hall	10,000	30%	Return Air Bypass	Reheat	X	X
RAHU-4	Tiered Lecture Hall	10,000	30%	Return Air Bypass	Reheat	X	X
AHU-3	Main Electrical Room	5,000	-	Full Economizer Mode	-	X	

Air Terminal Units

All eleven of the air handling units serve air terminal units, both variable volume and constant volume, located throughout the building. All of the main boxes are selected from six different sizes chosen according to the design airflow that the box is tracking. While this is fairly consistent, there are also specialty boxes that have been specified for this job as well. Located within the Lower Level and Level Three lecture halls are classroom terminal boxes that focus on the sound control associated with the air distribution. These units all have sound attenuators built into their casing due to the amount of air they are distributing for these larger spaces.

Water Distribution

Table 2. Pump Design Conditions

Unit	System	Type	Design Pump Data		
			Capacity (GPM)	Total Head (FT. H_2O)	Max NPSH
CHP-1	Chilled Water	End Suction	600	75	7.5
CHP-2	Chilled Water	End Suction	600	75	7.5
CWP-1	Condenser Water	End Suction	600	50	7.5
CWP-2	Condenser Water	End Suction	600	50	7.5
HWP-1	Preheat/Reheat	End Suction	400	75	5.0
HWP-2	Preheat/Reheat	End Suction	400	75	5.0
HWP-AHU-E-1	Freeze Protection	Inline	80	10	2.6
HWP-AHU-E-2	Freeze Protection	Inline	55	10	2.6
HWP-AHU-W-1	Freeze Protection	Inline	70	10	2.6
HWP-AHU-W-2	Freeze Protection	Inline	95	10	2.6

Hot Water Pumps

Table 2 outlines all of the pumps that are used to distribute water throughout the building. Relative to the chilled water system, there are two end suction, chilled water pumps that are linked directly to each centrifugal chiller. Similarly, there are also two end suction, condenser water lines that each have an associated pump. All four of these pumps have a consistent capacity of 600 GPM and a maximum net positive suction head of 7.5.

Chilled Water Pumps

On the hot water side, there are two different types of pumps utilized to distribute the necessary water. Similar to the chilled water system, the two main hot water pumps are end suction with a 400 GPM capacity. Both of these pumps incur 75 feet of head and have a maximum NPSH of 5.0. On the upper levels of the building, there are four different pumps that are associated with the four main air handling units. These particular pumps are all inline-type with capacity ranging from 55-95 GPM. The main function of all four of these pumps is to prevent freezing on the cooling coil as the air handling unit conditions the outdoor air. The associated head with each of these pumps is about 10 feet of head, which is relatively low comparatively.

System Schematics

Chilled Water Plant

As previously discussed, the building's chiller plant consists of two cooling tower cells and two centrifugal chillers. Shown below in Figure 1, each cell has a VFD that is dependent upon the required airflow needed in the cooling tower. Other sensors located within the cells include a basin temperature sensor as well as a water level sensor to track the performance of the cooling towers. These sensors will adjust properly dependent upon the building's need for chilled water. To help the chillers track their performance as well, there are pressure sensors on either side of the supply and return lines. Given that the return water may be cold enough without utilizing the cooling towers, there is a bypass line that is monitored by a chilled water return temperature sensor.

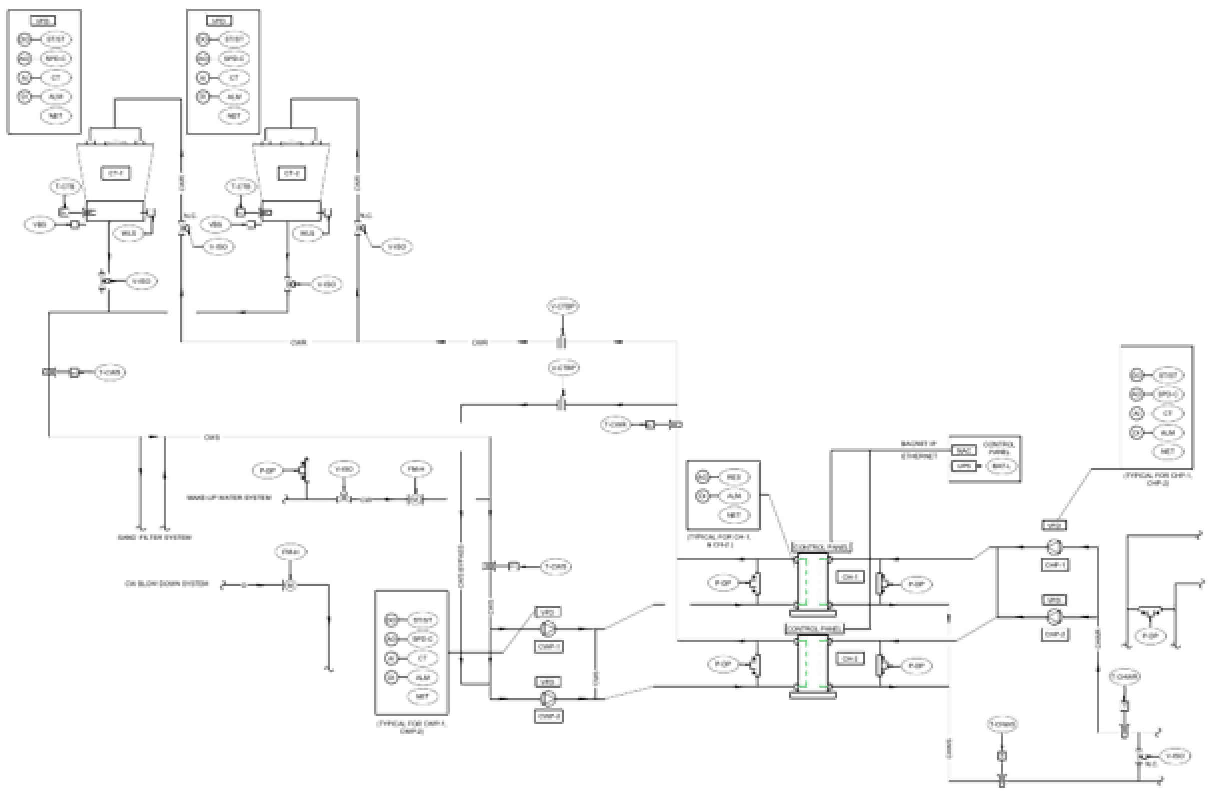

Figure 1. Chilled Water Plant Controls

Hot Water Plant

As with the chilled water plant controls, most of the hot water plant is dependent on the building requirements. There are valves that regulate how much hot water is being pumped from the campus hot water system. All of these associated valves are monitored by temperature sensors on the supply and return lines. In addition to the temperature sensors, there are also pressure differential sensors located on each of the pumps that help track how much water is being circulated throughout the building.

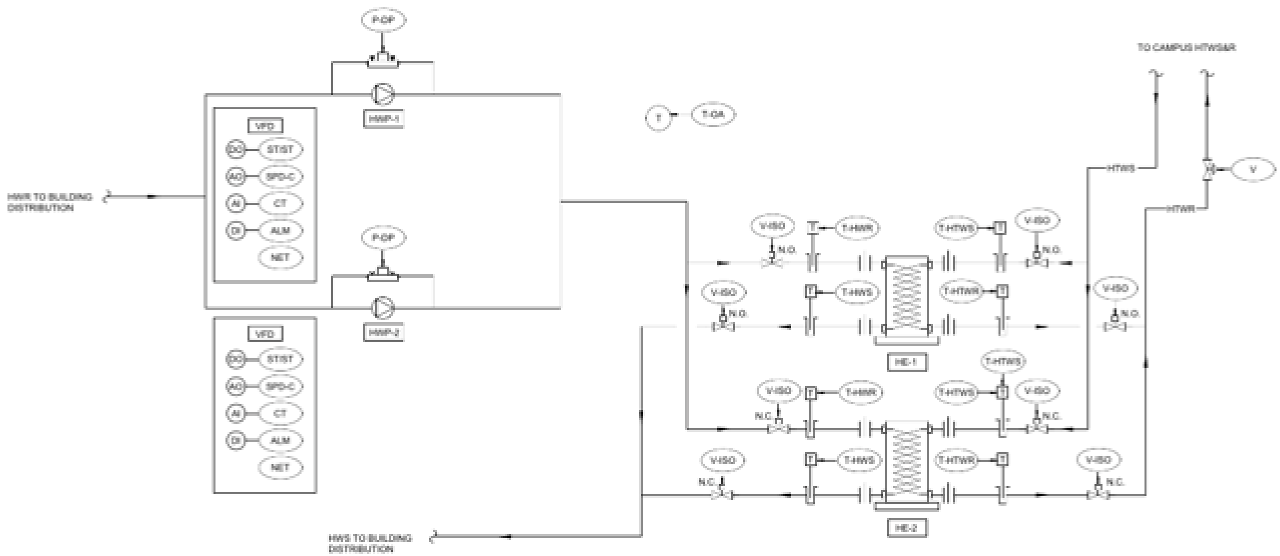

Figure 2. Hot Water Plant Controls

DOAS System Controls

Starting at the outdoor air inlet in the bottom left corner, there are several dampers that are directly linked to the exhaust dampers (see Figure 3). Both of these sensors monitor the associated temperatures and air quality conditions to adjust how much air should be entering and leaving from the ducted system. As the air enters the DOAS system, it flows directly through the enthalpy wheel, which is collecting energy that would otherwise be lost. Depending on the temperature of the outdoor air following the enthalpy wheel and the mixing process with return air, there is also an additional preheat coil as well as a cooling coil. The associated valves that track the relative temperatures in the room and entering/exiting the ducts regulate the amount of water flowing through each coil. Before fully entering the ductwork to be delivered into the room, the air flows through two different filters as shown before.

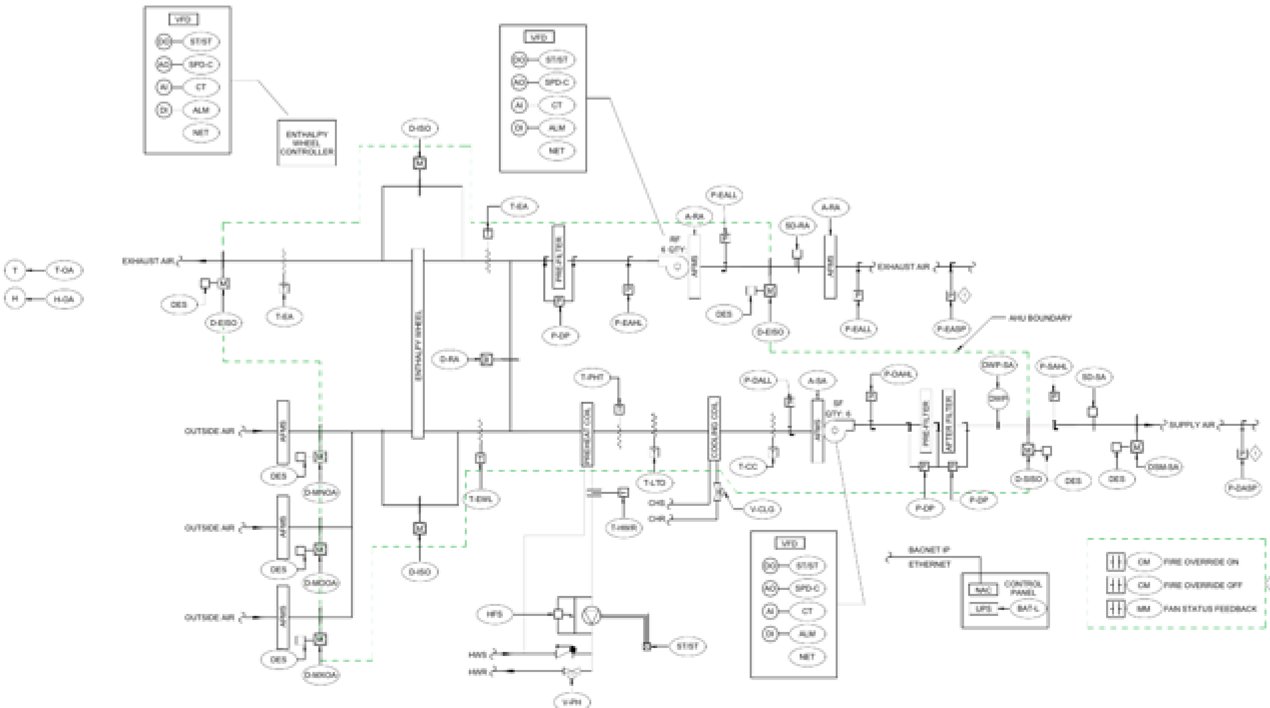

Figure 3. DOAS Controls

East & West AHU Controls

Similar to the last AHU system control scheme, Figure 4 shows dampers located on the supply, exhaust, and return ducts. Each of these regulates the amount of air that can be mixed appropriately to condition the building space. However, different than the previous scheme, the pre-filter and after filter are located following the mixed air condition. Once filtered, the air goes through the preheat and cooling coils to further condition the air. Pressure sensors are located on either side of the supply distribution return air fans to regulate the associated VFD.

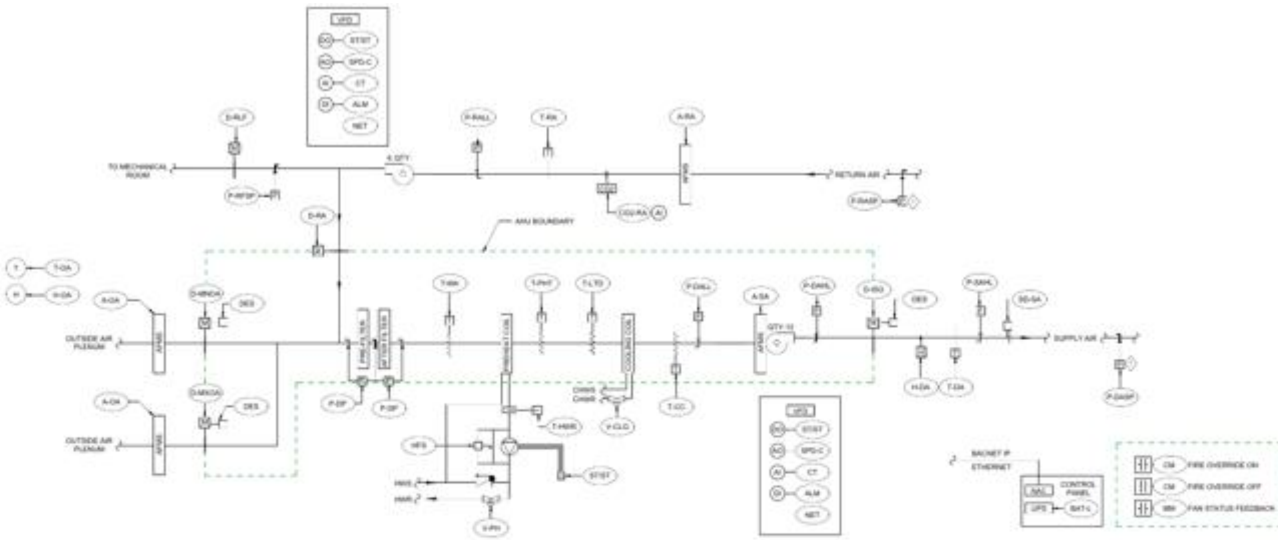

Figure 4. 30% OA AHU Controls

Tiered Lecture Hall Controls

As a continuation from the DOAS system controls above, this ventilation air enters the RAHU controls scheme in the bottom left corner (see Figure 5). Similar to both previous designs, there are dampers on the associated supply, return, and exhaust ductwork. Once mixed, there is a temperature sensor that modulates whether or not water should flow through the cooling coil or the reheat coil. As air flows through the lecture halls and returns in the plenum, there are temperature and CO_2 sensors that analyze the air quality. This directly impacts whether or not the air can bypass the mixing process and recirculate through the reheat coil to flow back into the respective space.

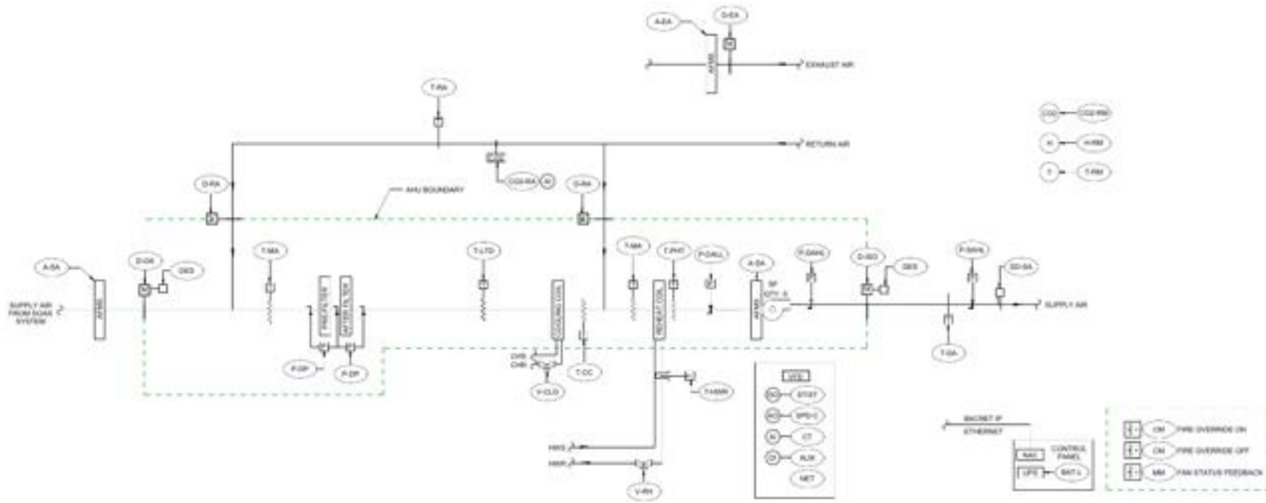

Figure 5. RAHU Controls

Air Distribution Box Controls

Both Figure 6 and Figure 7 have an identical controls scheme with regards to the main reheat system within the VAV box. Thermostats and CO_2 sensors within the designated spaces regulate these boxes. By controlling the boxes with these two sensors, the associated valve V-RH is able to open and close appropriately for the box to recirculate and reheat the air. The main difference between Figure 6 and 7 is the addition of fin-tube radiation along the perimeter. Similar to the reheat valve, the V-RAD valve is also modulated by the thermostat and CO_2 sensor within the respective space. This will regulate how much hot water is circulated within the coil to heat the perimeter of the lecture halls.

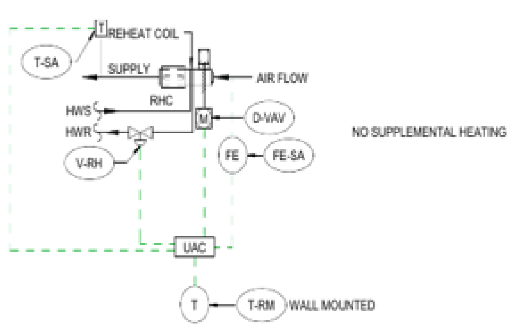

Figure 6. Box Controls w/ Fin Tube Radiation

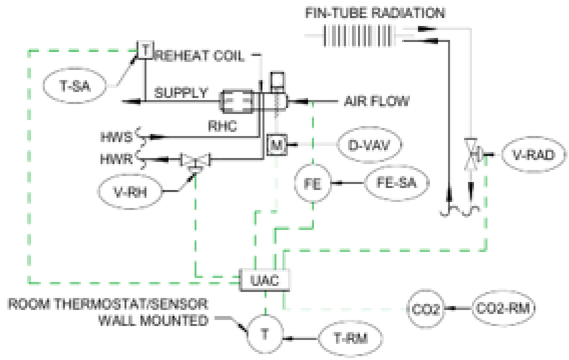

Figure 7. Box Controls w/o Fin Tube Radiation

Mechanical Space Requirement

In total, there is a significant amount of mechanical space allotted as shown to the right in Table 10. This table shows the breakdown of the overall space that is occupied by any mechanical equipment. For example, in the Lower Level Mechanical space, this is where the 6-inch campus piping hooks into the main heat exchanger. Similarly, each RAHU located on the Lower Level has its own mechanical room underneath the tiered lecture hall.

Table 3. Mechanical Space

Space	SF
Mech. Pent. East	10,403.00
Cooling Tower	848.00
Mech. Pent. West	10,594.00
Lower Level Mech.	2,559.00
RAHU-1	1,805.00
RAHU-2	646.00
RAHU-3	288.00
RAHU-4	996.00
Shafts	2,054.00
Total	**30,193.00**

With eleven air handling units to distribute air within this building, there are two main floors, one in each wing that are designated solely to mechanical equipment. The east wing penthouse supports the cooling towers and chiller setup in addition to the two main AHUs that distribute air. Likewise, the west wing penthouse is dedicated to all of the air handling units that supply the west wing lecture halls, office spaces, corridors, and all other support spaces. This building, unlike most designs, has a very strong mechanical presence in regards to overall square footage occupied. From the original 200,000 SF, the mechanical spaces above occupy about 15% of the total building usable space.

Building Load Estimation

In the original analysis that BR+A performed to calculate the respective airflows and energy consumption, Trane TRACE was used as the primary software. For this report, the original analysis was used as the 'base case', and Trane TRACE was again utilized to compare the proposed design changes. Additionally, BR+A had created an eQuest model to analyze the energy consumption in the Northeast Education Building. This model was also updated to reflect the proposed design changes and the results can be found below.

Design Conditions

Outdoor Design Conditions

Provided below in Table 4 are the outdoor design considerations used to design the Northeast Education Building. There are two sets of data provided – the first cited from the ASHRAE 2009 Fundamentals Handbook and the actual design parameters specified by BR+A. As shown in Figure 8, this building is located in ASHRAE 90.1 Climate Zone 4A. This Climate Zone is defined by ASHRAE as a mixed – humid climate.

Table 4. Outdoor Design Specifications (ASHRAE 2009 Fundamentals Handbook)

	Coldest Month	*Heating Dry Bulb (96.6%)*
ASHRAE	*January*	9.9
Designed		10.0

Warmest Month	*Cooling (0.4%)*		*Dehumidification (0.4%)*		
	Dry Bulb	Mean Coincidental Wet Bulb	Dew Point	Hour	Mean Coincidental Wet Bulb
July	92.3	75.0	75.2	132.4	81.8
	91.1	73.1	-	-	-

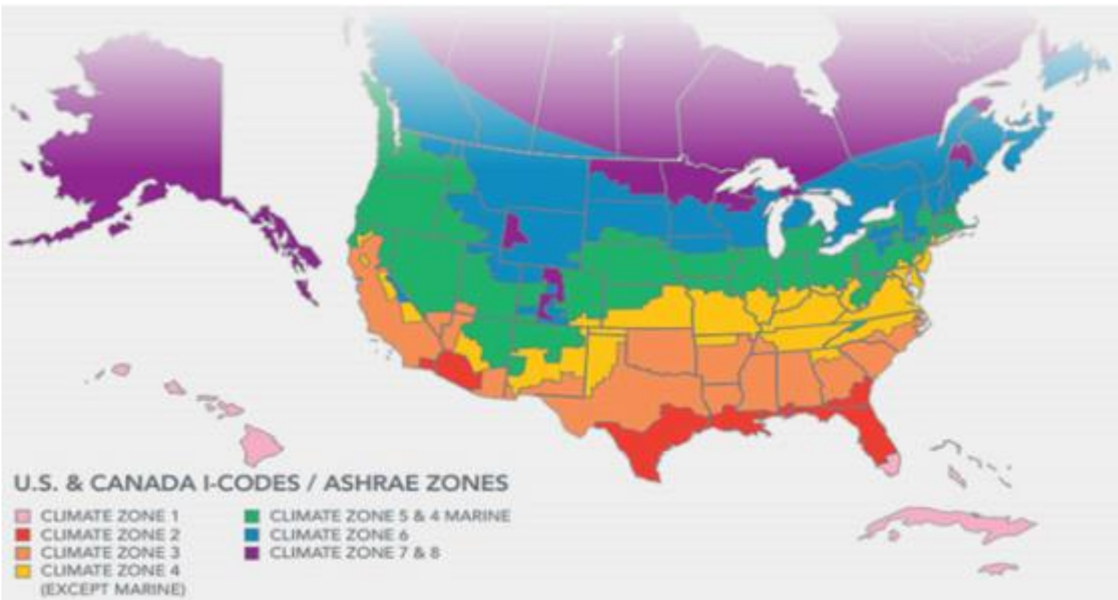

Figure 8. ASHRAE 90.1 Climate Zone Map

Indoor Design Conditions

Shown below in Table 5, there were four main spaces that BR+A analyzed during their indoor air design. Overall, the indoor air temperatures were set to be 75 ºF during the summer and 70 ºF during the winter. The Northeast Education Building has more design restrictions in the summer, trying to maintain the relative humidity at 50% and the wetbulb temperature at 62.5 ºF.

Table 5. Indoor Design Specifications (BR+A)

Indoor Design Conditions	db (°F)	wb (°F)	RH (%)	h (BTU/lbm)	Supply Air Enthalpy
Summer Office/Conference/Classroom/Lecture Hall Design Conditions	75	62.54	50	28.149	22.91
Winter Office/Conference/Classroom/Lecture Hall Design Conditions	70	-	-	-	13.34

Building Construction

The following building construction was utilized in every rendition of the Trane TRACE model. From the original base load scenario calculated by BR+A to the newly proposed design, these inputs were constant in creating the energy model.

Table 6. Building Construction and Associated U-values

Type	Layer Description	U-value	Shading Coefficient
Wall	Face brick, 12" HW Conc., 1" insul.	0.168	-
Roof	Steel sheet, 5" insul.	0.066	-
Window	Double clear 1/4"	0.630	0.80

Building Load Assumption

Typical Room Lighting & Miscellaneous Loads

Table 7. Energy Model Inputs & Design Specifications

Room Type	People (Count)	Lights (W/SF)	Misc. Load (W/SF)	Temp. Setpoint (°F)	Air Changes/ Hour
Break Room (8 People)	8	1.2	1.5	75	-
Breakout Space	10 SF/P	1.3	1	75	-
Café	15 SF/P	1.4	1	75	-
Classroom Support	40 SF/P	1.4	1	75	-
Conference (12 People)	12	1.3	1.5	75	-
Conference (25 People)	25	1.3	1.5	75	-
Conference (49 People)	49	1.3	1.5	75	-
Corner Office	100 SF/P	1.1	2	75	-
Corridor	0 SF/P	0.5	0.25	75	-
Fire Command Center	0 SF/P	1.5	0.25	75	-
Fire Pump/Water	0 SF/P	1.5	0.25	75	-
Flat Classroom (120 People)	120	1.4	2	75	-
General Access Lab	40 SF/P	1.4	2	75	-
Janitor	0 SF/P	0.8	0.25	75	10
Language Lab (40 People)	40	1.4	2	75	-
Lecture (300 People)	300	1.4	2	75	-
Lobby/Corridor/Study	150 SF/P	1.3	0.75	75	-
Lobby/Security	150 SF/P	1.3	0.5	75	-
Media Lab	40 SF/P	1.4	2	75	-
Office	100 SF/P	1.1	2	75	-
Open Office	100 SF/P	1.1	2	75	-
Quiet Study	100 SF/P	1.2	1	75	-
Reception	34 SF/P	1.2	1	75	-
Seminar (20 People)	20	1.4	2	75	-
Stairwell	0 SF/P	0.6	0.25	75	-
Storage	0 SF/P	0.8	0.25	75	-
Tiered Classroom (120 People)	120	1.4	2	75	-
Toilet	0 SF/P	0.9	0.25	75	10
Vestibule	0 SF/P	0.5	0.25	75	-

As seen above in Table 7 and previously in Table 6, the set point temperature for all of the building spaces was designed for 75F. Likewise, all of the inputs shown in Table 7 depict how each space was analyzed in the original and newly proposed designs. Each space has a determining factor or factors depending on the expected occupancy, lighting requirements, or equipment requirements. Spaces such as restrooms or janitorial closets have an associated air changes per hour specification because these rooms are typically driven by the exhaust air system.

Ventilation Requirements

This building design focuses mainly on lecture halls, classroom, and office space; therefore, there is a large amount of humidity that this system must condition. Overall, there are four main air handling units that provide the air distribution across all six occupied floors. Two of these systems, AHU-E-1 and AHU-W-1, are designated outdoor air systems (DOAS) that serve mainly the larger lecture halls and classroom spaces. These spaces also have smaller individual recirculating units; however, with a 300-person capacity for each lecture hall, the indoor air requirements are extremely stringent when it comes to ventilation.

These two systems strictly ventilate and condition these larger spaces, whereas, the remaining two units, AHU-E-2 and AHU-W-2, cover the smaller classroom and office spaces in the building. Both air handling units have a larger air distribution capacity than the DOAS systems and utilize air-side economizers and an enthalpy wheel to extract some of the exhaust heat. All in all, the building's ventilation was designed depending on whether the systems were heating or cooling in the respective seasons. As seen below in Table 8, both the AHU-E-2 and W-2 were designed with a 30% OA economizer having both of these units focus primarily on the office spaces, conference rooms, and corridors. On the other hand, AHU-E-1 and W-1 were designed as 100% OA for the large lecture halls and classroom spaces. Below this table, however, all of these systems' OA rates are adjusted for heating. Table 9 displays a new ventilation scheme for almost every one of the four units. The recirculating unit, AHU-W-2, has been adjusted from 30% to 100%, but the other respective unit remains at 30% during heating. Likewise, the DOAS systems have also been adjusted; however, these have been decreased from 100% OA to 50%.

Table 8. Cooling Air Handling Unit Loads (BR+A)

System	Area	Total CFM	CFM/SF	O.A. %	Outdoor Air CFM
Recirculation West (AHU-W-2)	81,183	65,379	0.8	30%	9,900
DOAS West (AHU-W-1)	18,366	34,617	1.9	100%	13,015
Recirculation East (AHU-E-2)	28,274	30,664	1.1	30%	4,034
DOAS East (AHU-E-1)	20,293	44,160	2.2	100%	14,461
AHU Cooling Totals	**148,116**	**174,820**	**1.2**	**-**	**41,410**

Table 9. Heating Air Handling Unit Loads (BR+A)

System	Area	Heating CFM	CFM/SF	O.A. %	Outdoor Air CFM
Recirculation West (AHU-W-2)	81,183	52,303	0.6	100%	52,303
DOAS West (AHU-W-1)	18,366	25,963	1.4	50%	12,981
Recirculation East (AHU-E-2)	28,274	22,998	0.8	30%	6,899
DOAS East (AHU-E-1)	20,293	33,120	1.6	50%	16,560
AHU Heating Totals	**148,116**	**134,384**	**0.9**	**-**	**88,744**

Original Estimation Results

Based on the design assumptions above, the model heating and cooling loads were calculated using TRANE Trace 700 to give a general estimate of the required airflow within the Northeast Education Building. As shown in Table 10, there are a few discrepancies between the model and designed heating and cooling loads. For example, the Total OA CFM of the two DOAS systems were only calculated for about 50% of the designed quantities.

This discrepancy is most likely an "error" on the TRACE software because of the system limitations that do not allow the user to input a true DOAS system. While the Trace inputs reflect a 100% OA requirement, there are other design factors that are not accounted for in the program and reflect this discrepancy between the model and design loads. Ultimately, this is one of the limitations of TRACE, and while it provides a general reference for designing building airflows, it cannot be the only means of calculations. As shown in the table, BR+A adjusted their design sizes from the original Total Supply column to the designed Actual Size column, which was taken from the design documents.

Table 10. Heating & Cooling Load Comparison (Design Values provided by BR+A)

	Air Handling System	Total Supply [CFM]	Total OA [CFM]	Heating [MBh]	Cooling [Ton]	Actual Size [CFM]
MODEL	*DOAS East AHU-E-1*	39,722.00	14,463.00	597.00	132.80	-
	DOAS West AHU-W-1	34,279.00	13,428.00	510.00	119.90	-
	Recirc. East AHU-E-2	28,801.00	4,471.00	744.00	80.90	-
	Recirc. West AHU-W-2	58,972.00	10,283.00	1,545.00	173.20	-
	TOTAL	**161,774.00**	**42,645.00**	**3396.00**	**291.79**	**SF/Ton**
DESIGN	*DOAS East AHU-E-1*	44,160.00	30,000.00	580.00	202.00	30,000.00
	DOAS West AHU-W-1	34,617.00	25,000.00	651.00	158.00	25,000.00
	Recirc. East AHU-E-2	30,664.00	11,600.00	331.00	93.00	40,000.00
	Recirc. West AHU-W-2	65,379.00	21,750.00	3,513.00	199.00	75,000.00
	TOTAL	**174,820.00**	**88,350.00**	**5,075.00**	**226.81**	**SF/Ton**

Energy Consumption & Associated Costs

The following section describes the building's energy consumption as originally designed based on the two energy models that were created in eQuest and Trane TRACE 700. In addition to the energy consumed, this section will outline a monthly and annual utility cost outlining the different electrical and mechanical systems in the Northeast Education Building. For larger images of the provided graphs, please see Appendix A.

Building Energy

Sources

The Northeast Education Building has two means of obtaining the energy required to operate the building. To provide the appropriate heating, the building utilizes the updated university high-temperature heating system. This central cogeneration plant provides electricity and central heating to two of the five campuses located within this university. Once piped into the building, there is a water-water heat exchanger that has a minimum capacity rating of 8,000 MBH.

Conversely, while the heating is provided by the campus system, the cooling plant has been designed within the Northeast Education Building itself. As shown previously in Figure 1: Chilled Water Plant, the building was designed with a two-cell cooling tower and two centrifugal chillers that have a 600-ton capacity for the overall building needs. All in all, the building design could be altered in which there is an associated boiler to produce the heat required in the system. However, with the updated cogeneration plant and high-temperature piping system, this is an unnecessary addition to the building design. BR+A utilized the campus heating system appropriately while adding the building-generated cooling plant to save additional energy costs.

Rates

The Northeast Education Building is supplied mainly by a cogeneration plant, which produces the necessary electricity and hot water for the building. In Table 11 below, the average utility/ energy costs are listed for the electricity consumed and the cost of purchased hot water from the university. Based on the U.S. Energy Information Administration (eia), the average energy consumption is priced at about 13.69 cents for every kWh used (see Figure 9 below). Some of the required utility cost data is unavailable currently; therefore, the other two rates were based on TRANE Trace values, which reference the pertinent city in which the project is located. Lastly, the water rate used in calculations was referenced from the Water Utility Department in East Brunswick, New Jersey.

Table 11. Energy Rate Analysis

	Electric Consumption (Cents/kWh)	Electric Demand ($/kW)	Purchased Hot Water ($/MMBTU)	Water ($/gallon)
Current Design	$0.1369	$8.13	$4.82	$3.45
Source of Cost	U.S. eia	TRANE Trace	TRANE Trace	East Brunswick Utility

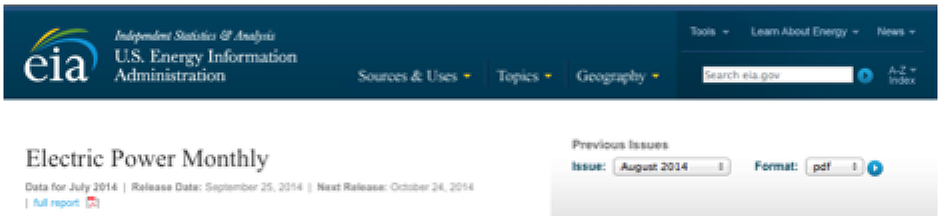

Table 5.6.A. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector,

by State, July 2014 and 2013 (Cents per Kilowatthour)

		Residential		Commercial		Industrial		Transportation		All Sectors	
Census Division and State	Graph	July 2014	July 2013	July 2014	July 2013	July 2014	July 2013	July 2014	July 2013	July 2014	July 2013
New England		**17.17**	**15.68**	**14.37**	**13.80**	**11.59**	**12.61**	**NM**	**NM**	**15.08**	**14.34**
Connecticut		19.45	17.31	14.96	14.37	12.97	12.53	10.06	11.03	16.73	15.55
Maine		15.31	14.26	11.91	11.54	7.96	8.50	--	--	12.22	11.90
Massachusetts		16.27	15.12	14.63	14.45	12.63	13.78	NM	NM	14.96	14.50
New Hampshire		17.23	16.11	13.95	13.30	11.52	11.23	--	--	14.86	14.14
Rhode Island		15.85	13.31	13.54	11.55	12.12	10.75	15.08	13.61	14.36	12.27
Vermont		17.93	17.23	14.73	14.39	10.28	10.10	--	--	14.79	14.46
Middle Atlantic		**16.95**	**16.62**	**13.99**	**13.98**	**7.38**	**7.54**	**12.74**	**12.69**	**13.86**	**13.94**
New Jersey		16.52	16.42	13.58	13.79	11.50	11.92	11.62	9.69	14.69	14.85
New York		20.31	20.04	16.73	16.67	6.36	6.26	14.33	14.38	16.75	17.08
Pennsylvania		13.96	13.12	9.49	9.26	7.10	7.23	7.39	7.74	10.35	10.08

Figure 9. U.S. Energy Information Administration – Electric Power Monthly Rates

Annual Energy Consumption

Electrical Consumption

The annual electrical energy data is shown on the following page in Figure 10. As seen in the figure, the TRACE model developed a consumption graph based solely on the building's on-peak and off-peak consumption rates. In essence, the graph is an additive representation of the total energy usage broken out by the main building systems. This includes the hot water distribution system, chilled water distribution system, air handling units, and overall building lighting.

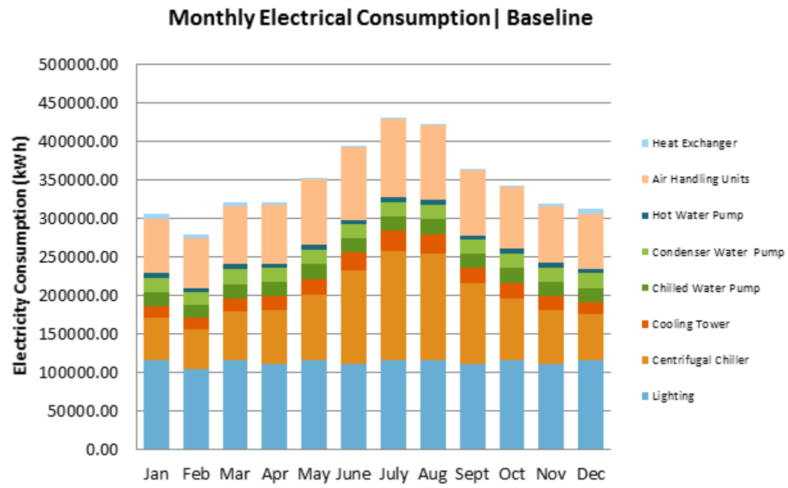

Figure 10. Baseline Monthly Electrical Consumption

Overall, this graph displays a typical energy trend seen in the northeastern part of the country. Simply, from a pictorial representation, it is evident that the highest electrical consumption occurs in the May – August range as the cooling capacity increases and the chiller operation increases as well.

Furthermore, the annual baseline energy consumption is shown below in Figure 11. Unlike Figure 10, the annual report shows the breakdown of each major system as it compares to the overall energy consumption of the building. The three major energy consumers in the original design are the air handling units (23%), centrifugal chiller (25%), and lighting system (33%).

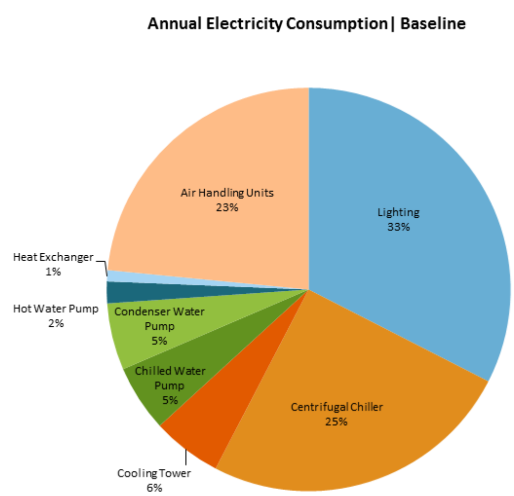

Figure 11. Baseline Annual Electrical Consumption

Again, these results are pretty standard in the northeast region with a typical VAV air distribution system. Overall, the lighting system is the largest consumer on an annual basis, staying relatively consistent each month, which is mainly due to the current lighting controls (see Figure 10). Without harvesting the natural daylight or utilizing occupancy sensors to control the lighting, there is a consistent amount of energy expelled to light the Northeast Education Building.

Water Consumption

Another major factor in the building's energy usage is the annual water consumption for cooling and heating purposes. Shown below, the monthly water consumption for cooling applications is displayed in Figure 12 and heating applications in Figure 13. There is a noticeable correlation between the main water used on a monthly basis between the cooling and heating applications. For example, from June – September there is a spike in the cooling water used to operate the building chilled water systems. This directly correlates back to Figure 10 on the previous page in which the chiller and cooling tower electrical energy usage increases during this time period as well. Similarly, taking a look at Figure 13, there is a spike in hot water purchased during November – April for all of the building's hot water systems. Unlike the monthly water consumption, however, there is minimal hot water purchased during the off-season (June-September), whereas, the water consumption only decreases to about 20% during the winter months.

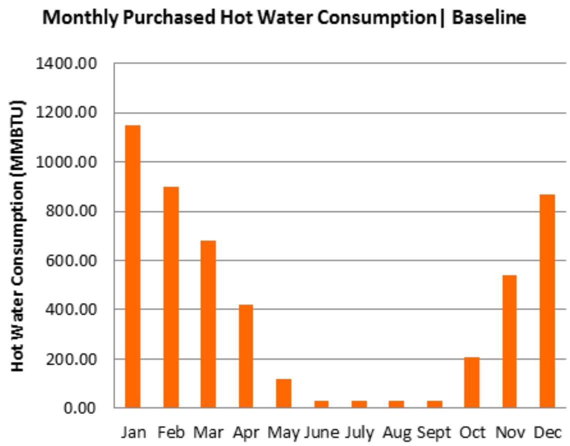

Figure 12. Baseline Hot Water Consumption

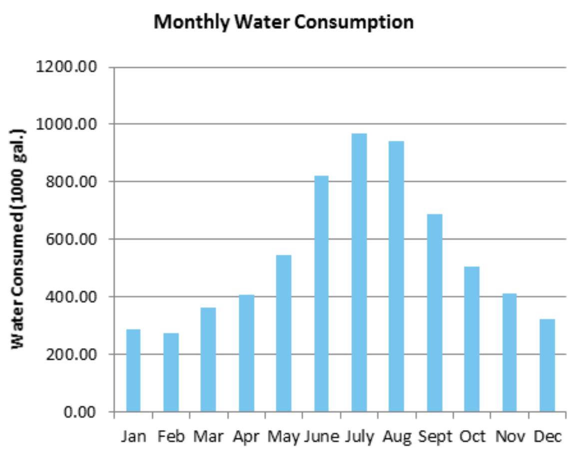

Figure 13. Baseline Water Consumption

Annual Operating Costs

In total, the Northeast Education Building requires about $615,961 to operate based on the provided information to the right. The values shown in the above figures are representative of the TRANE Trace model that has been created for the original project. Shown in Table 12, the Annual Utility Costs are broken down into similar categories based on the overall electrical and water needs. Primarily, electricity plays the biggest part in the utility costs for the Northeast Education Building, consuming about 92% of the total cost. Of this 92%, the lighting and chiller systems are the largest consumers at about 30% and 23% respectively.

Table 12. Energy Rate Analysis

Annual Utility Costs		
Electricity	**$569,260.22**	**92%**
Lights	*$185,171.75*	*30%*
Centrifugal Chiller	*$142,841.36*	*23%*
Cooling Tower	*$31,761.91*	*5%*
CHW Pump	*$30,382.83*	*5%*
CW Pump	*$30,508.74*	*5%*
HW Pump	*$9,926.78*	*2%*
Fan Coil Supply Fan	*$5,104.38*	*1%*
AHU	*$133,562.46*	*22%*
Purchased Hot Water	**$24,148.20**	**4%**
Water	**$22,552.65**	**4%**
Total	**$615,961.07**	**100%**

Likewise, shown on the following page in Figure 14, the annual utility costs are broken down into a monthly graph. From this graph, it is evident that the monthly lighting costs are consistent whereas the cost of the centrifugal chiller and purchased hot water fluctuates with the respective there is a spike in energy from December through January with the increase in purchased hot water; however, this energy increase is about $10,000 less than the spike from June through August. Especially in July and August, there is a significant increase in chiller energy and water usage in addition to the electricity consumption by the air handling units. Overall, the peak utility costs for this building occur in July at about $62,380.

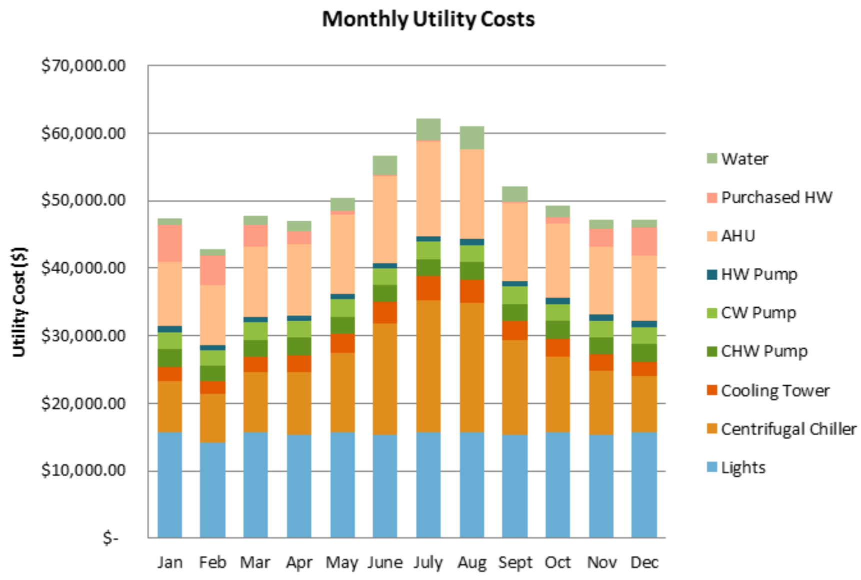

Figure 14. Monthly Utility Costs

LEED Analysis

Attached in the Appendix files is the overall [LEED Master Scorecard], which defines how many points are available for each category and how many were obtained through the original design. As noted in the Master Scorecard, the Northeast Education Building was designed as a LEED Silver project with the potential of 10 additional points following construction. Outlined below are the specific areas in which this building was designed to receive credit for the energy efficient design.

Water Efficiency

Water Use Reduction – 20% Minimum

BR+A and TGE were able to reduce the water usage by at least 20% in the overall building and landscape design. The building's fixture flow rates were specified as the following: Lavatory = 0.5 GPM, Sinks = 1 GPM, Shower = 2 GPM, WC = 1.6 GPF, Urinals = 1 GPF. Additionally, Sufest using the following flush/flow rates to get >40% reduction: Lavatory = 0.1 GPC, Sinks = 1.5 GPM, Shower = 1.8 GPM, WC = 1.28 GPF, Urinals = .125 GPF.

Water Efficient Landscaping – Reduce by 50%, No Irrigation

Two of the four points available were documented because the shrub lawn area is already permanently drip irrigated on campus. There is a French drain system being installed and rain sensor to shut the system off if irrigation is unnecessary. This will provide the 50% reduction needed for this credit.

Energy & Atmosphere

Fundamental & Enhanced Refrigerant Management

The prerequisite for this category was accomplished by BR+A for using compliant HVAC&R refrigerants defined by ASHRAE. The enhanced refrigerant management category is still considered a ‘Maybe’ until the final design is complete and further site testing can be done.

Optimize Energy Performance

Only two of nineteen credits were documented for this specific criterion. According to the USGBC, the project team must demonstrate a percentage improvement in the proposed building performance rating compared with the baseline building performance rating. Calculate the baseline building performance according to Appendix G of ANSI/ASHRAE/IESNA Standard 90.1-2007 (with errata but without addenda) using a computer simulation model for the whole building project. By achieving two points, the Northeast Education Building has provided the following:

New Buildings	Existing Building Renovations	Points
12%	8%	1
14%	10%	2

Figure 15. Minimum Energy Cost Savings Percentage for Each Point Threshold

Indoor Environmental Quality

Minimum Indoor Air Quality Performance

This credit requires the building to fully comply with ASHRAE 62.1-2007. As shown in the Technical Report 1, the Northeast Education Building falls into this category and is fully compliant with the ASHRAE standards.

Outdoor Air Delivery Monitoring & Increased Ventilation

Both of these credits follow the minimum IAQ prerequisite with the chance to obtain one credit from each. As per the design, there are CO_2 sensors to monitor the requirements for increased or decreased ventilation. Likewise, all of the systems and demand loads have been sized for a 30% increase in the ventilation required within the building.

Controllability of Systems – Lighting

In particular, this credit states that individual lighting controls must be provided for 90% (min.) of all building occupants. Ultimately, the individualized controls allow them to adjust the lighting to suit task needs and preferences. Upon completed construction, BR+A will need to confirm that controls will be provided for all of the multi-occupant spaces to enable adjustments that meet group needs and preferences.

Thermal Comfort – Design

This credit requires the project team to meet the requirements of ASHRAE Standard 55-2004, Thermal Comfort Conditions for Human Occupancy (with errata but without addenda). Overall, they must demonstrate design compliance in accordance with the Section 6.1.1 documentation. BR+A has fully complied with ASHRAE 55-2007, which grants them this credit of one point towards the overall LEED accreditation.

LEED Analysis Summary

As a whole, this project has been designed from an energy efficiency standpoint; therefore, there are several elements that have already created a sustainable building. Along with the sustainable design that has been documented in the LEED certification, the overall project team has worked to comply with 54 credits allowing their building to become LEED Silver certified upon completion.

However, while there are several credits that have been covered in the initial design, the analysis provided in this report shows that there are other areas that can be improved upon. For instance, the controllability of the lighting systems is a major category that can be studied. While the larger occupant spaces have been originally accounted for, there are circulation areas that underutilize the amount of natural daylight in this building. Optimizing the energy performance of this building and its associated mechanical systems is another area that was studied heavily in this report. Both of these areas of study would potentially allow the building to receive a LEED Gold certification if further controllability and system monitoring were implemented. This would allow additional credits to be realized for the overall building project.

ASHRAE Standard 62.1 Compliance

ASHRAE 62.1 Section 5: Systems and Equipment

5.1 Ventilation Air Distribution

Ventilating systems shall be designed in accordance with the requirements of the following subsections.

5.1.1 Designing for Air Balancing

The ventilation air distribution system shall be provided with means to adjust the system to achieve at least the minimum ventilation airflow as required by Section 6 under any load condition.

AHU Unit Number	SERVICE	AHU SYSTEM– SEE NOTE 1	AHU QUANTITY	LOCATION	SUPPLY CFM (NOTE 8)	Design Maximum Outside Air (cfm) (Note 12)	Minimum Occupied Outside Air (cfm) (Note 12)
AHU-E-1	EAST WING	A	1	EAST WING PENTHOUSE	30,000	30,000	6,000
EAHU-E-1	EAST WING	A	1	EAST WING PENTHOUSE	–	–	–
AHU-E-2	EAST WING	B	1	EAST WING PENTHOUSE	40,000	11,600	3,750
AHU-W-1	WEST WING	A	1	WEST WING PENTHOUSE	25,000	25,000	5,000
EAHU-W-1	WEST WING	A	1	WEST WING PENTHOUSE	–	–	–
AHU-W-2	WEST WING	C	1	WEST WING PENTHOUSE	75,000	21,750	11,750
						MIN/ECONOMIZER	
RAHU-1	NORTHEAST TIERED LECTURE HALL	D	1	LEVEL 1	10,000	3,300/5,000	1,000
RAHU-2	NORTHEAST TIERED LECTURE HALL	D	1	LEVEL 1	10,000	3,300/5,000	1,000
RAHU-3	NORTHEAST TIERED LECTURE HALL	D	1	LEVEL 1	10,000	3,300/5,000	1,000
RAHU-4	NORTHEAST TIERED LECTURE HALL	D	1	LEVEL 1	10,000	3,300/5,000	1,000
AHU-3	MAIN ELEC ROOM	E	1	LOWER LEVEL	5,000	–	–

1. AHU SYSTEM AND DISTRIBUTION TYPES:
   A. 100% O.A. AHU WITH ENTHALPY WHEEL W/ ENTHALPY WHEEL BYPASS FOR OUTDOOR AIR TURNDOWN.
   B. AHU WITH MIXED RETURN AIR SUPPORTING EAST WING ONLY (W/ FULL ECONOMIZER MODE)
   C. AHU WITH MIXED RETURN AIR SUPPORTING WEST WING ONLY (W/ FULL ECONOMIZER MODE)
   D. RETURN AHU WITH RETURN AIR BYPASS (REHEAT) SUPPORTING TIERED LECTURE HALLS (QTY: 4)
   E. RETURN AHU WITH FULL ECONOMIZER MODE
2. COOLING COIL PERFORMANCE SHALL BE SCHEDULED UPON IN-ACTIVE (BROKEN) HEAT WHEEL OPERATION.
3. PRE-HEAT COIL PERFORMANCE SHALL BE SCHEDULED UPON IN-ACTIVE (BROKEN) HEAT WHEEL OPERATION.
4. SUPPLY & EXHAUST/RETURN TUNNELS SHALL BE STACKED. UNITS SHALL NOT EXCEED 16'-0" IN HEIGHT (INCLUDING BASE & ISOLATORS)
5. SUPPLY & EXHAUST/RETURN TUNNELS SHALL UTILIZE FAN WALL TECHNOLOGY. FAN ARRAY TO BE CONTROLLED BY VFD'S
6. SOUND ATTENUATOR SIMILAR TO VIBRO ACOUSTICS RFL-ULV (3'-0" LONG)
7. ENTHALPY WHEEL SHALL BE SEGMENTED W/ SUPPORTS, HAVE PILLOW BLOCK BEARINGS, AFMS TO MONITOR O.A. CFM, CONTROLS, ECONOMIZER BYPASS.
8. CFM NOTED IS SUPPLY AIR @ DISCHARGE OF AHU AND EXHAUST AIR AT UNIT EXHAUST CONNECTION. (SUPPLY AND EXHAUST FANS TO BE SIZED AS REQUIRED TO ACCOUNT FOR ENTHALPY WHEEL PURGE ALLOWING AN ADDITIONAL 5% OF UNIT CFM.)
9. TOTAL STATIC PRESSURE VALUES SCHEDULED INCLUDE PRESSURE DROPS FOR DIRTY FILTERS.
10. RAHU-1,2,3&4 BASED ON CARRIER SIZE 17 MODULAR TYPE AIR HANDLING UNIT.
11. AHU-3 BASED ON CARRIER SIZE 15 PACKAGED AHU
12. DESIGN MAXIMUM OUTDOOR AIR IS FOR SIZING COILS AND SHOULD BE A MAXIMUM LIMIT ON THE SYSTEM OPERATION WHEN NOT IN ECONOMIZER MODE. MINIMUM OCCUPIED OUTSIDE AIR IS FOR NORMAL SYSTEM OPERATION. OUTDOOR AIR SHALL BE INCREASED ABOVE MINIMUM AS REQUIRED BASED ON LOCAL DEMAND CONTROLLED VENTILATION REQUIREMENTS.

Figure 16. AHU Schedule and Associated Notes

5.1.2 Plenum Systems

When the ceiling or floor plenum is used both to recirculate return air and to distribute ventilation air to ceiling-mounted or floor-mounted terminal units, the system shall be engineered such that each space is provided with its required minimum ventilation airflow.

AIR TERMINAL BOX ASSEMBLY SCHEDULE

UNIT NUMBER	TYPE	ASSEMBLY: DESIGN RANGE CFM MIN-MAX	ASSEMBLY: MAX. APD IN. WG (*)	ASSEMBLY: TURNDOWN MIN. CFM	AIR VALVE MAX. APD IN. WG	HOT WATER COIL AIR SIDE: MAX. HEATING CFM (**)	EAT °F	LAT °F (MIN) (**)	MAX FV FPM	MAX APD IN. WG	MIN ROWS	MAX FPI	MIN FIN THICK. IN.	HOT WATER COIL WATER: GPM	MIN. TUBE O.D. IN.	EWT °F	LWT °F	MAX ΔP FT. WG	INLET STATIC PRESS. (IN.)	SOUND CONTROL SECTION: NOISE CRITERIA (AT LISTED INLET SP) MAX. RAW POWER LEVEL dB (LEAVING ASSEMBLY) DISCHARGE SPL @ 1.5" WG: 125Hz	250Hz	500Hz	1KHz	2KHz	4KHz	MAX. APD IN. WG	LINING HOSPITAL GRADE	MAX. ASSEMBLY DEPTH (IN)	SYSTEM SIDE: CONNECT SIZE (IN)	SYSTEM SIDE: DUCT SIZE (IN)	ROOM SIDE: CONNECT SIZE (IN)	ROOM SIDE: DUCT SIZE (IN)	ACCESSORIES: ACCESS DOOR BEFORE COIL	ACCESSORIES: ACCESS DOOR AFTER COIL	NOTES	REMARKS (ACCEPTABLE MANUFACTURERS SUBJECT TO CONFORMANCE WITH SPECIFICATIONS)
VCV-5	VARIABLE VOLUME	125-250	0.30	60	0.03	125	55	85	360	0.10	1	8	0.0095	0.3	1/2	180	140	10	1.5	67	63	58	56	54	53	0.17	YES	12	5"	6"	12x10	12x6	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR
VCV-6	VARIABLE VOLUME	150-400	0.30	70	0.03	200	55	85	560	0.10	1	8	0.0095	0.6	1/2	180	140	10	1.5	67	63	58	56	54	53	0.17	YES	12	6"	8"	12x10	12x8	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR
VCV-8	VARIABLE VOLUME	300-650	0.30	140	0.03	325	55	85	560	0.10	1	8	0.0095	0.8	1/2	180	140	10	1.5	67	63	58	56	54	53	0.17	YES	15	8"	12"	14x15	14x12	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR
VCV-10	VARIABLE VOLUME	500-925	0.30	225	0.03	463	55	85	560	0.10	1	8	0.0095	1.4	1/2	180	140	10	1.5	67	63	58	56	54	53	0.17	YES	15	10"	14"	16x15	16x12	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR
VCV-12	VARIABLE VOLUME	800-1400	0.30	300	0.03	700	55	85	560	0.10	1	8	0.0095	1.9	1/2	180	140	10	1.5	67	63	58	56	54	53	0.17	YES	18	12"	16"	20x18	20x12	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR
VCV-14	VARIABLE VOLUME	1000-1650	0.30	440	0.03	825	55	85	560	0.10	1	8	0.0095	2.1	1/2	180	140	10	1.5	67	63	58	56	54	53	0.17	YES	18	14"	16"	24x18	24x12	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR
CV-5	CONSTANT VOLUME	65-250	0.30	60	0.03	250	55	85	360	0.10	1	8	0.0095	0.7	5/8	180	140	10	1.5	67	63	58	56	54	53	0.17	YES	12	5"	6"	12x10	12x6	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR
CV-6	CONSTANT VOLUME	75-400	0.30	70	0.03	400	55	85	560	0.10	1	10	0.0095	1.2	5/8	180	140	10	1.5	67	63	58	56	54	53	0.17	YES	12	6"	8"	12x10	12x8	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR
CV-8	CONSTANT VOLUME	150-650	0.30	140	0.03	650	55	85	560	0.10	1	10	0.0095	1.5	5/8	180	140	10	1.5	67	63	58	56	54	53	0.17	YES	15	8"	12"	14x15	14x12	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR
CV-10	CONSTANT VOLUME	250-925	0.30	225	0.03	925	55	85	560	0.10	1	10	0.0095	2.3	5/8	180	140	10	1.5	67	63	58	56	54	53	0.17	YES	15	10"	14"	16x15	16x12	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR
CV-12	CONSTANT VOLUME	350-1400	0.30	300	0.03	1400	55	85	560	0.10	1	10	0.0095	3.1	5/8	180	140	10	1.5	67	63	58	56	54	53	0.17	YES	18	12"	16"	20x18	20x12	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR
CV-14	CONSTANT VOLUME	475-1650	0.30	440	0.03	1650	55	85	560	0.10	1	10	0.0095	3.7	5/8	180	140	10	1.5	67	63	58	56	54	53	0.17	YES	18	14"	16"	24x18	24x12	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR
VV-5	VARIABLE VOLUME	125-250	0.20	60	0.03	—	—	—	—	—	—	—	—	—	—	—	—	—	1.5	67	63	58	56	54	53	0.17	YES	12	5"	6"	12x10	12x6	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR
VV-6	VARIABLE VOLUME	150-400	0.20	70	0.03	—	—	—	—	—	—	—	—	—	—	—	—	—	1.5	67	63	58	56	54	53	0.17	YES	12	6"	8"	12x10	12x8	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR
VV-8	VARIABLE VOLUME	300-650	0.20	140	0.03	—	—	—	—	—	—	—	—	—	—	—	—	—	1.5	67	63	58	56	54	53	0.17	YES	15	8"	12"	14x15	14x12	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR
VV-10	VARIABLE VOLUME	500-925	0.20	225	0.03	—	—	—	—	—	—	—	—	—	—	—	—	—	1.5	67	63	58	56	54	53	0.17	YES	15	10"	14"	16x15	16x12	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR
VV-12	VARIABLE VOLUME	800-1400	0.20	300	0.03	—	—	—	—	—	—	—	—	—	—	—	—	—	1.5	67	63	58	56	54	53	0.17	YES	18	12"	16"	20x18	20x12	YES	YES	1, 2, 3, 4	ENVIRO-TEC, PRICE, NAILOR

(*) MAXIMUM PRESSURE DROP AT MAXIMUM DESIGN CFM.
(**) MINIMUM TEMPERATURE AT MAXIMUM HEATING CFM

NOTES:
1. THE DISCHARGE SOUND LEVEL SHALL BE LESS THAN SCHEDULED IN EACH FREQUENCY WHEN THE ASSEMBLY IS TESTED AND CERTIFIED IN A CERTIFIED NOISE LABORATORY. THE TEST SHALL BE WITH 1.5" WC AT THE INLET OF THE BOX AND AT THE MAXIMUM SCHEDULED AIR FLOW. IN ADDITION THE ASSEMBLY PRESSURE DROP SHALL BE LESS THAN SCHEDULED. THE ORDER OF COMPONENTS SHALL BE VALVE, COIL, SILENCER OR VALVE, SILENCER, COIL, BUT SHALL BE TESTED AS SUPPLIED.
2. THIS TEST SHALL OCCUR IF ALL COMPONENTS ARE BY THE SAME MANUFACTURER OR IF THE COMPONENTS ARE BY DIFFERENT MANUFACTURER.
3. CERTIFIED TEST DATA SHALL BE PROVIDED FOR EACH BOX ASSEMBLY AND FOR EACH BOX TYPE INCLUDING EXHAUST RETURN ASSEMBLIES.
4. EACH HEATING COIL SHALL BE PROVIDED WITH AN ACCESS DOOR ON EACH SIDE, UP STREAM AND DOWN STREAM.

Figure 17: Air Terminal Box Assembly Schedule

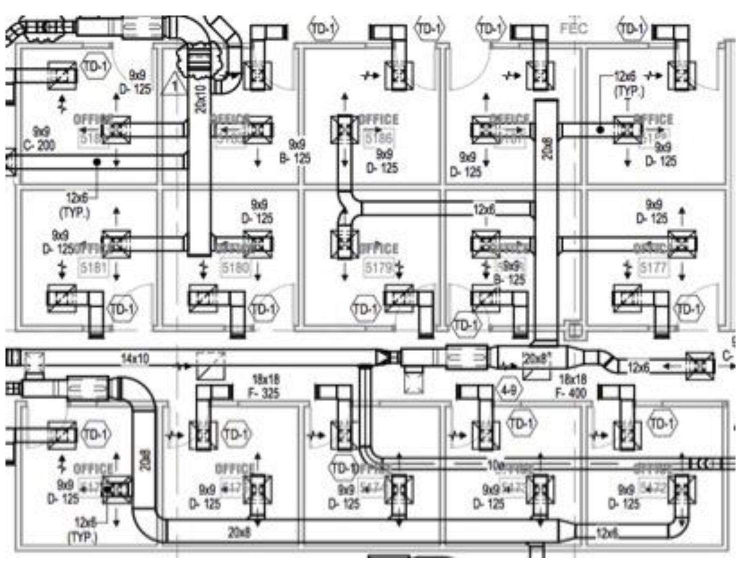

Figure 18: Typical Air Distribution System

5.1.3 Documentation

The design documents shall specify minimum requirements for air balance testing or reference applicable national standards for measuring and balancing airflow. The design documentation shall state assumptions that were made in the design with respect to ventilation rates and air distribution. See Table 7: Energy Model Inputs & Design Specifications above.

5.2 Exhaust Duct Location

Exhaust ducts that convey potentially harmful contaminants shall be negatively pressurized relative to spaces through which they pass, so that exhaust air cannot leak into occupied spaces; supply, return, or outdoor air ducts; or plenums.

All bathrooms are exhausted by EAHU-E-1 and EAHU-W-1 depending on which side the respective building space is located. As shown below in Figure 19, by exhausting 300 CFM and supplying 200 CFM of ventilated air, this restroom is negatively pressurized.

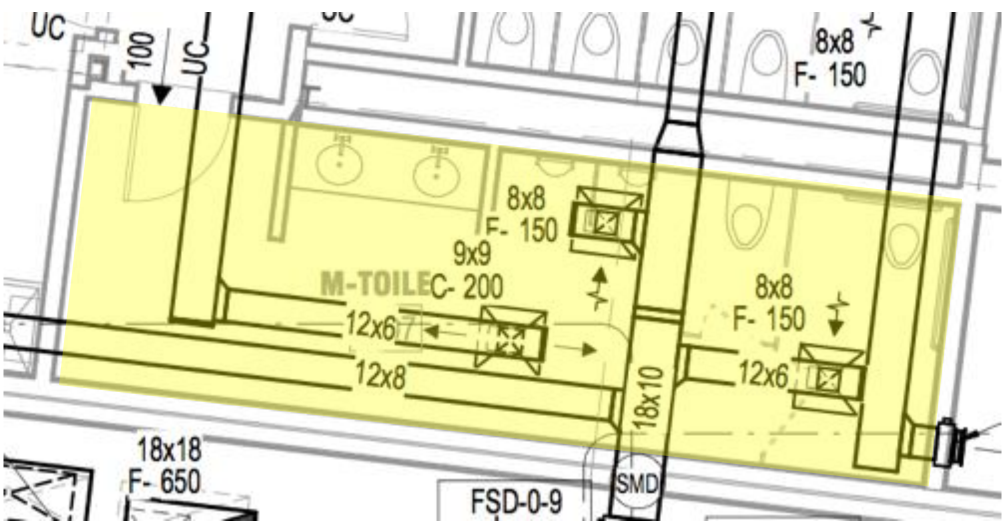

Figure 19: Typical Restroom Air Distribution

5.3 Ventilation System Controls

Mechanical ventilation systems shall include controls in accordance with the following subsections.

5.3.1

All systems shall be provided with manual or automatic controls to maintain no less than the outdoor air intake flow (V_{ot}) required by Section 6 under all load conditions or dynamic reset conditions. Shown in Figure 20 on the following page, all floors are monitored by specific VAV boxes. Each terminal unit has been sized appropriately based on the ventilation and heating/cooling requirements calculated by BR+A. The Min Flow column shown above provides each space with the ventilation air requirements required by Section 6 of ASHRAE 62.1.

Level 1 South VAV & FPB Schedule						
Terminal Unit #	Terminal Unit Type & Size	Max Flow	Min Flow	GPM (Flow)	Associated PRB #	FPB Type
1-4	VCV-10	500	500	1.00	PRB-1-1	-
1-5	VCV-8	800	600	1.00	PRB-1-1	-
1-6	VCV-8	400	400	NO COIL	PRB-1-1	-
1-7	FPB-4	1040	400	3.90	PRB-1-1	A
1-8	VCV-12	1050	400	0.75	PRB-1-2	-
1-9	FPB-4	1450	600	3.90	PRB-1-2	A
1-10	FPB-4	1050	400	3.90	PRB-1-2	A
1-11	FPB-3	900	450	2.80	PRB-1-2	A
1-12	FPB-4	1000	500	3.90	PRB-1-2	B
1-14	FPB-3	750	750	2.80	PRB-1-3	A
1-15	VCV-8	450	450	0.75	PRB-1-3	-
1-16	FPB-3	800	400	2.80	PRB-1-3	A
1-17	VCV-6	325	325	NO COIL	PRB-1-3	-
1-18	FPB-3	750	300	2.80	PRB-1-3	A
1-19	FPB-4	1320	500	3.90	PRB-1-4	A
1-20	VCV-10	800	400	0.75	PRB-1-4	-
1-21	VCV-6	200	200	0.50	PRB-1-4	-
1-22	VCV-6	300	300	0.50	PRB-1-4	-
1-23	FPB-3	900	400	2.80	PRB-1-4	A
1-24	FPB-3	900	400	2.80	PRB-1-4	A
1-25	FPB-2	480	480	2.00	PRB-1-4	A
1-26	FPB-4	1200	500	3.90	PRB-1-4	B
1-27	VCV-6	300	300	0.50	PRB-1-4	
1-28	FPB-4	1000	500	3.90	PRB-1-2	A
1-29	FPB-4	1000	500	3.90	PRB-1-2	A
1-30	FPB-4	1000	500	3.90	PRB-1-2	A

Figure 20: Typical VAV Schedule

5.3.2

Systems with fans supplying variable primary air (V_{ps}), including single-zone VAV and multiple-zone recirculating VAV systems, shall be provided with one or more of the following:

- Out air intake, return air dampers, or a combination of the two that modulate(s) to maintain no less than the outdoor air intake flow (V_{ot})
- Outdoor air injection fans that modulate to maintain no less than the outdoor air intake flow (V_{ot})
- Other means of ensuring compliance with Section 5.3.1

All of the systems supplying primary air to the building zones are regulated by variable speed fans and are specified with outdoor air intakes (see Figure 16). In conjunction with the air intakes on all of the fans, the building is designed to have return air dampers as provided in Figure 21.

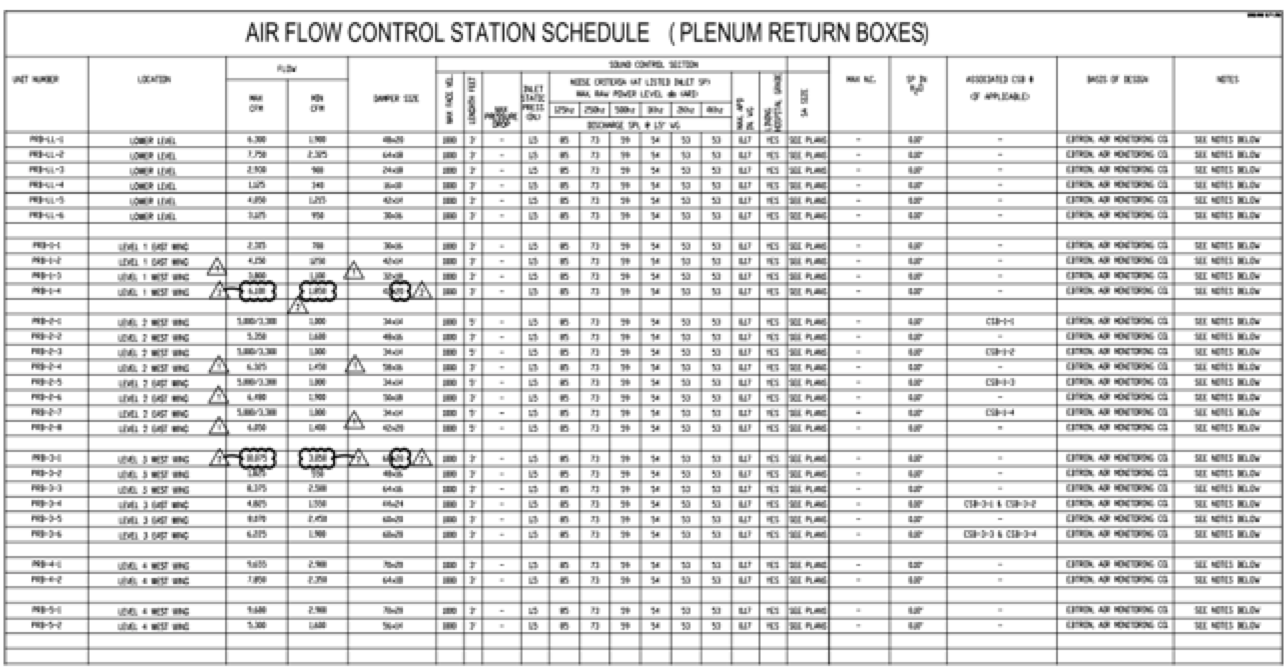

Figure 21: Return Air Dampers

5.4 Airstream Surfaces

All airstream surfaces in equipment and ducts in the heating, ventilating, and air-conditioning sys- tem shall be designed and constructed in accordance with the requirements of the following subsections.

5.4.1 Resistance to Mold Growth

Material surfaces shall be determined to be resistant to mold growth in accordance with a standardized test method, such as the "Mold Growth and Humidity Test" in UL 181,[3] ASTM C 1338,[4] or comparable test methods.

Per MEP Specs:

Division 23 – 230713: Duct Insulation

- ASTM G 21 – Standard Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi.

Division 23 – 233600: Air Terminal Boxes

- Insulation must comply with:
    - UL 181
    - Bacteriological standard ASTM C 665

5.4.2 Resistance to Erosion

Airstream surface materials shall be evaluated in accordance with the "Erosion Test" in UL 1813 and shall not break away, crack, peel, flake off, or show evidence of delamination or continued erosion under test conditions.

5.5 Outdoor Air Intakes

Ventilation system outdoor intakes shall be designed in accordance with the following subsections.

5.5.1 Location

Outdoor air intakes (including openings that are required as part of a natural ventilation system) shall be located such that the shortest distance from the intake to any specific potential outdoor contaminant source shall be equal to or greater than the separation distance listed in Table 5.5.1.

Based on Figure 22 and Figure 23 on the following page, all of the provided intakes for each AHU and EAHU are through an architectural plenum. As illustrated in Figure 22, the air intake is appropriately spaced from all exhaust outlets and cooling tower intakes as well. Both of these figures depict the typical layout for all of the AHUs in this project design.

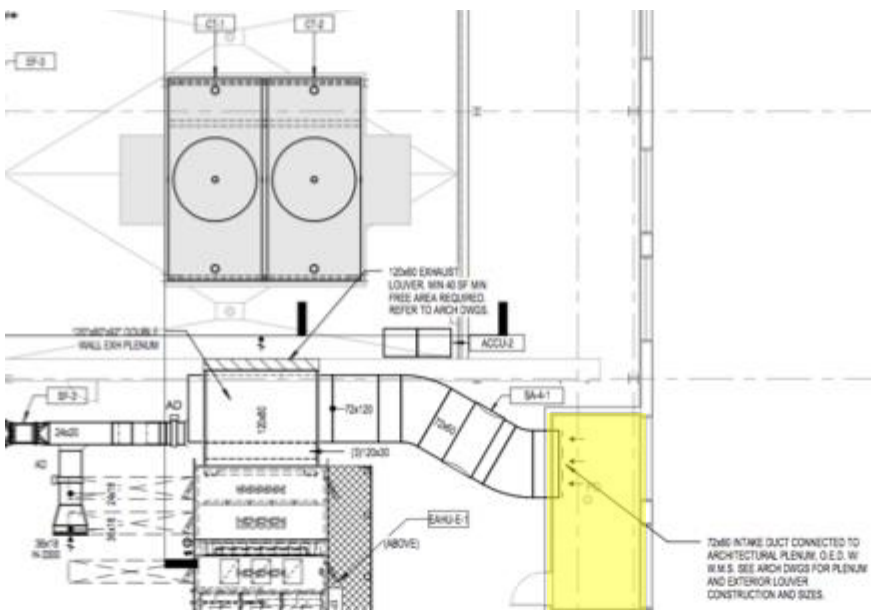

Figure 22: EAHU-E-1 Outdoor Air Intake

Figure 23: EAHU-W-1 Outdoor Air Intake

5.5.2 Rain Entrainment

Outdoor air intakes that are part of the mechanical ventilation system shall be designed to manage rain entrainment in accordance with any one of the following:

- See ASHRAE 62.1 Section 5.5.2 for full description

Per MEP Specs:

Division 23 – 237323: Built-Up Air Handling Units

- AMCA 500 – Test Methods for Louvers, Dampers and Shutters.

5.5.3 Rain Intrusion

Air-handling and distribution equipment mounted outdoors shall be designed to prevent rain intrusion into the airstream when tested at design airflow and with no airflow, using the rain test apparatus described in Section 58 of UL 1995.[12]

This section depicted in Figure 24 shows the architectural design enclosing all of the mechanical equipment inside of the building. All of the exhaust and air intakes are through mechanical shafts provided by the architect. Each of these shafts has the appropriate louver system to prevent snow, rain, wind, and bird intrusion.

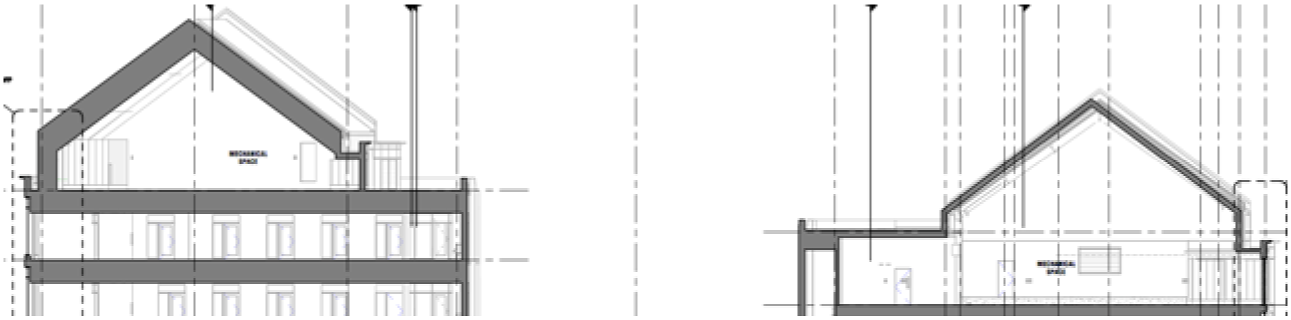

Figure 24: East-West Section – Mechanical Space

5.5.4 Snow Entrainment

Where climate dictates, outdoor air intakes that are part of the mechanical ventilation system shall be designed to manage water from snow, which is blown or drawn into the system, as follows:

- See ASHRAE 62.1 Section 5.5.4 for full description

Per MEP Specs:

Division 23 – 237323: Built-Up Air Handling Units

- Outdoor unit design conditions
  - Minimum wind loading shall be 120 miles per hour.
  - Minimum snow loading shall be 50 lbs. per square foot.
- Access Doors and Panels
  - Provide access doors of the same construction and thickness as the unit casing for all unit sections containing equipment requiring service, where dampers or damper operators are installed, or areas for cleaning of unit components such as coils, etc., is required. Access doors shall be equipped with continuous gaskets and shall fit in the door frame in a manner to guarantee 0% leakage at design pressure. Access door materials shall match casing material.

Division 23 – 233723: Roof Accessories

- Louvered Exhaust and Supply Roof Houses
  - Each ventilator must be rated for 100 mph wind load and 101.5 lbs./sq.ft. snow load

5.5.5 Bird Screens

Outdoor air intakes shall include a screening device designed to prevent penetration by a 0.5 in. (13 mm) diameter probe. The screening device material shall be corrosion resistant. The screening device shall be located, or other measures shall be taken, to prevent bird nesting within the outdoor air intake.

See Figure 24 above.

5.6 Local Capture of Contaminants

The discharge from noncombustion equipment that captures the contaminants generated by the equipment shall be ducted directly to the outdoors.

See Figures 22 and 23 above. Both of these figures demonstrate how each EAHU (exhaust) is ducted directly into an exterior mechanical shaft. All of the contaminants from the restrooms are exhausted outdoors.

5.7 Combustion Air

Fuel-burning appliances, both vented and unvented, shall be provided with sufficient air for combustion and adequate removal of combustion products in accordance with manufacturer instructions. Products of combustion from vented appliances shall be vented directly outdoors.

There are no sources of combustion appliances in this building. All of the hot water used throughout the building for fin tubes and unit heaters is supplied by the university (see Figure 25).

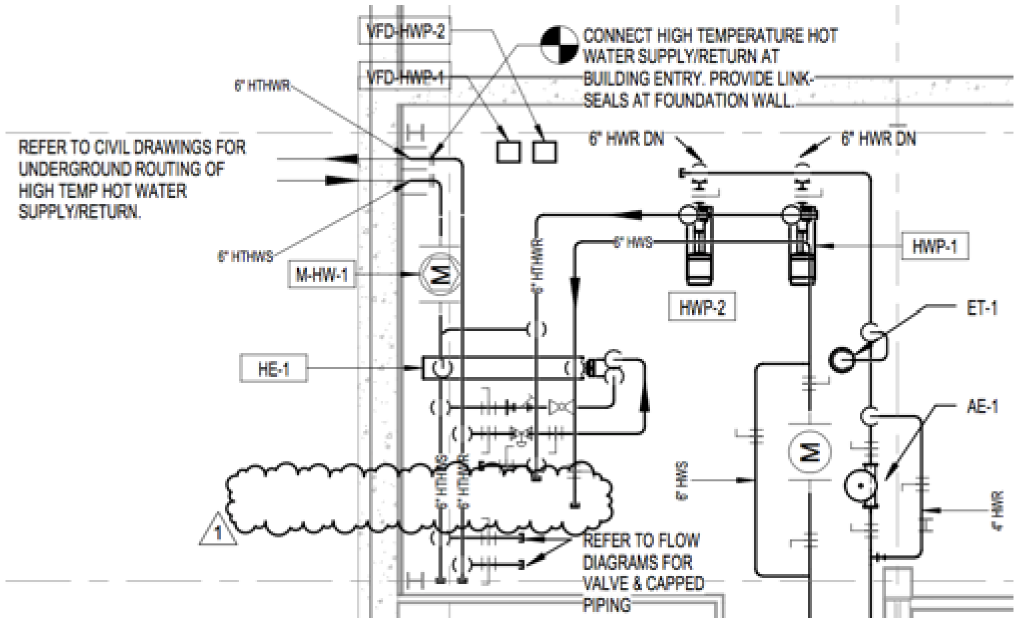

Figure 25: Hot Water Source

5.8 Particulate Matter Removal

Particulate matter filters or air cleaners having a minimum efficiency reporting value (MERV) of not less than 8 when rated in accordance with ANSI/ASHRAE Standard 52.215 shall be provided upstream of all cooling coils or other devices with wetted surfaces through which air is supplied to an occupiable space.

AIR HANDLING UNIT SCHEDULE (CONT.)																				
	FILTER										CASING									
	PRE-FILTER (MERV-8)					AFTER FILTER (MERV-13)														
AHU Unit Number	Max. Face Velocity	Specified Type	Minimum Efficiency, ASHRAE	Max. Pressure Drop Clean	Pressure Drop Dirty	Max. Face Velocity	Specified Type	Minimum Efficiency, ASHRAE	Max. Pressure Drop Clean	Pressure Drop Dirty	Double Wall	Internal Wall	Insulation	Min. SMACNA Leakage Class	Min. SMACNA Pressure Class "H_2O	Unit Leaving Air Temperature °F (Including Added Fan Heat)	Inlet SA Number	POWER	Emergency Power	SELECTION BASED ON
AHU-E-1	400	A	30%	0.30	0.75	400	D1	85%	0.22	1.0	YES	SOLID	4	4	12	55	NOTE 8	480V-3Φ-60 Hz	N	
EAHU-E-1	400	A	30%	0.30	0.75	400	D1	85%	0.22	1.0	YES	SOLID	4	4	12	55	NOTE 8	480V-3Φ-60 Hz	N	
AHU-E-2	400	A	30%	0.30	0.75	400	D1	85%	0.22	1.0	YES	SOLID	4	4	12	55	NOTE 8	480V-3Φ-60 Hz	N	
AHU-W-1	400	A	30%	0.30	0.75	400	D1	85%	0.22	1.0	YES	SOLID	4	4	12	55	NOTE 8	480V-3Φ-60 Hz	N	
EAHU-W-1	400	A	30%	0.30	0.75	400	D1	85%	0.22	1.0	YES	SOLID	4	4	12	55	NOTE 8	480V-3Φ-60 Hz	N	
AHU-W-2	400	A	30%	0.30	0.75	400	D1	85%	0.22	1.0	YES	SOLID	4	4	12	55	NOTE 8	480V-3Φ-60 Hz	N	
RAHU-1	400	A	30%	0.30	0.75	400	D1	85%	0.22	1.0	YES	SOLID	2	2	-	65	NOTE 8	480V-3Φ-60 Hz	N	CARRIER
RAHU-2	400	A	30%	0.30	0.75	400	D1	85%	0.22	1.0	YES	SOLID	2	2	-	65	NOTE 8	480V-3Φ-60 Hz	N	CARRIER
RAHU-3	400	A	30%	0.30	0.75	400	D1	85%	0.22	1.0	YES	SOLID	2	2	-	65	NOTE 8	480V-3Φ-60 Hz	N	CARRIER
RAHU-4	400	A	30%	0.30	0.75	400	D1	85%	0.22	1.0	YES	SOLID	2	2	-	65	NOTE 8	480V-3Φ-60 Hz	N	CARRIER
RAHU-4	400	A	30%	0.30	0.75	-	-	-	-	-	-	SOLID	1	2	-	55	NOTE 8	480V-3Φ-60 Hz	N	CARRIER

Figure 26: AHU Filter Schedule

5.9 Dehumidification Systems

Mechanical air-conditioning systems with dehumidification capability shall be designed to comply with the following subsections.

5.9.1 Relative Humidity

Occupied-space relative humidity shall be limited to 65% or less when system performance is analyzed with outdoor air at the dehumidification design condition (that is, design dew-point and mean coincident dry-bulb temperatures) and with the space interior loads (both sensible and latent) at cooling design values and space solar loads at zero.

See Table 5: Indoor Design Conditions

5.9.2 Exfiltration

For a building, the ventilation system(s) shall be designed to ensure that the minimum outdoor air intake equals or exceeds the maximum exhaust airflow.

See Note 8 in Figure 16. This note explains that both of the AHUs exhausting the building are also supplying an equal amount of air within the building. Figure 16 also shows that all of the other AHUs are supplying a minimum of 30,500 CFM OA.

5.10 Drain Pans

Drain pans, including their outlets and seals, shall be designed and constructed in accordance with this section.

5.10.1 Drain Pan Slope

Pans intended to collect and drain liquid water shall be sloped at least 0.125 in./ft (10 mm/m) from the horizontal toward the drain outlet or shall be other- wise designed to ensure that water drains freely from the pan whether the fan is on or off.

Per MEP Specs:

Division 23 – 237323: Built-Up Air Handling Units

- Drain Pan Slope
  - Pan shall slope at a minimum of 1/8 in. per foot from the horizontal towards the drain outlet.

5.10.2 Drain Outlet

The drain pan outlet shall be located at the lowest point(s) of the drain pan and shall be of sufficient diameter to preclude drain pan overflow under any normally expected operating condition.

Per MEP Specs:

Division 23 – 237323: Built-Up Air Handling Units

- Drain Pan Slope
  - Drain pan outlet shall be at the lowest point or points of the pan with sufficient size to prevent overflow under any normal expected operating condition.

5.10.3 Drain Seal

For configurations that result in negative static pressure at the drain pan relative to the drain outlet (such as a draw-through unit), the drain line shall include a P- trap or other sealing device designed to maintain a seal against ingestion of ambient air while allowing complete drainage of the drain pan under any normally expected operating condition, whether the fan is on or off.

Per MEP Specs:

Division 23 – 237323: Built-Up Air Handling Units

- Drain Pan Slope
  - Unit manufacturer shall provide a drawing indicating the seal trap in accordance with the contract detail and verify the trap will fit with the unit sitting on a 4 inch thick house keeping pad. If the trap does not the unit base shall be increased in height to a point at which the trap will fit.

5.10.4 Pan Size

The drain pan shall be located under the water-producing device. Drain pan width shall be sufficient to collect water droplets across the entire width of the water-producing device or assembly. For horizontal airflow configurations, the drain pan length shall begin at the leading face or edge of the water-producing device or assembly and extend downstream from the leaving face or edge to a distance of either:

- See ASHRAE 62.1 Section 5.10.4 for full description

Per MEP Specs:

Division 23 – 237323: Built-Up Air Handling Units

- Each cooling coil drain pan including intermediate drain pans shall:
  - The minimum drain pan size shall be from the leading face of the coil to a distance down stream from the leaving face of one half of the total assembled height of the water producing height or written certified guarantee verified by testing that the water carryover beyond the drain pan is less then 0.0044 oz per square foot at the peak design dew point and peak design air velocity

5.11 Finned-Tube Coils and Heat Exchangers

5.11.1 Drain Pans

A drain pan in accordance with Section 5.10 shall be provided beneath all dehumidifying cooling coil assemblies and all condensate-producing heat exchangers.

Per MEP Specs:

Division 23 – 235700: Heat Exchangers

- Provide water-to-water heat exchangers in accordance with the capacities, piping and valving arrangements indicated and as scheduled on the drawings.
    - Heat exchangers shall be complete with all necessary outlets for supply and return primary water, water inlet and outlet, drain and vent connections, cleanout handholes and tapings for temperature and pressure gauges. Fouling factors for both tube and shell shall be a minimum of 0.002 unless scheduled otherwise.

Division 23 – 238235: Terminal Heat Transfer Units

- FAN COIL UNITS
    - The condensate drain pan shall be fabricated of 18 gauge galvanized steel with closed cell, fire retardant, foam insulation coating. Removable pan extension shall be available at the coil header end of the unit to provide positive control of condensate from valves and controls. This extension, being easily removable, shall provide ready access to valves and piping after unit installation.

- FINNED TUBE RADIATION INSTALLATION
    - Pitch heating elements in direction of flow. Provide manual air vent at high point and drain valve at low point.
    - Provide access to all valves, vents, drains, etc., for all radiation types as required. Install control valves in ceilings above radiation where valves do not fit within enclosure or as indicated on the drawings.

5.11.2 Finned-Tube Coil Selection for Cleaning

Individual finned-tube coils or multiple finned-tube coils in series without intervening access space(s) of at least 18 in. (457 mm) shall be selected to result in no more than 0.75 in. wc (187 Pa) combined dry-coil pressure drop at 500 fpm (2.54 m/s) face velocity.

Per MEP Specs:

Division 23 – 238235: Terminal Heat Transfer Units

- FAN COIL UNITS
  - CLEANING
  - After construction is completed, including painting, clean exposed surfaces of units. Vacuum clean coils and inside of cabinets.

5.12 Humidifiers and Water-Spray Systems

Steam and direct-evaporative humidifiers, air washers, direct-evaporative coolers, and other water-spray systems shall be designed in accordance with this section.

5.12.1 Water Quality

Water purity shall meet or exceed potable water standards at the point where it enters the ventilation system, space, or water-vapor generator. Water vapor generated shall contain no chemical additives other than those chemicals in a potable water system.

Per MEP Specs:

Division 23 – 232500: Chemical Water Treatment

- Chemicals
  - Hot Water (for loops operating at temperatures exceeding 120°F)
    - Provide a nitrite based program designed to provide metal corrosion and scale protection. Program must be designed to provide corrosion rates of not more than 5 mpy for mild steel and 1 mpy for copper.
  - Chilled Water (for loops operating at temperatures below 120°F)
    - Provide a molybdenum based program designed to provide multi- metal corrosion and scale protection. Program must be designed to provide corrosion rates of not more than 5 mpy for mild steel and 1 mpy for copper.

5.12.2 Obstructions

Air cleaners or ductwork obstructions, such as turning vanes, volume dampers, and duct off- sets greater than 15 degrees, that are installed downstream of humidifiers or water spray systems shall be located a distance equal to or greater than the absorption distance recommended by the humidifier or water spray system manufacturer.

As shown in Figure 27, the cooling tower design is not obstructed by any ductwork or associated equipment.

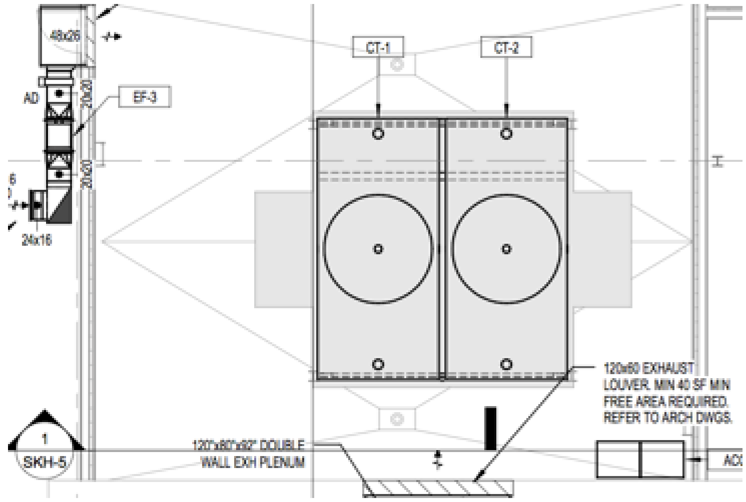

Figure 27: Cooling Tower Design

5.13 Access for Inspection, Cleaning, and Maintenance

5.13.1 Equipment Clearance

Ventilation equipment shall be installed with sufficient working space for inspection and routine maintenance (e.g., filter replacement and fan belt adjustment and replacement).

Per MEP Specs:

Division 23 – 237323: Factory Built-Up Air Handling Units

- Space Limitations
    - The air handling units shall be designed within the dimensions and space limitations, as indicated on the drawings and as specified.
    - The unit manufacturer shall take these dimensions and space limitations into consideration for the design required and shall submit dimensional data on the drawings.
    - Advise the Engineer early in the bid process should any problems be

detected with existing space limitations.

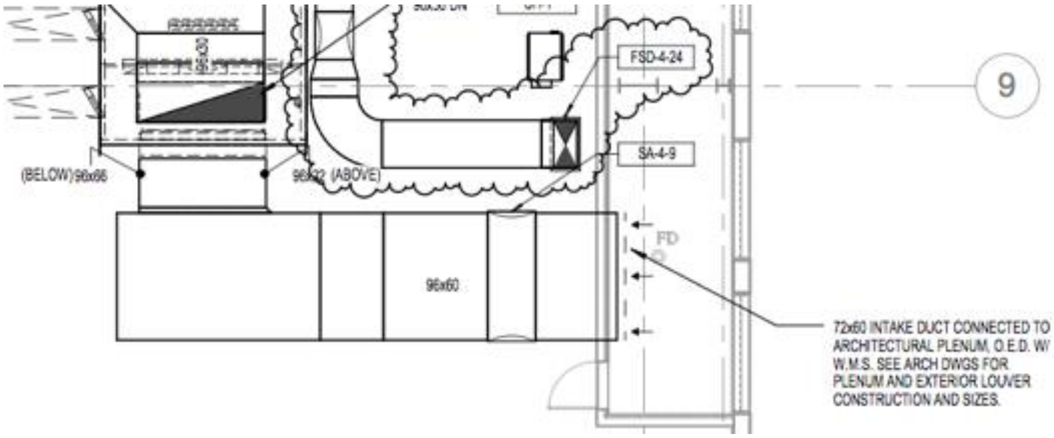

Figure 28: Ventilation Equipment Clearance

5.13.2 Ventilation Equipment Access

Access doors, panels, or other means shall be provided and sized to allow convenient and unobstructed access sufficient to inspect, maintain, and calibrate all ventilation system components for which routine inspection, maintenance, or calibration is necessary. Ventilation system components comprise, for example, air-handling units, fan-coil units, water-source heat pumps, other terminal units, controllers, and sensors.

Per MEP Specs:

Division 23 – 237323: Factory Built-Up Air Handling Units

- Access Doors and Panels
    - Provide access doors of the same construction and thickness as the unit casing for all unit sections containing equipment requiring service, where dampers or damper operators are installed, or areas for cleaning of unit components such as coils, etc., is required. Access doors shall be equipped with continuous gaskets and shall fit in the door frame in a manner to guarantee 0% leakage at design pressure. Access door materials shall match casing material.
    - Each access door shall have a built-in static pressure probe port for ease of pressure readings across various internal components and to limit unnecessary or unauthorized access inside the unit.
    - Each access door shall be mounted with stainless steel hinges to prevent door racking and air leakage. At least (2) cast aluminum chrome plated

handles operable from either side shall be provided. Other door accessories shall include handles and stainless steel hardware to ensure long-term, proper door operation.

- Each door shall contain a thermal window of double pane safety glass at eye level when the viewer stands on the adjacent floor or grating outside the unit (coordinate with heights of housekeeping pads, vibration isolators, etc.), sized at a minimum of 10” round or 12" by 12", properly sealed to operate safely against the suction or pressure. Windows shall be non-fogging.
- Removable access panels shall be provided in unit sections where components are larger than the door opening. Panels shall be of the same construction as doors.

5.13.3 Air Distribution System

Access doors, panels, or other means shall be provided in ventilation equipment, duct-work, and plenums, located and sized to allow convenient and unobstructed access for inspection, cleaning, and routine maintenance of the following:

All AHUs within this project are designed with adequate space for maintenance and cleaning (see Figure 29). The above Section 5.13.2 Access Doors and Panels can also be referenced for this section as well.

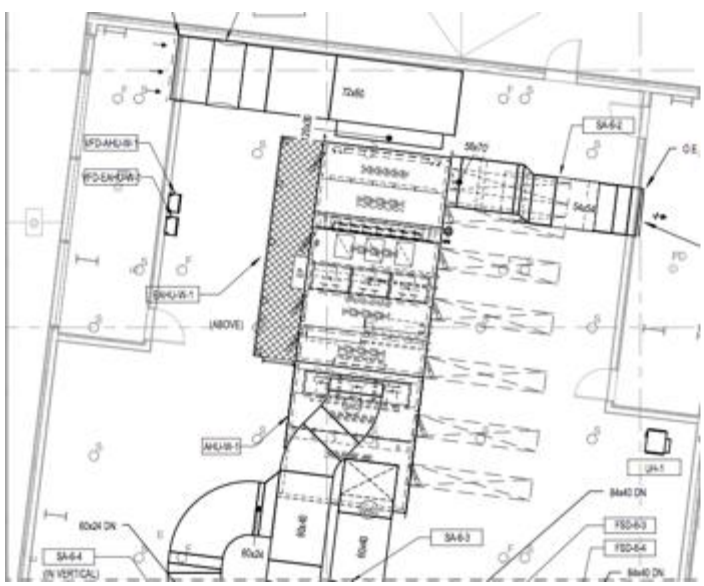

Figure 29: AHU-W-1 Maintenance Access

5.14 Building Envelope and Interior Surfaces

The building envelope and interior surfaces within the building envelope shall be designed in accordance with the following subsections.

5.14.1 Building Envelope

The building envelope, including roofs, walls, fenestration systems, and foundations, shall comply with the following:

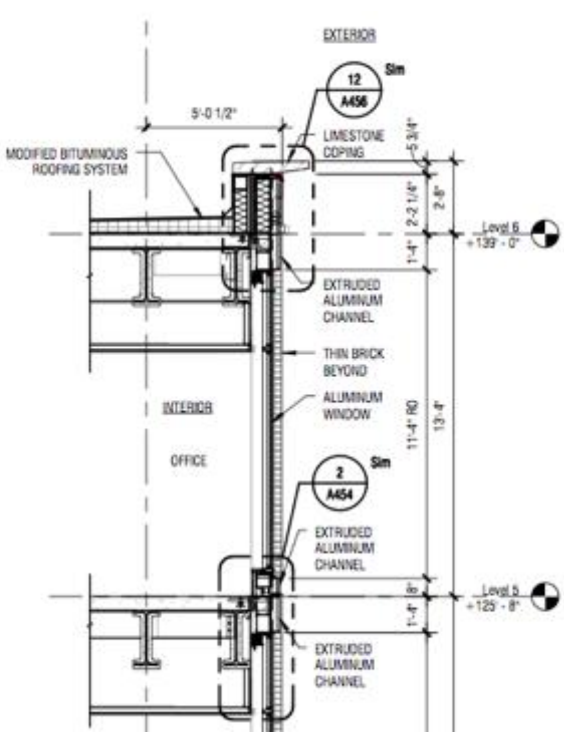

Figure 30: Upper Levels & Roof Envelope

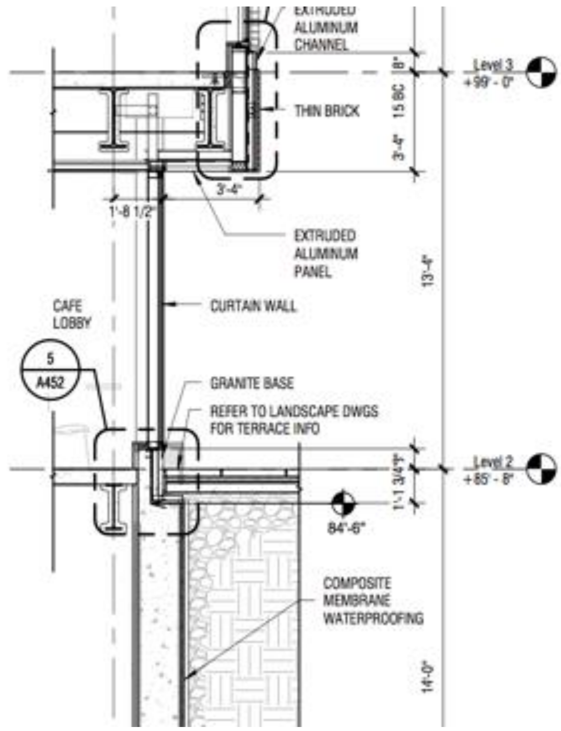

Figure 31: Ground & Lower Level Envelope

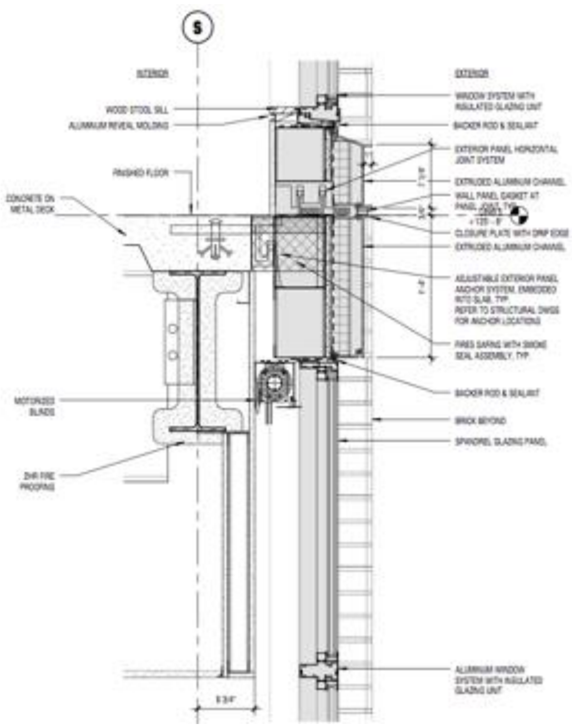

Figure 32: Section Detail Panel Joint

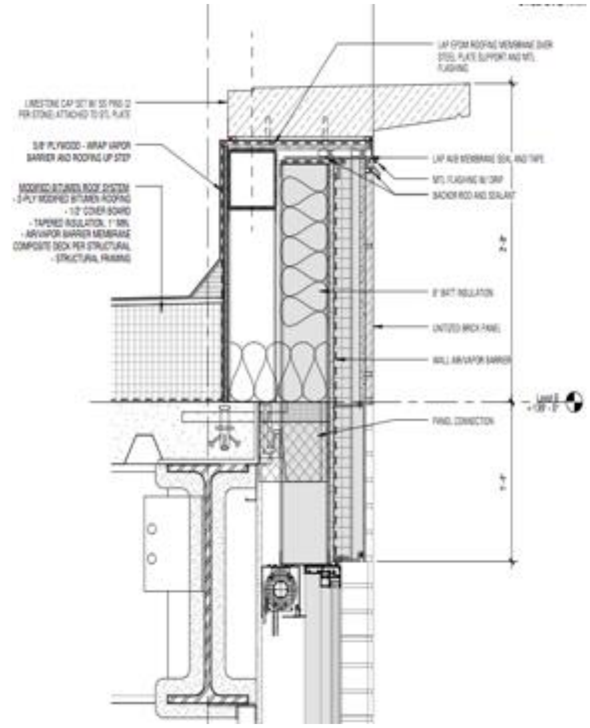

Figure 33: Section Detail Limestone Coping

5.14.2 Condensation on Interior Surfaces

Pipes, ducts, and other surfaces within the building whose surface temperatures are expected to fall below the surrounding dew-point temperature shall be insulated. The insulation system thermal resistance and material characteristics shall be sufficient to prevent condensation from forming on the exposed surface and within the insulating material.

Per MEP Specs:

Division 23 – 230719: HVAC Piping Insulation

- PIPING INSULATION INSTALLATION
    - Ensure insulation is continuous through interior walls. Pack around pipes with fire proof self-supporting insulation material, fully sealed. Insulation on all cold surfaces where vapor barrier jackets are specified must be applied with a continuous, unbroken vapor seal. Hangers, supports, anchors, and other heat conductive parts that are secured directly to cold surfaces must be adequately insulated and vapor sealed to prevent condensation.

5.15 Buildings with Attached Parking Garages

Does not apply.

5.16 Air Classification and Recirculation

Air shall be classified, and its recirculation shall be limited in accordance with the following subsections.

5.16.1 Classification

Air (return, transfer, or exhaust air) leaving each space or location shall be designated at an expected air-quality classification not less than that shown in Tables 5.16.1, 6.2.2.1, or 6.5, or as approved by the authority having jurisdiction. Air leaving spaces or locations that are not listed in Table 5.16.1, 6.2.2.1, or 6.5 shall be designated with the same classification as air from the most similar space or location listed in terms of occupant activities and building construction.

There is no air classification specified within the given drawings. However, as shown previously in Figure 19, all of the restroom air is directly exhausted to the exterior of the building. This Class 2 air is the only “contaminated” air within this building; the remaining spaces consist of offices and classrooms.

5.16.2 Redesignation

5.16.2.1 Air Cleaning. If air leaving a space or location passes through an air-cleaning system, redesignation of the cleaned air to a cleaner classification shall be permitted, using the subjective criteria noted above, with the approval of the authority having jurisdiction.

Does not apply.

5.16.2.2 Transfer**.** A mixture of air that has been transferred through or returned from spaces or locations with different air classes shall be redesignated with the highest classification among the air classes mixed.

Does not apply.

5.16.3 Recirculation Limitations

When the Ventilation Rate Procedure of Section 6 is used to determine ventilation airflow values, recirculation of air shall be limited in accordance with the requirements of this section.

5.16.3.2.5 Class 2 air shall not be recirculated or transferred to Class 1 spaces.

Exception: When using any energy recovery device, recirculation from leakage, carryover, or transfer from the exhaust side of the energy recovery device is permitted. Recirculated Class 2 air shall not exceed 10% of the outdoor air intake flow.

As shown in Figure 34, the EAHUs from each wing of this building are utilizing an enthalpy wheel for energy recovery. Note 7 specifies that OA CFM will be monitored; this will ensure that the Class 2 air does not exceed 10% of the OA intake.

ENTHALPY WHEEL (NOTE 7)																					
		Summer Performance										Winter Performance									
		Supply Air Side					Return/Exhaust Air Side					Supply Air Side					Return/Exhaust Air Side				
DIAMETER(IN)	Max. Face Velocity (FPM)	EDB °F	EWB °F	LDB °F	LWB °F	Max.Δ P Inch H2O	EDB °F	EWB °F	LDB °F	LWB °F	Max.Δ P Inch H2O	EDB °F	EWB °F	LDB °F	LWB °F	Max.Δ P Inch H2O	EDB °F	EWB °F	LDB °F	LWB °F	Max.Δ P Inch H_2O
120	786.5	91.1	73.1	80.5	66.9	0.98	–	–	–	–	–	10.0	8.0	50.5	41.1	0.89	–	–	–	–	–
120	786.5	–	–	–	–	–	75.0	62.5	85.6	69.5	0.98	–	–	–	–	–	70.0	53.3	29.5	26.7	0.89
NOT USED																					
120	658.7	91.1	73.1	79.9	66.4	0.81	–	–	–	–	–	10.0	8.0	52.8	42.7	0.74	–	–	–	–	–
120	658.7	–	–	–	–	–	75.0	62.5	86.2	69.9	0.81	–	–	–	–	–	70.0	53.0	27.2	24.7	0.74

7. ENTHALPY WHEEL SHALL BE SEGMENTED W/ SUPPORTS, HAVE PILLOW BLOCK BEARINGS, AFMS TO MONITOR O.A. CFM, CONTROLS, ECONOMIZER BYPASS.

Figure 34: Enthalpy Wheel Schedule

5.17 Requirements for Buildings Containing ETS Areas and ETS-Free Areas

The requirements of this section must be met when a building contains both ETS areas and ETS-free areas. Such buildings shall be constructed and operated in accordance with Sections 5.17.1 through 5.17.8. This section does not purport to achieve acceptable indoor air quality in ETS areas.

Does not apply.

ASHRAE 62.1 Conclusions

All nine of the building systems were analyzed in Technical Report 1 to provide a full overview of the ventilation requirements. Being an education building with approximately eight lecture halls, each having 300 seats, there is a large amount of ventilation air required. Additionally, the third, fourth, and fifth floors have a significant amount of offices organized in the west wing which require additional outside air as well.

Through the analysis of the Northeast Education Building, it is evident that ventilation within the lecture halls was a main focus of BR+A’s mechanical design. All of the ground level lecture halls have their own recirculating air handling unit beneath the flooring and distribute the air through a plenum under the seating. Likewise, a dedicated outdoor air system has been provided, AHU-W-1 and AHU-E-1, to supply all of the Seminar, Lecture Hall, and Classroom spaces.

Respective Calculations

Breathing Zone Outdoor Airflow

$$V_{bz} = R_p \cdot P_z + R_a \cdot A_z$$

Where:

V_{bz} = the breathing zone outdoor airflow

A_z = zone floor area (net occupiable) [ft.]

R_a = Outdoor airflow rate required per unit area per unit area from ASHRAE Standards 62.1 Table 6.1 [CFM/ft^2]

P_z = Zone population [persons] Pz

R_p = Outdoor airflow rate required per unit area per person from ASHRAE Standards 62.1 Table 6.1 [CFM/person]

Zone Outdoor Airflow (V_{OZ})

$V_{OZ}= V_{bz}/E_z$

Zone Air Distribution Effectiveness (E_z) from ASHRAE 62.1 Table 6.2

E_z=1.0

ASHRAE Standard 90.1 Compliance

90.1 Section 5: Building Envelope

5.1 General

5.1.4 Climate

Determine the climate zone for the location. For U.S. locations, follow the procedure in Section 5.1.4.1. For international locations, follow the procedure in Section

5.1.4.2.

Reference Figure 8: ASHRAE 90.1 Climate Zone Map

This particular building is located in the Northeast region of the United States. Figure 8 above, shows that building is in climate zone 4A.

Conditions provided by ASHRAE 90.1

- Mixed-Humid
- Thermal criteria: CDD50°F≤4500 and 3600<HDD65°F≤5400

5.5 Prescriptive Building Envelope Option

As seen on the following page, Table 13 and 14, show the compliance data with respect to vertical fenestrations and overall building insulation. As Table 13 illustrates, the overall glazing to wall percentage is slightly over the 40% maximum, calculated to be ~45%. Likewise, Table 14 shows the design parameters that were used to construct all design models for the Northeast Education Building. Based on ASHRAE Table 5.5-4 Building Envelope Requirements for Climate Zone 4 (A,B,C), two of the design criteria were not met in the original design (see Appendix for ASHRAE Table 5.5-4). Based on the given information, it will require further analysis to determine why these parameters may not have been met in the original design.

Table 13: Building Gross Wall Area vs. Fenestration

Unit	Wall Area (ft.^{2})	Glass Area (ft.^{2})	Percent
AHU-E-1 (100% O.A. VAV)	3849	1657	43.05
AHU-W-1 (100% O.A. VAV)	942	318	33.76
AHU-E-2 (30% O.A. VAV)	15467	8132	52.58
AHU-W-2 (30% O.A. VAV)	40626	17124	42.15
Tiered Lecture L2 - 300P - 1	1824	255	13.98
Tiered Lecture L2 - 300P - 2	2193	1052	47.97
Tiered Lecture L2 - 300P - 3	1906	953	50.00
Tiered Lecture L2 - 300P - 4	1995	998	50.03
Tiered Lecture L3 - 300P - 1	1220	610	50.00
Fan Coil Unit (Stairwells)	7543	3717	49.28
TOTALS	77565	34816	**44.89**

Table 14: Building & Glazing Material Property Compliance

Material	Maximum U-Value	Designed U-Value	Compliance
Slab	0.0870	0.2126	**No**
Roof	0.0320	0.2135	**No**
Wall	0.0640	0.0645	Yes
Window	0.5000	0.4500	Yes

6.5 Prescriptive Path

6.5.1 Economizers

Each cooling system that has a fan shall include either an air or water economizer meeting the requirements of Sections 6.5.1.1 through 6.5.1.6.

AHU Unit Number	SERVICE	AHU SYSTEM- SEE NOTE 1	AHU QUANTITY
AHU-E-1	EAST WING	A	1
EAHU-E-1	EAST WING	A	1
AHU-E-2	EAST WING	B	1
AHU-W-1	WEST WING	A	1
EAHU-W-1	WEST WING	A	1
AHU-W-2	WEST WING	C	1
RAHU-1	NORTHEAST TIERED LECTURE HALL	D	1
RAHU-2	NORTHEAST TIERED LECTURE HALL	D	1
RAHU-3	NORTHEAST TIERED LECTURE HALL	D	1
RAHU-4	NORTHEAST TIERED LECTURE HALL	D	1
AHU-3	MAIN ELEC ROOM	E	1

AHU SYSTEM AND DISTRIBUTION TYPES:
A. 100% O.A. AHU WITH ENTHALPY WHEEL W/ ENTHALPY WHEEL BYPASS FOR OUTDOOR AIR TURNDOWN.
B. AHU WITH MIXED RETURN AIR SUPPORTING EAST WING ONLY (W/ FULL ECONOMIZER MODE)
C. AHU WITH MIXED RETURN AIR SUPPORTING WEST WING ONLY (W/ FULL ECONOMIZER MODE)
D. RETURN AHU WITH RETURN AIR BYPASS (REHEAT) SUPPORTING TIERED LECTURE HALLS (QTY: 4)
E. RETURN AHU WITH FULL ECONOMIZER MODE

Figure 35: AHU Schedule Prescriptive Path Compliance

6.5.6 Energy Recovery

6.5.6.1 Exhaust Air Energy Recovery. Each fan system shall have an energy recovery system when the system's supply airflow rate exceeds the value listed in Tables 6.5.6.1-1 and 6.5.6.1-2, based on the climate zone and percentage of outdoor airflow rate at design conditions.

As seen on the previous page, Figure 35 explains how the Northeast Education Building complies with ASHRAE 90.1 Section 6.5. Between all eleven systems, this building has an economizer on three systems, an enthalpy wheel heat recovery system on four systems, and thermostatic controls that will help prevent the reheating and recooling of air.

6.7 Submittals

6.7.1 General

The authority having jurisdiction may require submittal of compliance documentation and supplemental information in accordance with Section 4.2.2 of this standard.

Full construction documents, along with operation and maintenance manuals will be turned over the owner upon completion of the building. Commissioning upon the building is being and will be completed post construction for LEED certification.

7. Servicewater heating

All hot water is supplied by the local municipality (see Figure 36).

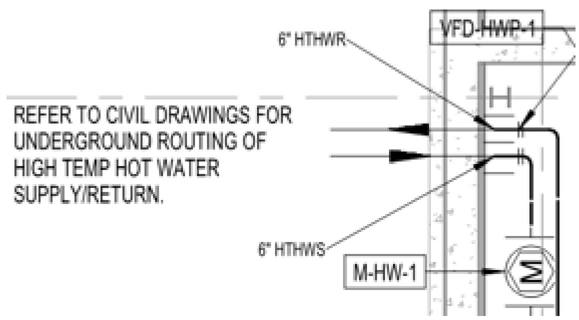

Figure 36: Service Hot Water

90.1 Section 9: Lighting

9.2 Compliance

9.2.2 Prescriptive Requirements

9.2.2.1 Building Area Method. This method for determining the interior lighting power allowance, described in Section 9.5, is a simplified approach for demonstrating compliance.

See Table 7: Energy Model Inputs & Design Specifications

ASHRAE 90.1 Conclusions

This report outlines the prescriptive requirements of ASHRAE 90.1 and how the Northeast Education Building was designed in regards to these requirements. As seen above, some aspects of the building envelope do not comply with the 90.1; however, this building has been modelled extensively in energy modelling software to be certified as a LEED building. In that respect, the Northeast Education Building was analyzed further in depth to find why some of these compliances were not met. Overall, there are many aspects of the mechanical system that are designed well above the ASHRAE criteria.

Mechanical System Evaluation

The overall objective of the Northeast Education Building is to integrate both the north and south ends of campus through a unique design. As the newest addition to the campus mall, this building allows students and staff to flow in between the east and west wings as they make their way to class each day. With four of the newest and largest lecture halls on campus, this building will act as a main educational hub when completed in 2016. The main objective was not only to connect the north and south ends of campus, but also to design a comfortable, learning space with a more modern mechanical system. Utilizing a displacement ventilation design, the main lecture halls are able to operate using less energy than a typical ceiling distribution system.

One of the major drawbacks that has been realized through each Technical Report is the overall use of ductwork throughout the building. The two main units, AHU-E-2 and AHU-W-2, consume a large amount of electricity throughout the year and in total the air handling units use about 23% of the overall energy needed for the building. While these units are capable of maintaining and supplying the appropriate building conditions, it is useful to explore other options such as a hydronic system known as chilled beams or fan coils. This particular study will only affect the office spaces located on Levels 3-5 because that is where they will be most effective. Currently, with the air-driven VAV system that maintains the offices, there is a lot of strain on the air handling units and associated fan energy. Another major design consideration is the use of displacement ventilation in the upper level lecture halls. The Northeast Education Building has already been designed with displacement ventilation in the lower level lecture halls; therefore, the study will revolve around adding these additional spaces to the current design and analyzing why these spaces may have been designed differently in the first place.

All in all, from a mechanical perspective, the overall design is sustainable and energy efficient. One of the major areas of concern, however, would be the amount of energy used by the lighting design. With no daylighting consideration or use of high-tech devices to control the amount of natural light, these classrooms and offices are consuming unnecessary amounts of electricity. There seems to have been a greater focus on the mechanical systems in this building, especially with the amount of mechanical space provided between the Lower Level and the respective Penthouse Mechanical Levels as well. To help the overall building design, there needs to be a reassessment of the building lighting scheme to see whether or not daylighting is a feasible possibility. With improvements on the mechanical distribution systems and lighting controllability, this building design could potentially be LEED Gold certified. The next section will outline further how these design considerations were evaluated in a newly proposed design.

Chapter 2 | Proposed Redesign

System Evaluation

This building, being the first built in the central campus of the respective university in 50 years, will become a landmark for students and faculty alike. The goal of this project was to introduce a newly engineered office and classroom design that would reflect new technology while maintaining the historical aspect of this university. From the previous analysis performed in all three Technical Reports, the original mechanical design is adequately planned to provide the appropriate heating and cooling required throughout the year. With the use of displacement ventilation in the Ground Level lecture halls in combination with a DOAS air system, this design provides an energy efficient solution that can be expanded upon in the upper levels.

As discussed in the Technical Report 3, a large portion of this building is occupied by mechanical space. Between duct and piping shafts, two mechanical penthouses, and abundant space provided beneath the lecture halls for air handling units, there is no shortage of space for the associated equipment. While this is seen as a positive, there is potential to reduce the space occupied by mechanical work in researching different alternatives. The design is able to perform by ASHRAE standards and currently meets LEED Silver requirements. With new considerations taken, this proposal will outline further investigation into systems that can potentially reduce capital costs and lifecycle costs with the associated energy reductions.

Alternatives Considered

The list of possible alternatives provided below outlines potential areas of the original design that can be investigated further. As mentioned previously, the current design already employs several energy-saving systems; however, this report will provide other options that may not have been studied or designed based on time constraints of the original project.

Alternatives

1. Implement chilled beam system or fan coil units in the office spaces on Levels 3-5 and evaluate:
    a. Energy performance
    b. Structural impacts
    c. Cost savings
    d. Plenum space payback
    e. Humidity and condensation constraints
    f. Heating/Cooling constraints
    g. Air requirements
    h. Pump requirements
    i. Acoustical implication
2. Expand the displacement ventilation system into the Third Level lecture halls to evaluate:
    a. Energy performance
    b. Cost savings
    c. Humidity constraints
    d. Heating/Cooling constraints
    e. Air requirements
    f. Fan requirements
    g. Indoor Air Quality
3. Building envelope analysis to evaluate:
    a. Energy performance
    b. Thermal properties
    c. Potential moisture issues
    d. Adequate design for new distribution system
4. Compare current CO_2 and occupancy sensor design with demand control ventilation system
5. Perform a central cooling optimization study
    a. Energy performance of design
    b. Refrigerant study
6. Investigation of potential on-site renewable energy
7. Implement the use of a thermal storage system for building cooling requirements to evaluate:
    a. Energy performance
    b. Cost savings

Limitations

While there is a comprehensive list of potential areas to investigate, with limited time and resources, not every area will be studied at length. To provide a beneficial report to summarize the overall findings of the future investigation, there will be more attention given to certain topics early on. The topics provided above all play a crucial part in the overall mechanical and building systems currently designed for the Northeast Education Building. In some cases, redesigning specific systems such as a new cooling and heating distribution may have other implications regarding the overall building operation. For example, by installing chilled beams or a fan coil system, the structural integrity will have to be investigated, building envelope studied, and overall mechanical structure re-evaluated. Therefore, while several of these potential areas of interest relate to one another, some may receive more attention than others. Ultimately, the recommendation report will be based on the each system that has been comprehensively studied to provide the most benefit to the original project.

Proposed Alternatives

By studying potential systems and alternative means of adequately conditioning this building, in no way does this report imply that the current design is wrong or needs to be improved upon. Through value engineering and coordination efforts between all respective design companies, there may have been certain limitations to the project that did not allow these systems to be studied. Overall, this analysis will be provided to study whether or not potential energy paybacks are available as well as gain pertinent educational value through studying some of the newer, innovative mechanical designs.

Displacement Ventilation Expansion

In reviewing the construction documents for the Northeast Education Building, there are four main lecture halls on the Second Level that utilize a displacement ventilation system. While this proves to be beneficial in conjunction with a DOAS system, there are three remaining lecture spaces on the Third Level that could also potentially benefit from a similar design. Currently, these three spaces are being handled by the same two air distribution systems as the lower lecture halls. However, these operate on a typical ceiling distribution with VAV mixing boxes to condition the classrooms.

In reference to a previously used chart, Figure 37 displays the ~25% of electrical energy that is consumed by all of the air handling systems. The two pieces that are broken out directly reference the two units that supply the air to the lecture spaces. While this is only 6% as shown by the graph, by implementing a newly integrated displacement ventilation system, there could be potential energy savings regarding fan usage. By utilizing recirculating air handlers, there is not as much strain placed on the system to ventilate and condition the space appropriately. This system decouples the sensible and latent load requirements, which will potentially provide a means of reducing energy.

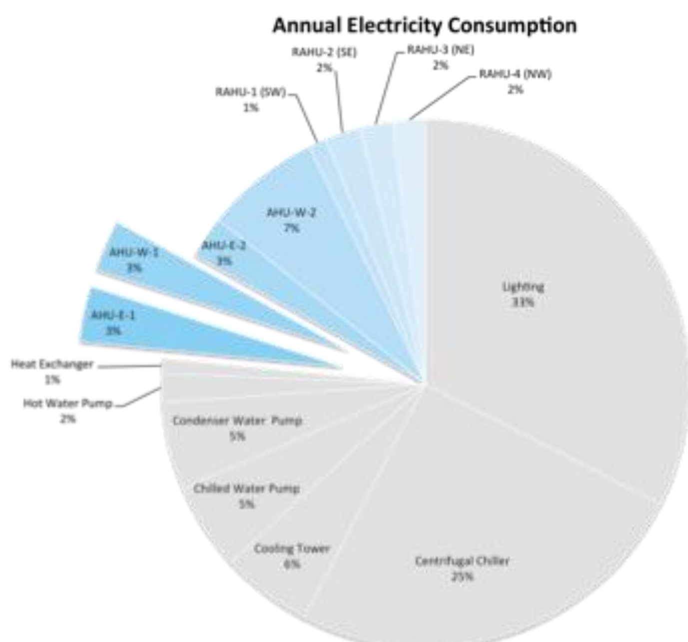

Figure 37: Annual Electricity Consumption

To fully examine the potential of replacing the ceiling distribution system with an integrated underfloor distribution system, there are two major areas of interest:

1. First, research displacement ventilation systems to understand the full design implications
    a. Space requirements
    b. Air constraints
    c. Humidity constraints
    d. Analyse feasibility of space provided on Level Three
2. Given that the system can be redesigned appropriately and implemented correctly, compare the energy usage and capital cost with the previous distribution.

Impact of Displacement Ventilation Expansion

As a result of implementing a new displacement ventilation system on the Third Level, there are going to be several areas within the mechanical design that will be impacted. Not only will there be airside considerations with the ductwork and associated air handling units, but also plenum space will have to be evaluated to coordinate all of the ducts and pipelines. This newly proposed design has to accommodate for the same ventilation and conditioning requirements as the current system while also taking the acoustics into consideration. Because the airflows are reduced in an underfloor distribution system, the zones will have to be re-evaluated to ensure the correct pressurization on this floor. Depending on whether or not the same recirculation AHUs on the Ground Level can be used for this system, the structural integrity of the Third Level floor may have to be redesigned for new units.

Chilled Beam Implementation

Currently, the primary design within the office space on Levels 3-5 is a typical overhead distribution system with VAV mixing boxes. While this system is a standard in most office buildings, utilizing a hydronic system such as chilled beams would provide a valid comparison in a further energy analysis. As discussed on the previous page, Figure 37 displays the overall airside energy usage. This chart shows that 12% of the electricity being used in the building is directly related to the air being distributed to offices and support spaces as well.

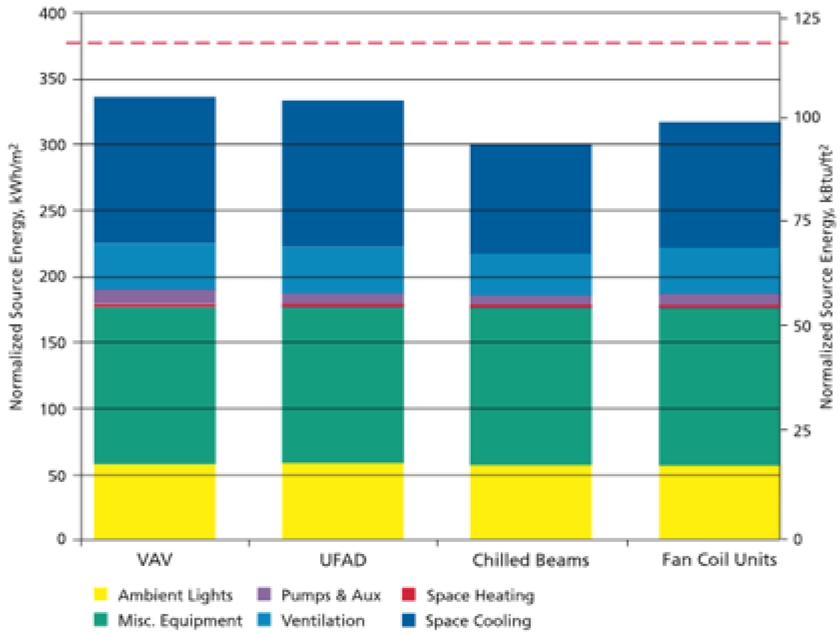

Figure 38: HVAC System Annual Energy Usage

Through previous research that has been conducted, Figure 38 shows that the overall space cooling needs are decreased with a chilled beam system. As compared to the current VAV system, this could provide potential energy savings and paybacks through waterside economization. In a journal article written by Tredinnick [1], he recommends using the DOAS evaporator return water to service a secondary chilled water loop used as the chilled beam supply water. This waterside economization would help to minimize the total pumping requirements and chiller electricity requirements as well.

Additionally, by implementing a chilled beam system, this would provide an opportunity to reduce the amount of ductwork within the plenum space. This new system would allow for smaller ducts to be routed appropriately throughout the offices while still maintaining the cooling and heating requirements. Other considerations that would be analysed alongside a chilled beam design include:

1. An acoustical analysis of the hydronic system as compared to the current air driven system
2. Envelope study to prove that the current design is adequate in maintaining the appropriate humidity levels within the building

3. Central cooling study to see how the current central plant can be optimized as the need for chilled water increases
4. Researching how thermal storage may benefit the cooling system when more chilled water is being utilized throughout the building

Impact of Chilled Beam System

While several of the points made above account for potential issues that this new system could impose, there are other major building impacts that affect the total operation. For example, due to the size difference between typical air distribution diffusers and chilled beams, a new ceiling layout will have to be considered. This also implies that a new lighting scheme could be necessary if the chilled beams are not able to be coordinated in the current ceiling grid. In addition to the ceiling coordination, the structure will have to be studied to account for these bigger induction units. Lastly and most importantly, the building envelope will have to be studied extensively where the proposed chilled beams would be implemented. Because this system has a high potential for humidity issues, the envelope must be able to maintain the appropriate amount of moisture within the building. When designing a chilled beam system, humidity constraints are one of the biggest concerns because this system operates on a higher working temperature.

Breadth Analysis

Construction Analysis

The main focus of this analysis will revolve around the chilled beam design that is going to be studied as an alternative to the current overhead air distribution. One of the main concerns with chilled beams in the U.S. market is the installation and capital cost of the system. While this system tends to be more expensive in the upfront costs, the market is starting to see a decrease in cost as the government regulations are creating a more stringent building energy restriction. Overall, this analysis will use RS Means to do a cost comparison between the two systems' installation and lifecycle costs. The payback period must be considered with the chilled beams because this could have been a deciding factor in the original design process.

Daylighting Analysis

After the main analysis of energy consumption in the Northeast Education Building in Technical Report Two, it is evident that the current lighting system uses a large portion of electricity. As shown above in Figure 37, to light this building, the current system uses ~33% of the total energy. By performing a daylighting analysis, there is a high potential that this building, based on its current orientation and location, can utilize the natural light during the day. Essentially, this would help alleviate the current need of lighting in the building because the daylight would account for the decrease in energy. By installing occupancy sensing low energy LED lights, there could be a significant decrease in energy usage from the lighting perspective. Once installed, these LED lights can also be integrated with the proposed chilled beam system.

Masters Coursework

Along with the analysis of implementing a chilled beam system, an overall central cooling study will provide beneficial information in optimizing this design. By using the information from Centralized Cooling Production and Distribution Systems, AE557, a study of the current cooling tower and chillers will provide a substantial base design. The information from this coursework will help to properly analyze the current chiller plant within the Northeast Education Building. With the increased need of chilled water distribution around the building, a full analysis of cooling towers, chillers, and distribution pumps will be beneficial to create a properly designed chilled beam system.

Furthermore, in conjunction with the AE557 coursework, AE559: Computation Fluid Dynamics will also aid in the analysis of the air distribution of the main lecture spaces within the building. With the current design of the Lower Level lecture halls utilizing displacement ventilation, this coursework will help show which distribution system, underfloor or overhead, provides the most beneficial mixing properties. Due to the size of these lecture spaces and the number of occupants, having the ability to provide adequate mixed air is essential.

Tools & Methods

Load Simulation

To fully analyse the impact of the proposed mechanical designs, software programs such as Trane TRACE and eQuest will be utilized. Both programs were used in the initial design phase to model the current systems and their improvements upon a base model. Trane TRACE will be used more so to analyse the heating and cooling requirements within each zone. With the potential of mechanical zones changing, an updated TRACE model will be created to analyse the pertinent adjustments. On the other hand, the current eQuest model will be modified to reflect any proposed design changes. Therefore, with the base and current model comparisons already created, the new design will display the energy impact of potential chilled beam and displacement ventilation systems.

Through previous reports, eQuest has proven to be a more useful energy modelling software, whereas, TRACE is more beneficial with analysing building loads. To further the analysis of the Northeast Education Building, both programs will be used to model the capital and lifecycle costs. As shown in Technical Report 2, these programs currently show a major discrepancy in some of the building systems' energy usage. Therefore, by gathering as much data from both programs relative to energy usage, a more accurate comparison will be made from the current building design.

Plan of Action

Attached in the Appendix files is a Proposed Timeline of required tasks that must be completed to successfully redesign the Northeast Education Building. This plan, while set up to be permanent, is subject to change over the course of redesign depending on the different design challenges that may occur. In that same respect, there are other research areas that may be included in the overall redesign if time permits. Below are the major milestones outlined in the overall timeline:

1. **Milestone #1** – January 23, 2015
    1. Research complete: enclosure study and displacement ventilation space feasibility study
    2. TRACE model completed with updated systems
2. **Milestone #2** – February 13, 2015
    1. eQuest model almost complete
    2. Chilled beam design underway
    3. Displacement ventilation started
3. **Milestone #3** – March 6, 2015
    1. Wrapping up eQuest simulation
    2. Displacement ventilation redesign continuing
    3. Construction breadth complete
4. **Milestone #4** – April 3, 2015
    1. Electrical breadth complete
    2. Presentation completed
    3. Practicing for final presentation

Chapter 3 | Proposed Redesign Analysis

Depth Study 1 | Chilled Beam Implementation

System Definition

Active Chilled Beams (ACB)

Similar to the fan coils explained above, these units are also decoupled from the standard ductwork design found in most office buildings in the U.S. While most of the technology and methodology is similar in these designs, chilled beams operate based on natural air induction as opposed to fan energy in the fan coils units. Active chilled beams are linked to a 100% dedicated outdoor air system (DOAS) to account for the humidity levels produced in the respective spaces. However, the main draw in using this technology is the use of higher cooling water temperatures. Unlike the conventional supply-return water differential found in FCUs, there is no need for a condensate drain pan or return air filters because this cooling process does not involve dehumidification or condensation.

Initial Research

The technology used in chilled beams has been around since the late 1930s when Carrier introduced a high-pressure perimeter induction air system suggested by Tredinnick [1]. Most of the current technology that has been developed follows this original idea by inducing warm, recirculated, room air with high-velocity, cold air. According to Tredinnick [1], the first use of a chilled beam radiating system was installed at the Volvo plant in Gothenburg, Sweden in the late 1960s. Since this first installation, the technology has transformed from a radiating system into a convective system used frequently throughout Europe and Australia. For the past 15 years, chilled beams have been the most prominent within the European building industry just as air driven systems have been in the U.S. As the push for ‘green technology’ becomes more widely recognized in the U.S., the transformation has begun from older techniques into newer ideas and designs such as chilled beams.

Provided by ASHRAE [2], there was a case study conducted in which chilled beams were studied at Astra Zeneca located in Boston, Massachusetts. With a new technology, it is often difficult to find pertinent research or practical examples of buildings in the U.S. utilizing the chilled beam system. Astra Zeneca is an international, research-based pharmaceutical company that is European owned. Prior to building in the U.S., they had used the chilled beam system and wanted to bring the technology to their U.S. buildings as well. Since 2000, Astra Zeneca has installed chilled beams in five buildings to serve offices, laboratories, a cafeteria, and an atrium with south facing glass. Through this study and research of the installed equipment, it was found that none of the buildings have had condensation issues. Due to the wide success and ease of use that this system has provided, ASHRAE [2] affirms that Astra Zeneca plans to build and install another chilled beam system in their newest building design. Their energy model, based on the performance of the previously studied buildings, shows a $100,000 savings over a conventional VAV system on a multimillion-dollar project.

Energy Savings

Given today’s industry focus on the energy consumed by buildings, the most pertinent benefit of implementing the chilled beam system is the associated energy savings potential. Often times, chilled beams require another specialty system known as a dedicated outdoor air system (DOAS) to manage the building humidity levels. While this can be seen as a drawback, having to design for an additional system, the combination of these two technologies meets the requirements of ASHRAE Standard 62.1. This standard governs the ventilation requirements within commercial buildings, and with the two systems working together, Roth [3] emphasizes that the required ventilation is actually decreased due to the precision of the DOAS system in delivering the required ventilation air. In conjunction with the benefit above, by utilizing these two systems together, the sensible cooling load is decoupled from the ventilation air delivery. Ultimately, by separating the two systems, the building's fan energy designed to supply the appropriate ventilation air can be drastically reduced. Alexander [4] also reiterates this point by saying that there are perpetual fan energy savings by using chilled beams as compared to VAV and other types of all-air systems.

Continuing with the associated energy savings of chilled beams, the decrease in required ventilation airflow also decreases the amount of outdoor air that needs to be conditioned (heated or cooled appropriately) within the building systems. With less air to condition, the building's chiller and boiler systems also see a significant decrease in the associated energy used. Likewise, it is shown by Roth [3] that chilled beams also operate on a higher chilled water temperature than conventional air conditioning systems. The average operating temperatures range from 55°F - 63°F compared to the standard 39°F - 45°F chilled water requirement. For building chilled water systems, this is a significant benefit to implementing a chilled beam cooling system. By adding a dedicated chiller for the chilled beam piping, this system will see a lower temperature lift because it does not have to cool the water to such extreme temperatures. Therefore, with a higher operating temperature, the associated chiller should operate at 15% to 20% higher efficiency than a conventional system according to Roth [3]. In addition to these savings, the associated DOAS system will also provide the appropriate temperature return water to service the secondary chilled water loop. Demonstrated by Alexander [4], this recirculation, better known as water-side economization, of the DOAS return water helps to minimize the total pumping requirements.

Building Limitations

Since chilled beams have trickled into the U.S. market, there have been some limitations presented by the technology, pertaining mostly to the locations and types of buildings in which they can be installed. Chilled beams, like all mechanical systems, have their restrictions in which they function the most efficiently and provide the comfort desired by the building occupants. Therefore, chilled beams have been used the most repeatedly in commercial office buildings, educational buildings, and some laboratories with high sensible loads. While this presents a large majority of the building projects in the U.S. industry, the technology cannot be used within spaces with high latent loads. Due to the warmer chilled water used in the system, Tredinnick [1] declares that chilled beams cannot be exposed to humid conditions or large quantities of unconditioned outside air. These particular spaces and building types include but are not limited to kitchens, pools, locker rooms, and gymnasiums. Similarly, Roth [3] explains that the HVAC system must be carefully designed so that high latent loads do not form condensation on the chilled water supply pipes and cooling coils. In essence, this condensation formed would cause a raining effect within the building and ruin the interior design elements.

Another limiting factor in the design process is the specific height of the ceiling provided within the building space. Chilled beams are rated for approximately 14-foot ceilings due to the characteristics of induced room airflow. Because of the mixing process of conditioned, recirculated air with ventilated air, there are limitations to which the high density, cold air can reach the floor and appropriately condition the space. Alexander [4] argues that research and current designs have proven that 14 feet is the maximum height chilled beams should be designed for to obtain the maximum cooling capabilities provided by this technology. Additionally, there are certain limitations on specific building types such as hospitals and certain laboratories. Due to high restrictions on air quality and conditioning within these spaces, chilled beams are not a plausible option because air is not permitted to be recirculated, but rather directly exhausted from the building.

Spaces Analyzed

From the previous chapters, Chapter 1: Existing Systems Overview and Chapter 2: Proposed Redesign, one of the main discussions revolved around utilizing chilled beams to replace the air-driven VAV boxes in the upper level offices. To the right are two typical office layouts in which chilled beams can be utilized in the spaces on Levels 3-5. In each layout, Option A, which encompasses both the blue and yellow highlights is the full analysis of the office spaces whereas Option B, in blue only, does not include any exterior offices. Exterior offices are defined by any space that is directly connected to the exterior façade by glazing or the exterior wall in general. By providing both layout schemes, each option has its advantages and disadvantages, which will be discussed further in the following section. To see these layouts in full rendering, please see Appendix A.

Figure 39: Typ. Office Layout Level 5

Figure 40: Typ. Office Layout Levels 3 & 4

System Analysis

Airflow Comparison

One of the major advantages of using chilled beams is the decreased airflow in the provided ductwork, often times allowing the engineer to downsize the necessary ducts to accommodate the building spaces. In that sense, one of the major analyses of this report is realizing the potential cost savings in sheet metal by implementing either chilled beam layout shown previously. This analysis will be outlined later in the report, Construction Breadth; however, there are also pros and cons to each scheme as stated previously beyond the cost savings in ductwork. For example, the airflow requirements of each option provide interesting data that should be analyzed further. Seen to the right in Table 15, is a basic comparison that was used in the overall analysis of the chilled beam system. While this table does not include all of the building spaces, it provides a brief overview of the amount of airflow reduction that is possible for each chilled beam layout.

Table 15: Active Chilled Beam Airflow Comparison

Building Proximity	*Room*	*Original Airflow*	*ACB Option A Airflow*	*ACB Option B Airflow*
Exterior	4181	175	50	175
	4182	225	75	225
Interior	4179	125	25	25
	4180	125	25	25
	4183	125	25	25
	4184	125	25	25
Interior	4176	125	25	25
	4177	125	25	25
	4178	125	25	25
	4185	125	25	25
	4186	125	25	25
	4187	125	25	25
Total Airflow		1650	375	650

A full analysis of the building airflow reduction can be found in the Appendix B files. From this brief analysis, it is evident that each option will take some of the strain off of the air handling units as they provide conditioned air to all of the appropriate spaces. Shown in Table 15, Option A is able to reduce the airflow by about 77% and similarly, Option B reduces the airflow by about 61%. From an initial standpoint, both chilled beam options seem very plausible and both provide an adequate savings with regards to the amount of air that is reduced in the building systems. As an energy saving option, this has the potential to reduce the overall size of the air handling units required to provide adequate air around the building. In the full analysis of each chilled beam option, there was a total of 78% air reduction (Option A) and 62% air reduction (Option B). Therefore, by simplifying the analysis in Table 15, this appropriately outlines the potential savings in each system. In general each interior office space is reduced by 80% airflow and each exterior space is reduced by ~66-71%.

Heating & Cooling

Another major advantage of the chilled beam system, as discussed above in Benefits of Technology section, is the overall operating temperature of the chilled beams. By allowing the system to operate at a temperature range of 55°F - 63°F, the energy requirements to provide chilled water will hypothetically decrease because the water can be 10°F warmer than the standard 39°F - 45°F. One of the potential drawbacks to this system, however, is the addition of radiant heating along the exterior glazing. This is where Option A and Option B differ because Option A substitutes all of the VAV boxes with chilled beams. Unfortunately, this induction hydronic system does not perform well in heating exterior building spaces because there is not enough airflow to throw the air far enough and create the appropriate mixing. Naturally, hot air is less dense than cold air, which is why this system operates well on the air conditioning side. However, because of this disadvantage, Option A represents the heating requirements that would be necessary to maintain this office space at a comfortable temperature. On the other hand, Option B does not include these spaces and instead, utilizes the original VAV design to heat and cool the exterior offices.

Another potential drawback of implementing a chilled beam system in conjunction with the original design is the mere fact that both the air system and hydronic system are operating on one chiller. What this means exactly is that while there is potential to increase the operating temperature for a chilled beam system and save on cooling capacity for the chiller, it is not quite possible when there are still VAV systems operating on the same system. Unlike the chilled beams, the air-driven system still requires the chiller to produce 45°F water to effectively throw the cold air into the space and appropriately condition and dehumidify the air. Even though the offices consume a large majority of the upper level building spaces, there are still several circulation, seminar, and conference spaces in the lower floors that will operate on the VAV system as well. Ultimately, this does not allow the chilled beam system to realize its full potential, and therefore will not allow the chiller to decrease its overall required tonnage or energy usage.

Depth Study 2 | Fan Coil Implementation

System Definition

Fan Coil Units (FCU)

This system is a compact, heat transfer unit that is mainly comprised of a fan, return air filter, water coils, and a condensate drain pan. Typically found in residential, commercial, and industrial buildings, these systems offer a simplistic design that is decoupled from the standard ductwork found in most U.S. buildings. Having both heating and cooling coils allows this unit to recirculate air in the summer and winter providing substantial air conditioning for sensible building loads.

Initial Research

Comparison of Fan Coils & Active Chilled Beams

The two main mechanical design schemes that are being studied in this report are fan coil units and active chilled beams. While fan coils have been a U.S. building standard in conjunction with VAV terminal boxes, chilled beams have started to trickle into the market through major U.K. owners and designers. Both systems operate on a similar hydronic scheme, providing equal advantages to plenum design and saving on building space; however, each system works on different physical principles making each design advantageous in different aspects. Through research of articles in major mechanical engineering journals such as ASHRAE and ASME, there have been several authors that outline the future of each technology.

To start, both fan coil units and active chilled beams have different working temperatures that allow each system to operate in a specific way. Fan coils are designed based on typical U.S. building water temperatures. Therefore, the standard chiller cools the water to 39°F - 45°F and the fan coil runs on these temperatures to cool the associated space. Conversely, the chilled beam system is designed on a different principle where the operating temperatures are 55°F - 63°F. While fan coils have the ability to operate on a similar temperature differential, The Chilled Beams & Ceilings Association [5] cautions that the maximum sensible chilled water temperature should only be raised to around 50°F. Anything above this temperature set point would involve dehumidifying the air at the air-handling unit, which would add cost to the overall system.

Another major component of the technical design involved in mechanical systems is the fan requirements to move the air in the appropriate manner. One of the major differences in these systems is the use of a fan at each individual space or a central fan at the air handling unit. Fan coil units, as the name suggests, have a built-in fan that moves the air about the space. Utilizing a fan per space in this manner has different consequences from a technical perspective. Ultimately, this allows each unit to perform in a flexible manner because not only can this system circulate the air, but also can dehumidify the air within the space. On the other hand, active chilled beams operate on a higher working temperature so that the system does not condensate and create unwanted moisture within the building plenum. Therefore, with higher working temperatures, the chilled beam system must be designed in conjunction with a DOAS system that can actively dehumidify the space as well. This involves a separate unit to pull outdoor air into the building and ventilate each space with the appropriate conditioned air.

The use of an individualized fan also allows the fan coil units to respond fairly quickly in a sudden temperature change within the building space. Because chilled beams recirculate air based on induction properties and rely mostly on the hydronic component of the system, there is slower response time than the fan coil units. According to Holland [6], chilled beams effectively move 30-40% more air around the space for the same cooling load as compared to fan coils. He explains that this essentially limits the cooling capacity of a chilled beam, whereas a fan coil unit can be connected to a more superior air distribution device that moves the air in a more effective manner. On the other hand, having a fan in each space also causes unwanted and unnecessary noise that is often associated with older mechanical systems. Unlike the chilled beam system, a virtually silent system because of the low-velocity air distribution and induced air recirculation, the fan coils must have a sound attenuator to operate in certain spaces. The fans may be selected to run at an appropriate background noise level (BNL) for classroom and office spaces; however, this also requires a higher upkeep and more frequent maintenance. With any added debris in the system, the increased pressure on the fan will cause a louder, less efficient performance. On the contrary, Alexander [4] shows that in a properly designed ACB project, the coil surfaces will not condense and the fins will remain dry. Therefore, maintenance vacuuming can be as infrequent as once every three to five years.

From the information provided on the technical side, there is evidence in favor of each system respectively. However, system energy usage and overall building consumption seem to be the driving factor in today’s mechanical designs. While fan coil units have individualized fans in each space, providing advantages as described above, the active chilled beam system requires a centralized DOAS unit to provide the adequate ventilation air. Argued by Alexander [4], by decoupling the ventilation load from the individual space loads, there are perpetual fan energy savings as compared to VAV and other types of all-air systems.

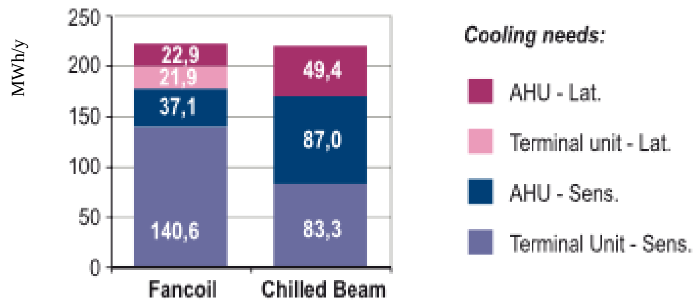

Figure 41: Annual Cooling Needs (MWh/year)

In Figure 41, provided by Ventura [7], he shows that while each system has its different cooling requirements based on the technical aspects of design, the total MWh/year is practically identical (see previous page). Therefore, as described previously, it is not necessarily the total cooling needed in the building, but more so how the system operates and utilizes the associated energy.

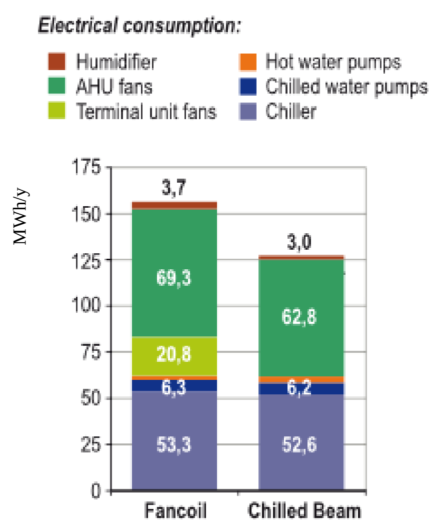

Figure 42: Electrical Annual Consumption (MWh/year)

As argued by Alexander [4], Ventura [7] also offers a similar argument that is shown in Figure 42. This graph easily depicts how most of the associated components of each system are almost identical in electrical energy usage – all except for the terminal unit fans. Ventura [7] states that the chilled beams help to reduce ventilation energy consumption by ~30%, and the absence of motors in the ACB design contributes significantly to its decline. Overall, there is approximately a relative difference of 18.5% in overall electrical consumption.

As demonstrated by the above figures and associated information, energy consumption and payback potential is extremely significant in mechanical design. Both systems offer equal cooling requirements; however, it is the way in which the systems consume energy that differentiates chilled beams and fan coil units. While 18.5% electrical consumption is not ground-breaking, a projected life cycle cost would outline a substantial difference in each system.

Spaces Analyzed

Different than the previous analysis of the chilled beam redesign, the proposed fan coil redesign only reflects the spaces in that of Figures 40 and 41, Option A. The reason the fan coils were not split into two scenarios like the chilled beams is because of how this system works differently than the active chilled beams. While both hydronic systems, the fan coils have individualized fans in each unit as described above. This allows the system to operate similarly whether the unit is serving an interior or exterior space because it has the ability to throw the cold or hot air to condition the space. In that respect, there would be no real advantage to creating two space analyses because there is no additional equipment required like the radiant paneling for active chilled beams in exterior spaces.

Table 16: Fan Coil Airflow Comparison

Building Proximity	Room	Original Airflow	FCU Airflow
Exterior	4181	175	170
	4182	225	265
Interior	4179	125	75
	4180	125	75
	4183	125	75
	4184	125	75
Interior	4176	125	75
	4177	125	75
	4178	125	75
	4185	125	75
	4186	125	75
	4187	125	75
Total Airflow		1650	1185

System Analysis

Airflow Comparison

Similar to the chilled beam analysis in the previous section, the total airflow for each space has been analyzed with respect to the original design (See Appendix B for full analysis). Table 16, above, displays another brief analysis based on the full analysis of each office space on Levels 3-5. Compared to the original design, the fan coils operate at a lower airflow similar to the chilled beams. On a space-to-space comparison, the fan coils provide an average savings on the interior office spaces of about 40% and a savings of about <15% on the exterior spaces. Table 16 represents only a 3% decrease in Room 4181, but other spaces are more drastically affected by the fan coil redesign. There are also some exterior spaces such as Room 4182 that are negatively affected by the implementation of fan coils. Unfortunately, the fan coils actually require an increase of about 18% airflow to accommodate for the appropriate conditioning of the space. This is not the only room affected in this way, but rather, as can be seen in the full analysis, there are quite a few exterior spaces that require more air with the fan coils than the original VAV design. Overall, the fan coils offer a 32% reduction in the total airflow of the respective spaces, so despite the additional airflow in the exterior rooms, there is still a decrease for the system.

Depth Study 1 & 2 Comparison

Airflow Comparison

Table 17: Full System Redesign Airflow Comparison

Building Proximity	Room	Original Airflow	ACB Option A Airflow	ACB Option B Airflow	FCU Airflow
Exterior	4181	175	50	175	170
	4182	225	75	225	265
Interior	4179	125	25	25	75
	4180	125	25	25	75
	4183	125	25	25	75
	4184	125	25	25	75
Interior	4176	125	25	25	75
	4177	125	25	25	75
	4178	125	25	25	75
	4185	125	25	25	75
	4186	125	25	25	75
	4187	125	25	25	75
Total Airflow		1650	375	650	1185
% Savings Full Analysis		-	78%	62%	32%

Depicted in the previous two air analyses, all three of the newly proposed designs offer adequate air reductions as compared to the original system. Once again, these are outlined above in Table 17 to show how exactly each system lines up. As stated in the above arguments, Option A for the chilled beam redesign outweighs Option B by about 16% in the amount of airflow it takes to condition the respective office spaces. However, now looking at the active chilled beam as compared to the fan coils, there is a significant jump from 78% savings to 32% savings and even from 62% to 32% for Option B. From an air savings perspective and analyzing both systems from a potential energy perspective, the chilled beams outperform fan coils in this regard. By providing 60% less airflow to the interior office spaces, chilled beams are able to drastically cut the overall air needs of the building.

As a whole, the systems were then analyzed looking at the full building once this initial analysis was completed. Not only does the potential airflow decrease allow the duct sizing to be reduced drastically, but also the air handling units themselves can also be reduced in this case. Each redesign allows for a decrease in the air handlings units; however, there are significant differences in the amount of each decreased unit. In the initial design, these referenced office and support spaces required 21,000 CFM from the 30% OA AHU-W-2. Now, with the new chilled beam design (Option A), there is only 4,585 CFM requirement to condition these spaces. Likewise, the chilled beam design (Option B) requires 8,030 CFM and fan coil design requires 14,305 CFM. As a whole, each design proposed has been able to decrease the original 21,000 CFM requirement; however, the original chilled beam proposal is evidently the most beneficial. Shown on the following page, Table 18 outlines each redesign and the possible air handling unit that may replace the original. Something to note about each design option is that they all require a dedicated outdoor air system to properly ventilate the office spaces. Therefore, as seen on the next page, all of the decreased units, AHU – W2, also involve an increased unit for the DOAS system AHU-W-1 and its coupled recovery unit EAHU-W-1.

First, taking a look at the reduction of AHU-W-2, Option A is able to decrease the total airflow by 20,000, downsizing the air handling unit by 27%. Similarly, Option B and Option C are also able to reduce the original air handling unit size by 17% and 9% respectively. However, analyzing the DOAS system for each redesign, there is a significant increase between the original design and each option. As stated before, each of the hydronic systems require the DOAS system to properly ventilate the space. Therefore, as shown above in Table 18, each AHU-W-1 and its associated recover unit must be upsized to accommodate for the new airflow design. While an 18% increase for the full chilled beam redesign is not extremely drastic, the 38% increase for the fan coils would make an interesting case for the associated ductwork upsizing involved and airflow pressurization that in the building. Additionally, all of these air handling units have an associated cost differential that may affect the project redesign as well. The full analysis of each air handling unit and cost associated with the system will be analyzed further in the report (See Construction Breadth).

Table 18: Full System Redesign Airflow Comparison

Redesign	Unit	System	Total CFM		
			Original	New	% Differential
ACB: Option A	AHU-W-2	Recirculation West	*75,000*	55,000	-27%
	AHU-W-1 EAHU-W-1	DOAS West Energy Recovery West	*25,000*	30,000	+18%
ACB: Option B	AHU-W-2	Recirculation West	*75,000*	62,000	-17%
	AHU-W-1 EAHU-W-1	DOAS West Energy Recovery West	*25,000*	33,000	+24%
FCU: Option C	AHU-W-2	Recirculation West	*75,000*	68,000	-9%
	AHU-W-1 EAHU-W-1	DOAS West Energy Recovery West	*25,000*	40,000	+38%

Depth Study Overview | Cost Analysis

General Overview

This section will outline the overall utility cost comparison between all three hydronic proposals. The original utility costs were shown previously in Table 12, and this is the baseline cost that each system will be compared with in this analysis.

Active Chilled Beam: Option A

From an initial comparison to the original data above, it appears that the breakdown of utility costs is about the same. The electricity, purchased hot water, and water all maintain the same percentage in the overall cost of the Northeast Education Building. However, taking a closer look at Table 19, the electricity decreases ~$10,000 annually. From the original cost analysis, there is a drastic decrease in the air handling electricity; however, the HW pump cost approximately doubles. This directly relates back to the original discussion above in which air flows are able to decrease for this system. Likewise, the amount of purchased hot water also increases for Option A as described below in the section Hot Water Requirements. From an overall standpoint, the Option A redesign incurs an annual utility cost of $608,237.09, which in turn is about $7,800.00 less per year than the original design. These cost savings will be further analyzed in the Construction Breadth section to determine if the redesign is feasible along with all of the other design implications.

Table 19: Chilled Beam: Option A Cost Analysis

Annual Utility Costs: Option A		
Electricity	**$559,594.84**	**92%**
Lights	$185,121.89	30%
Centrifugal Chiller	$141,616.40	23%
Cooling Tower	$34,055.05	6%
CHW Pump	$30,382.83	5%
CW Pump	$30,508.74	5%
HW Pump	$10,159.08	2%
HX	$5,162.64	1%
AHU	$122,588.21	20%
Purchased Hot Water	**$26,269.00**	**4%**
Water	**$22,373.25**	**4%**
Total	**$608,237.09**	**100%**

Active Chilled Beam: Option B

Comparatively, Option B is very similar to Option A in the overall cost analysis. Similar to Table 19, the air handling units take a major cut from the original design – approximately an $8,000 savings. Likewise, the purchased hot water costs are still increased from the original as well as the HW pump; however, with less chilled beams to account for, the cost decreases slightly from Option A. Overall, with the slight increase in purchased hot water and the significant decrease in air handling unit electricity, Option B saves the Northeast Education Building about $6,500 annually.

Table 20: Chilled Beam: Option B Cost Analysis

Annual Utility Costs		
Electricity	**$561,874.97**	**92%**
Lights	$185,121.89	30%
Centrifugal Chiller	$142,072.08	23%
Cooling Tower	$34,100.43	6%
CHW Pump	$30,382.83	5%
CW Pump	$30,508.74	5%
HW Pump	$10,107.81	2%
HX	$5,165.70	1%
AHU	$124,415.49	20%
Purchased Hot Water	**$25,126.66**	**4%**
Water	**$22,373.25**	**4%**
Total	**$609,374.88**	**100%**

Fan Coil Units: Option C

From first glance, the annual costs of the fan coil design are very similar to that of the original and the previous two chilled beam options. Overall, the main difference in Table 21 is the addition of the fan coil supply fans. As stated previously above, each zone that the fan coils are responsible for regulating requires its own supply fan. This is ultimately where the main difference in the hydronic systems lies – the chilled beams do not have an additional fan supplying the air to the appropriate spaces. Option C, however, is able to decrease the main air handling costs, but most of that cost is simply transferred into the fan coil fans. Basically, Table 21 outlines how fan coils are able to take the main fan energy from the air handling units and disperse it amongst the several units around the building. Similar to the notes above about chilled beams, the purchased hot water and HW pump costs are directly impacted by the use of a hydronic system in the building. All in all, there are not many other areas that seem to be impacted by this system or the previous two. Compared to the original, Option C is able to save about ~$1,100 annually.

Table 21: Fan Coil: Option C Cost Analysis

Annual Utility Costs		
Electricity	**$566,451.21**	**92%**
Lights	$185,309.70	30%
Centrifugal Chiller	$141,128.50	23%
Cooling Tower	$34,033.50	6%
CHW Pump	$30,382.83	5%
CW Pump	$30,508.74	5%
HW Pump	$9,890.89	2%
Fan Coil Supply Fan	$8,526.38	1%
AHU	$121,539.57	20%
Purchased Hot Water	**$26,269.00**	**4%**
Water	**$22,193.85**	**4%**
Total	**$614,914.06**	**100%**

Depth Study 3 | Photocell Implementation

System Definition

Photocell (PC)

A photosensor is an electronic component that detects the presence of visible light, infrared transmission (IR), and/or ultraviolet (UV) energy. Most photosensors consist of semiconductor having a property called photoconductivity, in which the electrical conductance varies depending on the intensity of radiation striking the material.

Spaces Analyzed

Unlike the previous two studies, this study takes a look at the main corridor spaces that allow the students and professors to transition throughout the building. As stated previously in the Chapter 1, there is a lot of potential to utilize the natural daylight that is already available in the original architectural design. With curtain wall designs on the East and West corridors throughout the main circulation spaces, there is potential to reduce the 33% lighting load (see Figure 11) with the addition of photocells.

Figure 43: Typical Photocell Building Space Analysis

Shown in Figure 43 is a typical layout for the area in which photocells will be analyzing the daylight available in each space. From floor to floor, the main idea behind the control scheme is the same; the photocells are placed appropriately in the corridors and exterior seminar spaces to control the amount of light and potentially reduce the amount of electricity used each year. While most of this study falls under the lighting and electrical analysis detailed later in the report, the full implementation of the photocell design integrated with the mechanical system is significant. (See Appendix A for all levels of photocell analysis).

Electricity Requirements

To show a brief overview of the photocell implementation, Figure 44 outlines how the addition of photocells would decrease the monthly electricity consumption. Although, the decrease does not appear to be extremely significant in the graph, the photocells would decrease the annual electricity consumption by 34,700 kWh. By allowing the building to be monitored on a more sophisticated system, there is less electricity needed to power the typical fluorescent T8 lighting scheme. This analysis of the lighting and associated electricity will be shown in more detail in the Lighting Breadth Section of this report.

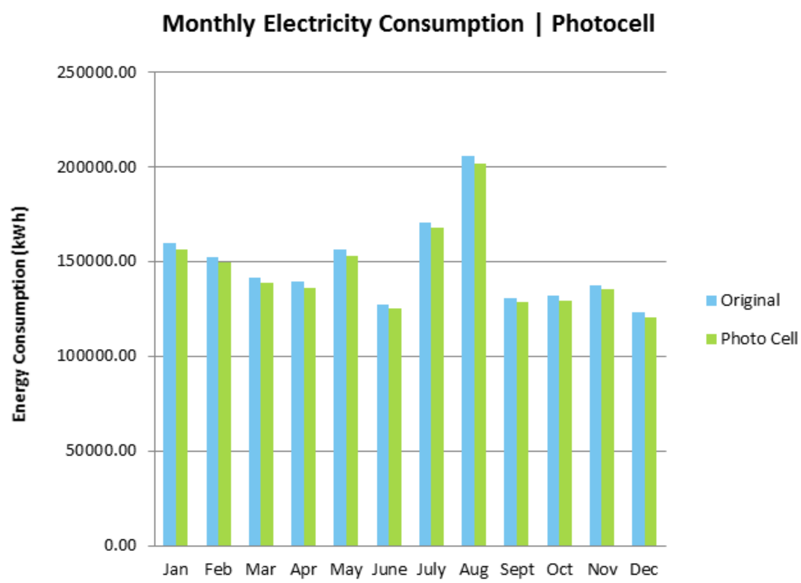

Figure 44: Electrical Consumption with Photocell Implementation

Depth Study Overview | Utility Analysis

General Overview

This section outlines the utility consumption that was discovered using eQuest energy modelling. There were three different redesign options including photocells, fan coils, and chilled beams as well as two combination redesigns that show the potential of combining both the fan coils and chilled beams with the photocell redesign. Different than the studies above, the chilled beams were not explicitly broken out into Option A and Option B. For the utility distribution graphs, this portion of the report outlines the general benefits of each technology as opposed to different design scenarios.

Electricity Requirements

The first graph displayed on the following page, Figure 45, depicts the full analysis of each system and the benefits that each technology provides to the mechanical system. As a whole, it is evident that each redesign has improvements upon the original VAV design as can be seen in Figure 45. The graphs following Figure 45 break out the individual and combination redesigns as compared to the original design in a less cluttered format. Shown in Figure 46, it is evident that the implementation of chilled beams provides the most beneficial improvement decreasing the peak load in August from 205,500 kWh to 190,900 kWh – a total of 14,600 kWh. While each new system provided in the following figures outlines the overall improvement in energy efficiency, the more interesting data is shown in Figure 47. This figure shows the combination of each hydronic system with the photocell technology. Ultimately, the goal of this study was to improve the overall mechanical system and decrease the consumption of electricity in the building. By providing a combination of the electrical and mechanical systems to improve system controllability, Figure 47 shows that both options decrease the annual electricity consumption.

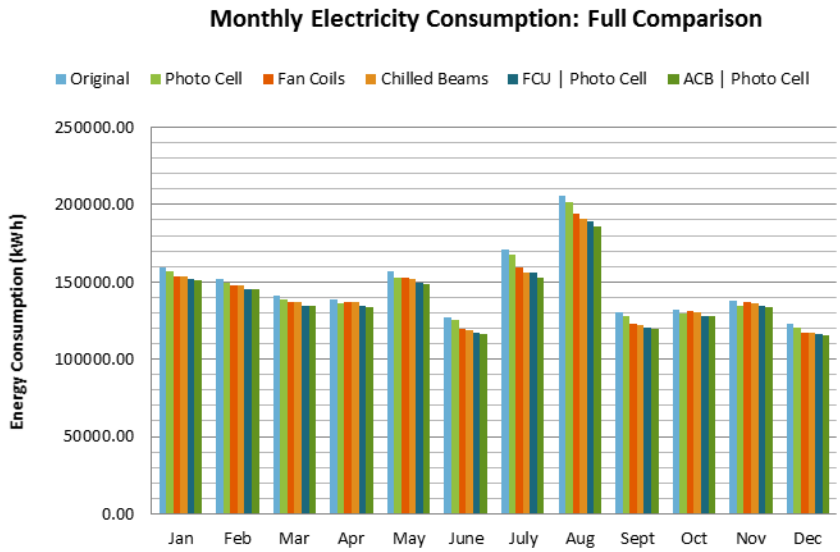

Figure 45: Full Analysis of Electricity Consumption

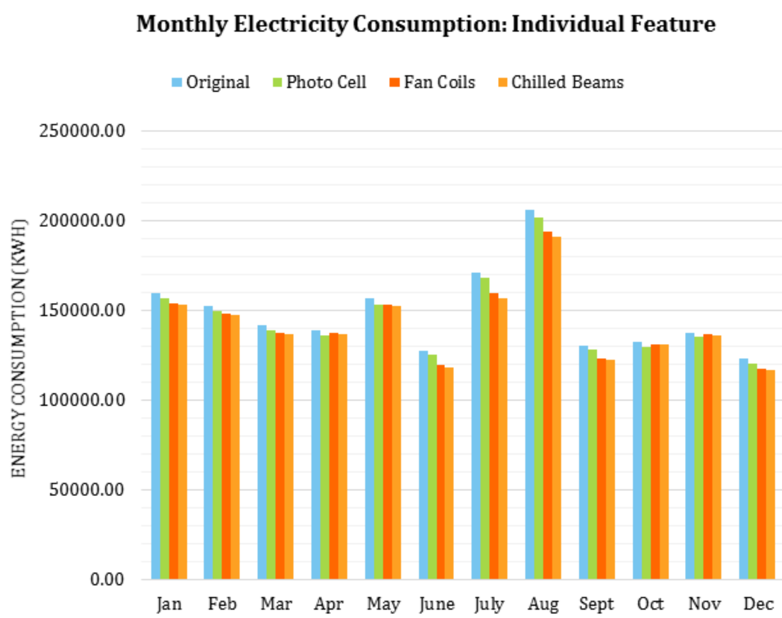

Figure 46: Individual Feature Electricity Consumption Comparison

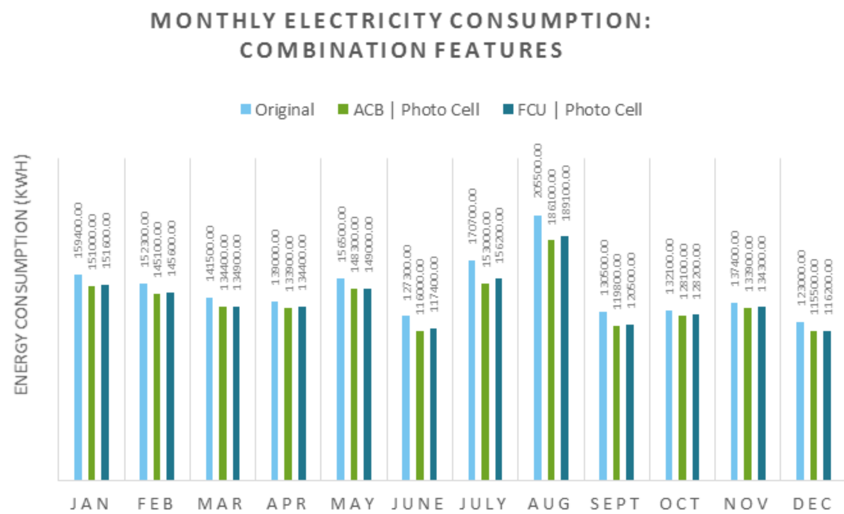

Figure 47: Combined Feature Electricity Consumption Comparison

Hot Water Requirements

Similar to the electricity requirements, the following three figures outline the hot water that is required to operate the Northeast Education Building. With the addition of each hydronic system and the photocell technology, there is an apparent increase in the hot water needed. Most notably during the winter months (November – March), the amount of hot water needed to heat the building increases. Shown in Figure 49, there is approximately no change between adding the photocells and the original design. Similarly, this same figure shows that between the two hydronic systems, there is no significant difference between the amount of hot water used as well. Overall, it makes sense that both of these systems would require more heat to operate as compared to the original air system because it is not just the coils in the air handling units that require heat. With the hydronic systems, there is a significant increase in piping to accommodate for heating and cooling the spaces appropriately. Therefore, with each system operating on the same principles, there will certainly be an increase and it is interesting to see that both of them require about the same amount of heat. This can also be seen in Figure 50 as the combination of photocells and the hydronic systems causes an increase in hot water consumption through the winter months. However, once again, through the summer months (June – September), the combined redesigns actually require about the same or even less hot water than the original.

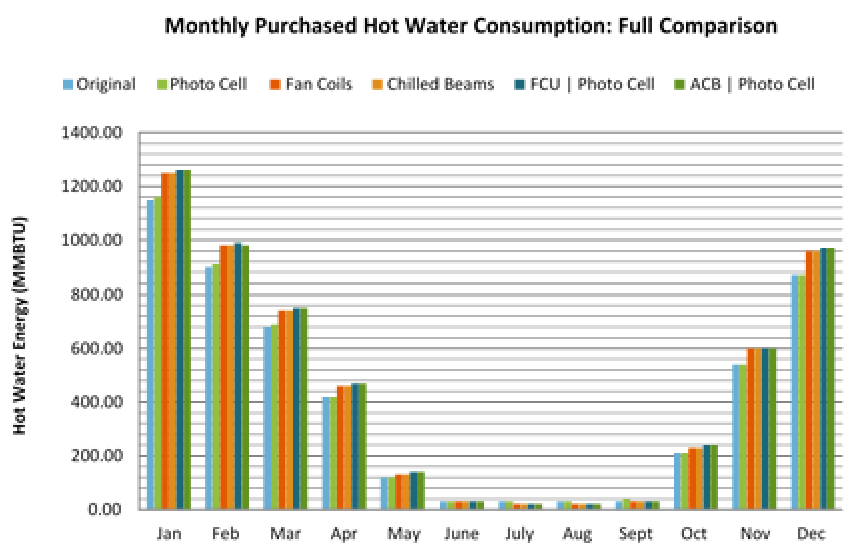

Figure 48: Full Analysis of Hot Water Consumption

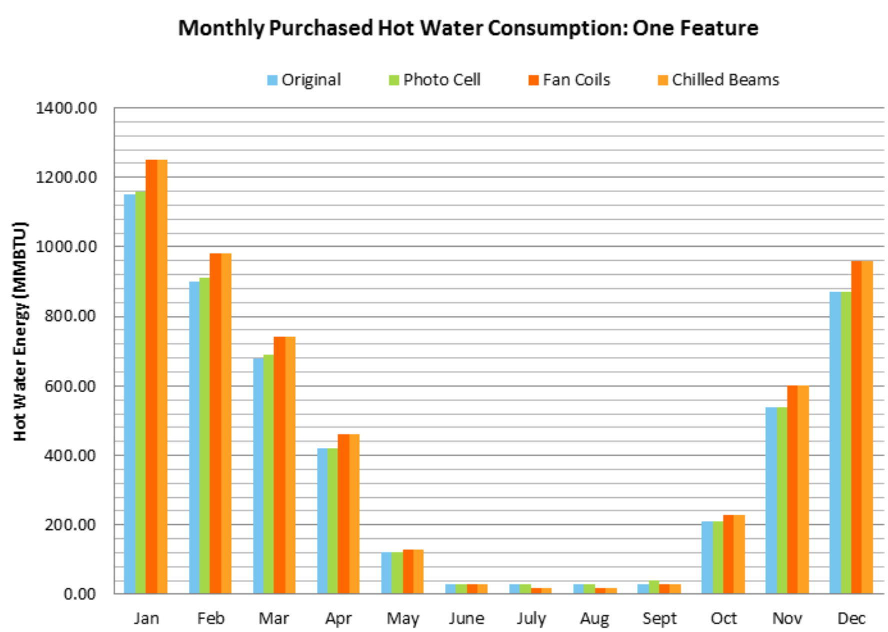

Figure 49: Single Feature Hot Water Consumption Comparison

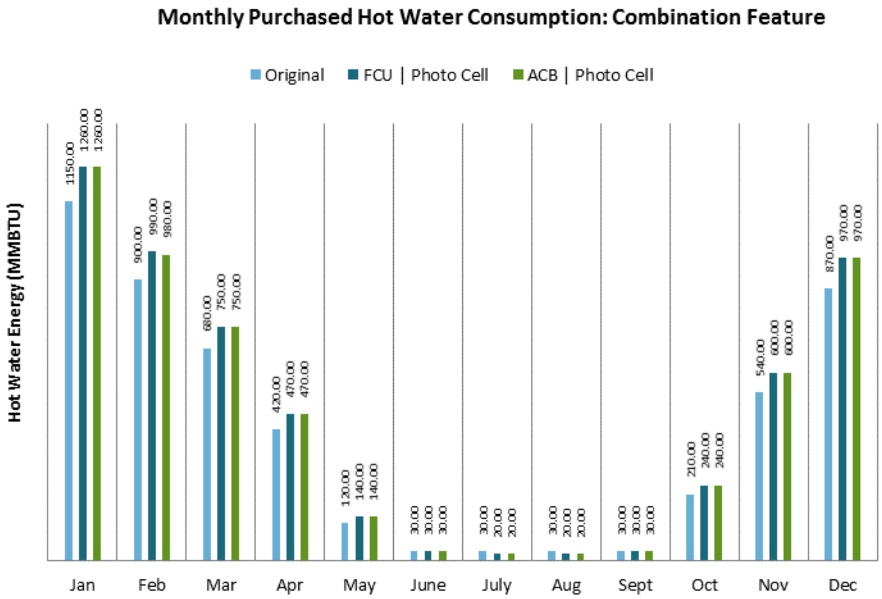

Figure 50: Combined Feature Hot Water Consumption Comparison

Master's Coursework | Displacement Ventilation

General Overview

From the initial design proposal, the other main mechanical design that was analyzed for its potential energy savings and coordination benefits was the displacement ventilation system in the four main lecture halls on the Ground Level. All four of these 300-occupant spaces utilized a technology that is once again not standard in the United States. Displacement ventilation has been prominent in Europe for about 40 years and has been recently studied in the U.S. as a potentially beneficial mechanical technology. This study was used to determine why the initial design team for the Northeast Education Building decided to use displacement ventilation on the lower level lecture halls but an overhead distribution system on the Third Level lecture halls. From a general standpoint, the energy usage as well as the overall occupant comfort was studied to show the benefits of each system and why the lecture halls were designed in this way.

System Definition

Displacement Ventilation (UFAD)

A typical displacement ventilation system supplies conditioned cool air from an air handling unit through a low induction diffuser. The cool air spreads through the floor of the space and then rises as the air warms due to heat exchange with heat sources in the space such as occupants, computers, and lights. The warmer air has a lower density than the cool air, and thus creates upward convective flows known as thermal plumes. The warm air then exits the zone at the ceiling height of the room.

System Considerations

- Underfloor air distribution (UFAD) allows the conditioned air to be supplied at 65F instead of the typical 55F because of the natural convection that occurs in the space. This higher temperature supply air being ducted into the room from the floor does not have to "thrown" as far into the space as with an overhead distribution system.
- Lighting loads can also be decreased in the initial design process of using a UFAD system because the air does not have to overcome these high temperature luminaires from the ceiling.
- Supply air should be designed for about 65F not only as an energy savings, but also to maintain the occupants' comfort level throughout the space. Because the air is being supplied towards the ground in this system, it reaches the occupant much faster than an overhead system. Thus, the air cannot be too cold or this will negatively affect the occupants as the air is supplied beneath them. Whereas an overhead system mixes the supply and room air before reaching the occupants, the UFAD system conditions the space in a different manner and the mixing process only occurs as the air rises from the respective occupants and heat sources.
- To ensure occupant comfort levels as well, the supply air velocity should be lower than that of an overhead system. Again, the air does not need to be "thrown" as far inside the room itself because of the natural convective properties. Therefore, it would be unnecessary to supply the air at the same velocity as an overhead system. UFAD operates on a much lower air velocity to ensure that unwanted drafts are not created within the space. The air is supplied at a higher temperature and lower velocity to condition the space ideally without the occupants realizing a discomfort or unwanted airflows.
- These design considerations also allow for potential cooling coil savings within the space as compared to the overhead distribution. Each system has its own energy benefits that will be discussed in the following section.

Energy Calculations

Fan Energy Savings

Given:

- (144) 70 CFM underfloor diffusers in typical Lower Level Lecture Hall
    - 10,080 CFM Total
- (20) 300 CFM overhead diffusers in current Third Level Lecture Hall 4225-E
    - 6,000 CFM Total
- $\mathrm{dp}_{\mathrm{inWG}} = 6.3$
- Energy cost of electricity = $0.1365/ kWh

Assumptions:

- Fan efficiency = 75%
- Motor efficiency = 92%
- Class room spaces occupied for 75% of the year when school is in session for about 12 hours a day.
- Therefore, $12\,\frac{hrs.}{day} * 365\ days * 0.75 = 3{,}285\ hrs. occupied$

Calculations:

$$\Delta \mathrm{P}_{\mathrm{BHP}} = \frac{(\Delta \mathrm{q}_{CFM} * \mathrm{dp}_{\mathrm{inWG}})}{\mu * 6356}$$

$$\Delta \mathrm{q}_{CFM} = 10{,}080 - 6{,}000 = 4{,}080\ CFM$$

$$\mu = \varepsilon_{fan} * \varepsilon_{mtr} = 0.75 * 0.92 = 0.69$$

$$\Delta \mathrm{P}_{\mathrm{BHP}} = \frac{(4080\mathrm{CFM} * 6.3)}{0.69 * 6356} = 5.86\ BHP \approx 6\ BHP$$

$$6\ HP * \frac{0.746\ kW}{HP} * 3285\ hrs * \frac{\$0.1365}{kWh} = \$1{,}993.81\ \approx \$\mathbf{2,000}\ \boldsymbol{fan\ savings}$$

Cooling Coil Savings

Given:

- Original design of the Third Level Lecture Hall requires 29 tons of cooling to condition the space (calculated by Trace).
- Redesign of UFAD in Third Level Lecture Hall requires 11 tons of cooling to condition the space (calculated by Trace).
- Chiller efficiency = 0.56 kW/ ton
- Energy cost of electricity = $0.1365/ kWh

Calculations:

$$coil\ savings\ = \Delta\text{ton} * \varepsilon_{chiller} * energy\ cost$$

$$coil\ savings = (29 - 11\ tons) * 0.56\left(\frac{kW}{ton}\right) * 3285\ hrs.* \ \frac{\$0.1365}{kWh}$$

$$= \$4{,}519.90\ \approx \$\mathbf{4,500}\ \boldsymbol{coil\ savings}$$

Energy Comparison

To see the full Trace analysis of each space, reference Appendix B. From the calculations shown above, it is evident that the displacement ventilation system offers more savings with the cooling coil requirements than the overhead distribution does with the fan energy. The overhead system benefits from supplying the air at a colder temperature because it does not need as much airflow to condition the space, hence the $2,000 fan energy savings. Similarly though, the displacement ventilation system is able to supply more air at a higher temperature, saving the associated chiller from producing as much cooling energy. Overall, there is more cost savings potential, about $2,500 from the calculations on the previous page, in using the UFAD system. By essentially cutting the cooling capacity in half, the UFAD system sees more of a benefit than the originally designed space, but there are also other design considerations that were involved in this design process; these will be discussed in the following section.

Design Considerations

Shown above is the energy analysis that proves the benefits of utilizing a displacement ventilation system for the building's lecture spaces. While this could be viewed as the only valid design consideration, there are additional analyses that must be weighed as well. In the initial design, there are recirculating units beneath each of the lecture halls that ultimately supply 70% of the air required. Each room has been calculated to need about 10,000 CFM based on the 300 occupants and associated building loads. Therefore, based on the building's mechanical design, this would be about 20,000 CFM constantly flowing through the building during typical class hours. From the original design analysis of the mechanical system, it was shown that all of the respective air handling units are located on the 6th floor of the west wing and 4th floor of the east wing. Realistically, the air for these spaces travels about six stories to the air handling units, which is an awful lot to be circulating on a constant basis. From the initial design, implementing these recirculation units saves a substantial amount of ductwork in the building plenums across the building levels. Each DOAS air handling unit has been rated to supply 10,000 CFM for each lecture hall, but in actuality, these units supply about 30%, accommodating for the necessary OA requirements while the recirculation units supply most of the conditioned air.

From an engineer's standpoint and logically speaking, by implementing the displacement ventilation system, the original design not only saves on cooling energy, but also saves on the overall sheet metal cost with the potential ductwork it would take to move the air about the building. In analyzing these spaces, this mechanical design makes complete sense in every respect. However, the upper level lecture hall was just proven to be less energy efficient and incur more utility costs on an annual basis. This may not make sense initially, but taking a look at the original drawings for the Northeast Education Building, it becomes quite evident why the designers chose the overhead distribution system. The Third Level Lecture Hall is located on the east wing, which happens to be the lower wing of the building. The associated DOAS air handling unit is located just above the lecture space, and this provides an easily accessible route for the associated ductwork. If this space were to be designed similar to the lower level, there would be an unnecessary amount of ductwork needed to route the air underneath the lecture seating and provide the appropriate air for the recirculation unit. Therefore, this lecture hall saves the additional cost of an air handling unit and the associated ductwork to apply a simplified design that can be directly ducted from above. Logically, the original design for this particular lecture space is the better choice. While each design makes sense with respect to its proximity from the air handling units, there was another study conducted to show potential benefits of the UFAD system in comparison to the overhead distribution. This next study was conducted to show different comfort levels and the stratification of the air distribution using each system in the lecture halls.

Occupant Comfort Levels | Master's Analysis

Shown on the following pages, Figures 51 and 53, display the two lecture hall geometries that are discussed in the analysis above. Both lecture hall geometries are identical, however, Figure 51 is modelled with an overhead distribution system that can be seen with several diffusers on the ceiling. Conversely, Figure 53 is modelled with the underfloor air distribution system with slot diffusers below each row in the auditorium seating. Prior to analysis, the hypothesis was that the displacement ventilation system would produce more beneficial results for the respective occupants in the space. From the provided results in Figures 52 and 54, it can be seen that this hypothesis is in fact correct. Figure 54, displaying the displacement ventilation, has a much more fluid distribution within the space and comparatively, the air velocity distribution is lower than that of the overhead system. More turbulent airflows can be seen near the occupants in the upper seating of the lecture hall with the overhead system. Likewise, there is not as much mixing occurring with the overhead system, which can be seen by the inconsistencies of air velocity around the space. Whereas, looking at the displacement ventilation results, each occupant in the rows receives an equal amount of airflow including the front of the room as well. The lowest slot diffuser provides air to the lecturer that would occupy the front space in the room. With this system, the supply air is able to mix equally and efficiently with the current room air. Unfortunately for the overhead system, each row has a different airflow velocity and thus an unbalanced distribution of air temperature and pressure within the space.

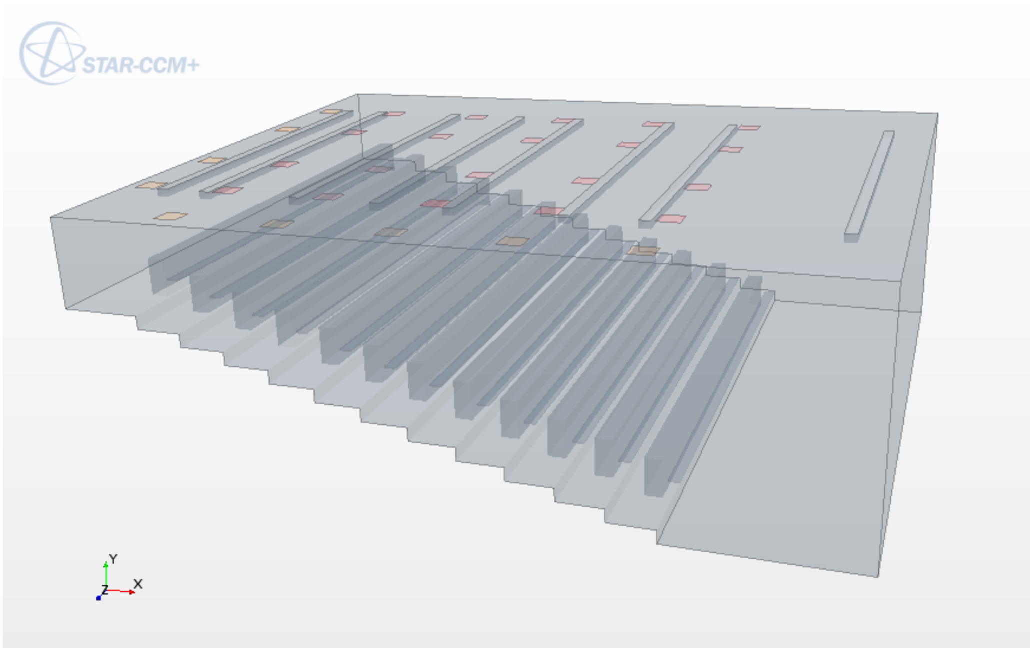

Figure 51: Overhead Distribution Design Geometry

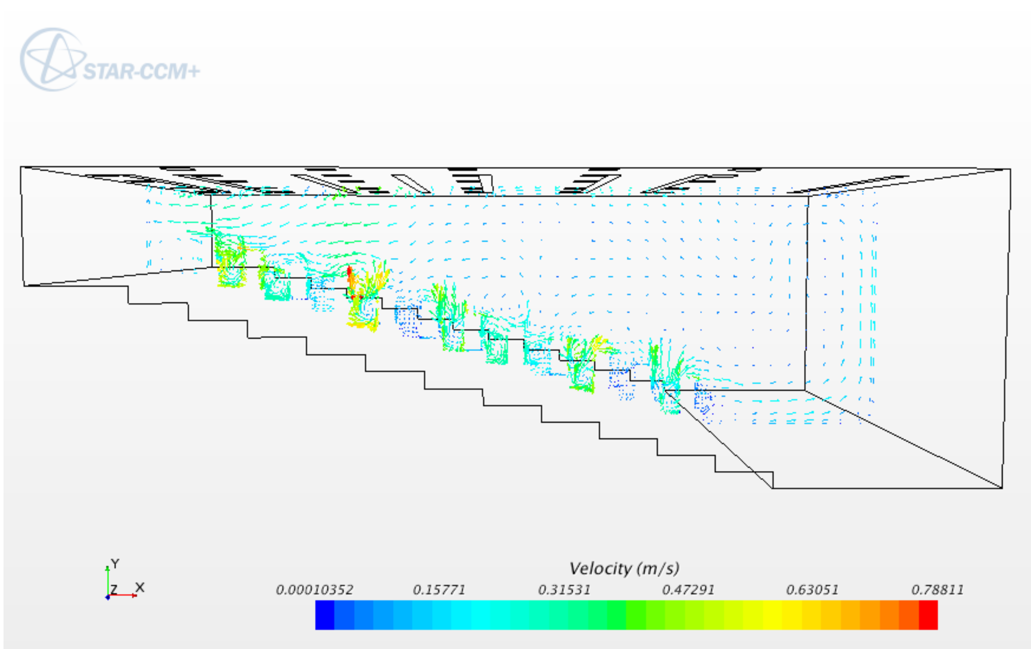

Figure 52: Overhead Distribution Design Velocity Distribution

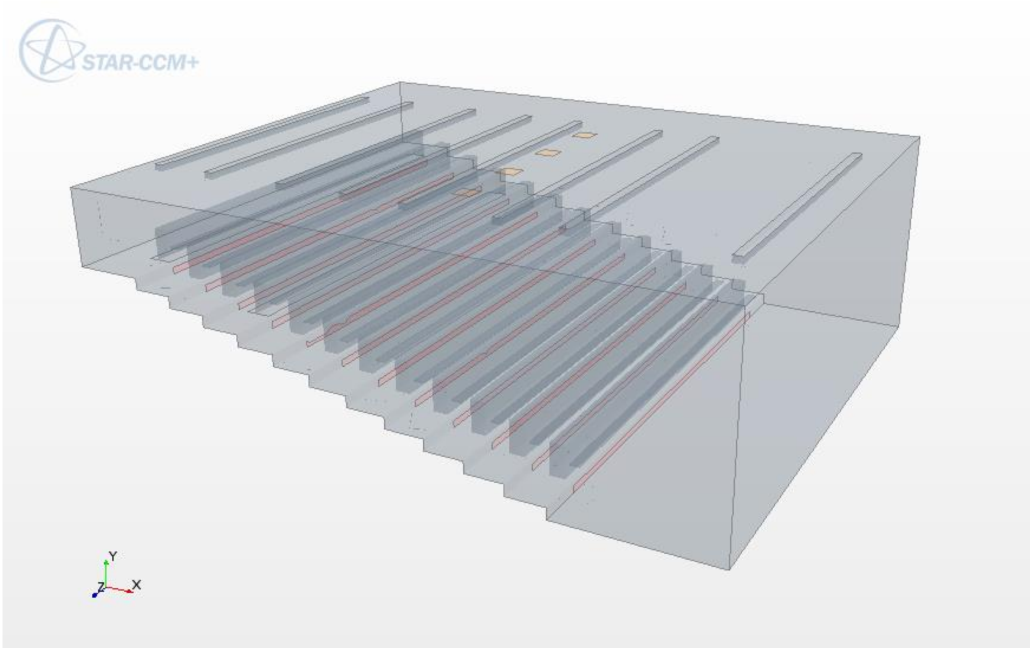

Figure 53: Displacement Ventilation Design Geometry

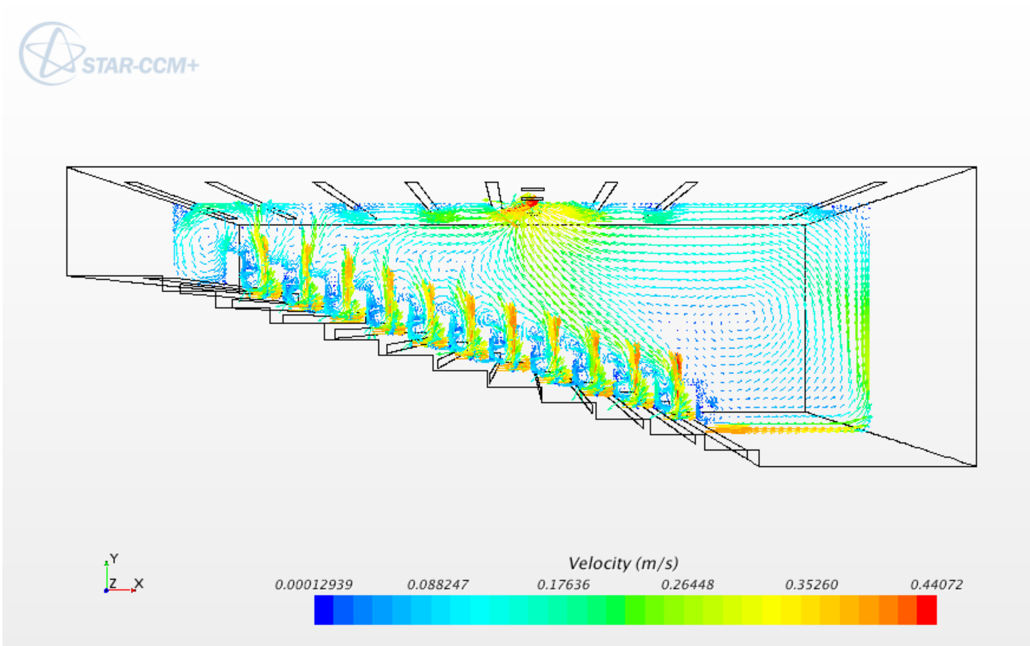

Figure 54: Displacement Ventilation Design Velocity Distribution

Depth Study Conclusions

There are several aspects to this Depth Study including a full analysis of the hydronic system redesigns and the implications that each system entails. Taking a look at the natural daylighting available, a new photocell system was studied to allow the Northeast Education Building to operate on a more sophisticated level, adjusting to daily conditions. Additionally, there is an associated utility and overall cost analysis of each system based on its annual usage of electricity, purchased hot water, and domestic water. From a general standpoint, looking back at the conclusions drawn in the previous section, there are benefits and drawbacks to each system studied.

From the initial analysis, the chilled beam: Option A redesign showed immense savings with regards to the overall airflow in the building ductwork and air handling units. While Options B and C also showed energy savings in this respect, the 78% airflow reduction shown by Option A is much greater than the other two reductions. The airflow reduction is not the only area of design worth looking at; however, it presents interesting design implications in the sense that only 20% of the original airflow is necessary to condition the interior offices. That 80% reduction allows ductwork to be downsized as well as the air handling units that were shown above. Overall, these air reductions were the basis of proposing different hydronic designs. Option A and B, both chilled beam schemes, outline the pros and cons of including exterior spaces in the chilled beam design. Stated previously, when using chilled beams on the exterior spaces of the building, the engineer must account for radiant panelling as well, which increases the amount of purchased hot water. On the flip side, however, by allowing the exterior spaces to be controlled by the original VAV design, there are fewer airflow reductions and in turn less savings on the air handling units.

Fan coils are an interesting design in that they operate very similarly to chilled beams, but the slight design principles behind each system cause different utility usage and overall performance differences as well. Outlined in the first airflow section, one of the more interesting discoveries found was that the fan coils required more airflow to the exterior spaces than the original VAV design. Although these increases were not drastic, it was interesting to see how all three of these systems compare from this one perspective. On the other hand, when analyzing the full utility cost for each proposed design, there were no major differences in the overall breakdown of electricity, hot water, and domestic water. While the individual system costs were adjusted, the electricity usage never decreased from its original 92% and likewise for the purchased hot water and domestic water. What is noteworthy between all three cost analyses, Option A-C, are the consistent decreases in the air handling unit electricity usage and the increases in the hot water pump electricity consumption. As a whole, these cost differences show the main functionality of an air-driven versus hydronic system. The original design consumed more fan energy in the air handling units and needed less hot water to heat the coils and condition the air. Conversely, with each hydronic option, there is a much more drastic decrease in AHU fan energy and a slight increase in the hot water consumption. The only exception to the previous statement is the fan coils because while decreasing the AHU fan energy, they also require a relatively high amount of individual fan energy for each unit causing the electricity consumption to increase again.

From a different design perspective, the other system that was discussed above was the implementation of photocells in the circulation and exterior building spaces. Overall, this system is simple yet sophisticated in the sense that it allows the building to monitor its own electricity usage and cut back on lighting costs. Generally, lighting costs are some of the most expensive and unnecessary costs in a building because the natural daylight is underutilized. Shown above in the utility graphs, eQuest has modelled an overview of the benefits of each individual system: fan coils, chilled beams, and photocells. More importantly, however, are the combined effects of implementing each hydronic system with the photocell design as well. All in all, with more control over the circulation spaces and less fan energy required by the chilled beam design, there is potential to see significant cost savings over the lifecycle of the building. A further analysis of this lifecycle will be looked at in the Construction Breadth section of the report.

Breadth Analysis 1 | Lighting & Electrical

Photocell Analysis

The amount of natural daylight in the Northeast Education Building has been discussed previously in this report as a way to save electrical energy. In Depth Study 3 | Photocell Implementation above, there is a brief discussion about the spaces analyzed in order to properly harvest as much natural energy as possible. From before, Figure 43 shows that most of the circulation space and exterior seminar and conference rooms provide an adequate amount of light in the building and show potential benefits with regards to the overall energy usage. In addition to using eQuest to provide an overview of potential light available in these spaces, the original lighting design was analyzed to get an overview of the luminaires used around the building. Shown below in Table 22 is the overview of spaces that would implement the photocells most appropriately. This table reflects the building lighting plans found in Appendix A.

Table 22: Original Luminaire Schedule

Level	Location	Original Luminaire	Lamp	No. of Lamps	Quantity	Lamp Power [W]
1	West Gallery	F60A	T8	4	10	32
	West Gallery	F60D	T8	2	1	32
	West Seminar	F28A	T8	2	8	32
	East Gallery	F64	T8	2	2	32
	East Gallery	F60B	T8	2	5	32
	East Gallery	F60A	T8	4	5	32
	East Seminar	F28A	T8	2	8	32
2	West Gallery	F60A	T8	4	21	32
	West Seminar	F28A	T8	2	8	32
	East Gallery	F64	T8	2	4	32
	East Gallery	F60B	T8	2	13	32
	East Gallery	F60A	T8	4	7	32
	East Seminar	F28A	T8	2	5	32
	East Seminar	F28A	T8	2	8	32
3	West Seminar	F28A	T8	2	6	32
	West Seminar	F28A	T8	2	7	32
	West Seminar	F28A	T8	2	4	32
	East Gallery	F60B	T8	2	3	32
	East Gallery	F60E	T8	1	9	32
	East Gallery	F60A	T8	4	10	32
	East Seminar	F60F	T8	2	5	32
4	West Seminar	F28A	T8	2	6	32
	West Seminar	F28A	T8	2	4	32
5	West Seminar	F28A	T8	2	6	32
	West Conference	F28A	T8	2	3	32
	West Seminar	F28A	T8	2	8	32

From a brief overview of the table above, all of the suggested luminaires that would be used in conjunction with the photocell technology are T8 fluorescent lamps. After analyzing the given Lighting Fixture Schedule in the provided drawing documents, there was no designation that these lamps were specified with a dimming ballast. These luminaires are designed as shown on the following figure, which allows a significant amount of light to be saved if these T8 lamps are dimmed or even shut off for part of the day. As designed, there are several fluorescent luminaires in the corridor in addition to the F5 LED luminaire that runs along the vertical wall in Figure 55. Between the LED T8 and the other T8 lamps having more sustainable controllability from the respective photocells, these lighting technologies should work in conjunction to save energy. One of the biggest concerns with implementing the photocells, as stated previously, is the compatibility with the current lighting system. To ensure compatibility with the

Northeast Education Building, dimming ballasts were analyzed in comparison to the original specification.

Equipment Specification

From the original drawing set, there was not a specific manufacturer or luminaire selected; therefore, in order to perform any type of analysis, the Sylvania lighting catalogue was used as a reference. To start, a typical T8 lamp was selected and is specified in the Appendix C section of this report. From the original drawing specifications, the lamp selected was a 32W OCTRON 800 XP that is 4' in length. The original ballasts were assumed to be QUICKTRONIC High Efficiency 32 T8 Instant Start with a normal ballast factor. These electronic ballasts were again selected based on the original specifications and reflect the original drawings in order to make an appropriate analysis. For the full ballast specification, see Appendix C.

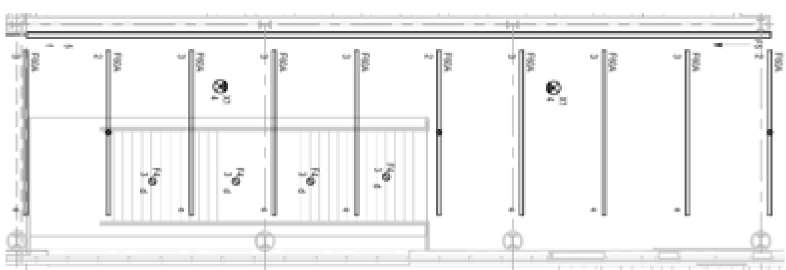

Figure 55: Typ. Corridor Lighting Scheme

Equipment Comparison

Following the original analysis of the original system, it was determined that dimming ballast would be necessary to maintain the current lighting scheme as well as achieve some additional energy savings. Therefore, Table 23 outlines the main differences between the originally scheduled instant start ballasts with the POWERSENSE dimming system that was then discovered in the Sylvania catalogue as well. Most of the specifications for each ballast system are very similar such as the input current required by the system and the rated lumens that each ballast is designed for. The Sylvania catalogue defines that the POWERSENSE system has a 100-5% dimming range; therefore, the system has two different values for some of the specifications below. With the ability to dim the current fluorescent system, Table 23 shows that the system lumens can range from 2,640 to 150 with an input voltage of 30 Watts to 8 Watts respectively. Throughout the day, when the photocells analyze the building spaces as having enough natural light, there is a potential to only input 27% of the original wattage. Especially in circulation spaces, there is not necessarily a need to have excessive lighting at full load 24 hours of the day. On the following page is an example calculation to show how energy can be saved using the photocells and associated dimming ballasts.

Table 23: Electronic Ballast Comparison

QUICKTRONIC High Efficiency 32 T8 Instant Start Universal Voltage Systems						
Item Number	Input Current [Amps]	Rated Lumens	No. of Lamps	Ballast Factor	System Lumens	Input Wattage [W]
49968	0.11	3000	1	0.88	2640	28
49969	0.20	3000	2	0.88	5280	55
49970	0.30	3000	3	0.88	7920	82
49971	0.39	3000	4	0.88	10560	107
QUICKTRONIC High Efficiency POWERSENSE 32 T8 Dimming Systems						
50705	0.12	3000	1	0.88/0.05	2640/150	30/8
50707	0.24	3000	2	0.88/0.05	5280/300	58/15
50714	0.30	3000	3	0.88/0.05	7920/450	84/20
50716	0.40	3000	4	0.88/0.05	10560/600	110/27

Sample Calculation

Assumptions:

- The available hours of the day in which natural light can be used year round are from 10a.m. to 4p.m. (6 hour window).
- The lights are on for a potential of 12 hours – occupancy sensors are used throughout the night hours to regulate the amount of electricity from 8p.m. to 8a.m.

- Use single lamp ballast to perform the calculation. The input wattage will be based on dimming ballast values for the part load performance (30/8W) and the instant start ballast for constant full load performance (28W).

Calculations:

6 Hours (full load lighting)

6 Hours (5% lighting load)

$$6hrs * 30W + 6hrs * 8W = 228\ [W - hrs]$$

$$12\ hrs * 28W = 336\ [W - hrs]$$

$$1 - \left(\frac{228}{336}\right) = \mathbf{32.15\%}\ \boldsymbol{reduction}$$

Project Compatibility

While not the most technical calculation, this example shows that even with a basic assumption of full load and 5% part load throughout the average day, there is potential to save 32.15% on the daily wattage needed to power the luminaires. In that respect, applying the photocells and dimming ballasts would be a beneficial step towards saving electricity on an annual basis. Overall, the ballasts are compatible seeing that this analysis uses both Sylvania specified equipment. As of now, another potential concern would be the placement of each photocell based on the proximity of light available through the exterior glazing and adapting to the current ceiling plan.

Fortunately, with the specified OSRAM ENCELIUM Ceiling-Mounted Occupancy Sensors specified in Appendix C, there is a wide range of sensors that can be installed in different size spaces. For example, displayed below in Figure 56, there are two examples of sensor ranges – 1,500 and 2,000 sq. ft. The image displayed on the right provides a good explanation of the different capabilities available with these specific occupancy/photocell sensors. Not only will these specific sensors have the ability read the available light in the area, but also they are able to detect motion in and out of the space. So hypothetically, during the night-time hours and slower periods of the day when class schedules may not be as prominent, the lights will be able to turn off completely saving more energy.

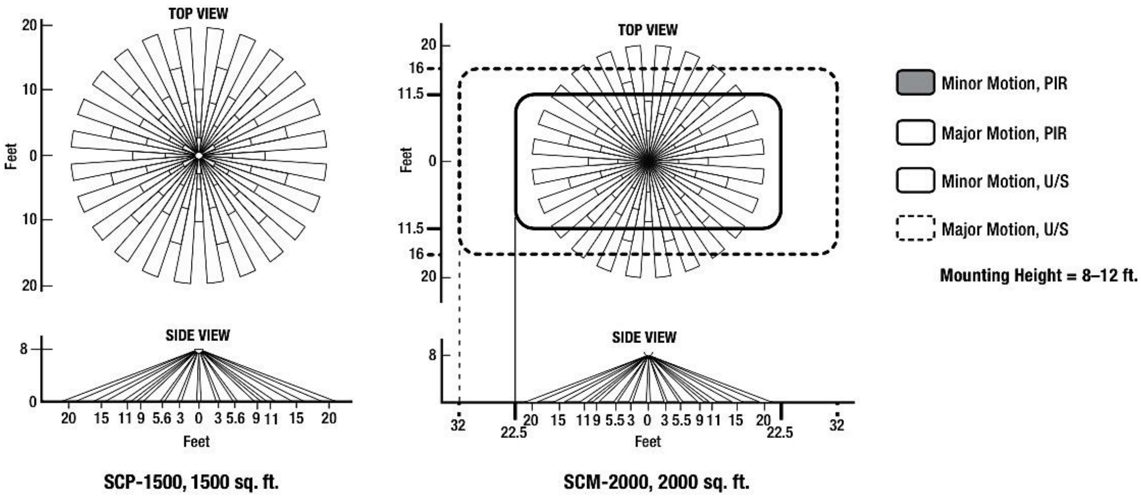

Figure 56: Osram Photocell Field of View

Luminaire Alternatives

A second consideration taken with the original lighting design and use of photocell technology was the replacement of all of the current fluorescent luminaires. From the previous discussion, applying a dimming ballast to accommodate for the current lighting scheme would be a valid solution to implementing the photocells. However, taking a step further, there is potential to reduce the overall electricity consumption by not only having more control over the lighting system, but also using luminaires that do not require as much power to operate. In that respect, the next area of study is to consider replacing the current T8 lamps but an LED alternative. Specifically, the new lamp that would be recommended is a Sylvania SubstiTUBE IS LED T8, which is very closely related to the original design and one of the main design concerns. By utilizing the same company as originally specified, it creates a direct comparison in the equipment selection such as ballasts and provides an accurate analysis of the proposed design.

Table 24: T8 Lamp Comparison

OCTRON 800 XP T8			
Item Number	Length [ft.]	Color Temp. [K]	CRI
21763	4	3000	85
SubstiTUBE IS LED T8			
73312	4	3000	82

From the comparison in Table 24, there is not really a major difference in lamp specifications alone. The only difference provided by Sylvania is the CRI, which is significant in lighting design; however, based on the location of these luminaires, it does not seem as if it will make the LED T8 lamps any less beneficial. In addition to the direct compatibility with the current system, one of the main benefits of using the Sylvania's LED T8 is the ability to couple this technology with the photocell/occupancy sensor as originally proposed. The only difference with these lamps is the specific ballast that must be used because the LEDs cannot be dimmed like the original design.

According to Sylvania, the LED T8s are engineered to operate on the existing instant start electronic ballasts that were originally specified for the building. However, unlike the original design, these T8 lamps will run on less power and provide an energy savings from the newer technology. Shown below in Table 25 is an overview of the necessary electronic ballasts needed to operate each system. Analyzing each ballast in comparison with the original design, it is obvious that the LED system will require about 35% of the original input power and current. Therefore, as a whole, this system has the potential to reduce the lighting load by 65% in the current design. On the following page is the actual analysis of the Northeast Education Building's lighting design load. As seen in the table provided, Table 26, there are circuits that achieve a 20% reduction or greater, and likewise, there are some circuits that achieve <10% reduction. Overall, there is an average savings of 15% in the lighting load, which is not extremely significant but does provide a step towards energy savings.

Table 25: Ballast Comparison

QUICKTRONIC High Efficiency 32 T8 Instant Start Universal Voltage Systems				
Item Number	Input Current [Amps]	No. of Lamps	System Lumens	Input Wattage [W]
49968	0.11	1	2640	28
49969	0.2	2	5280	55
49970	0.3	3	7920	82
49971	0.39	4	10560	107
QUICKTRONIC High Efficiency 32 T8 Instant Start LED Systems				
QHE1x32T8	0.07	1	2000	19
QHE2x32T8	0.13	2	3900	36
QHE3x32T8	0.19	3	5400	51
QHE4x32T8	0.25	4	7200	68

One factor to consider with regards to this LED redesign is the loss of the original dimming ballasts. While these particular lamps are able to provide an average of 15% savings in electrical energy, they are not compatible with dimming ballasts. Therefore, when coupled with the photocell/occupancy sensors, the only functionality that these luminaires will have is an ‘on/off’ scheme. From a designer’s perspective, it may not be possible or efficient to implement a control system in which the lights can only turn on and off.

Another foreseeable issue with using this technology is the system lumen difference (see Table 25 on the previous page). To verify that the LEDs would provide an appropriate light output, further analysis was completed. Also, because LED T8s are typically used as replacement lamps for existing systems, the following study was conducted with a new LED luminaire.

Table 26: Potential Energy Savings with LED T8 Light System

Level	Ckt. Load [W]	No. of Lamps	Qty.	Input Power [W]	Original Lum. Load [W]	Redesign Lum. Load [W]	Δ Load [W]	Redesign Circuit Load [W]	Avg. Power Savings
1	2400	4	10	68	1070	680	390	1991	17%
		2	1	36	55	36	19		
	700	2	8	36	440	288	152	548	**22%**
	2000	2	2	36	110	72	38	1672	16%
		2	5	36	275	180	95		
		4	5	68	535	340	195		
	400	2	8	36	440	288	152	248	**38%**
2	2400	4	21	68	2247	1428	819	1581	**34%**
	1600	2	8	36	440	288	152	1448	10%
	2000	2	4	36	220	144	76	1404	**30%**
		2	13	36	715	468	247		
		4	7	68	749	476	273		
	1500	2	5	36	275	180	95	1405	6%
	1600	2	8	36	440	288	152	1448	10%
3	1400	2	6	36	330	216	114	1286	8%
	1700	2	7	36	385	252	133	1491	12%
		2	4	36	220	144	76		
	1600	2	3	36	165	108	57	1462	9%
		1	9	19	252	171	81		
	2300	4	10	68	1070	680	390	1815	**21%**
		2	5	36	275	180	95		
4	1400	2	6	36	330	216	114	1286	8%
	1000	2	4	36	220	144	76	924	8%
5	1800	2	6	36	330	216	114	1686	6%
	2400	2	3	36	165	108	57	2343	2%
	2000	2	8	36	440	288	152	1848	8%
							Total Average Savings		15%

Light Output Verification

To verify the light output of a newly specified LED luminaire system, Sylvania RLL24 2x4 Recessed Troffers were modelled in AGi32 (See Appendix C for specifications). Two main spaces, including a typical Seminar room and Gallery corridor, were used to show the target illuminance and average illuminances delivered by the LED system. For this study, the following light loss factors were accounted for in AGi to model the space:

- Lamp Lumen Depreciation – 0.7
  - Based on L70, report states that for LED luminaires LLD = 0.7
- Luminaire Dirt Depreciation – 0.94
  - Clean environment
  - Closed luminaire
  - Direct Distribution
  - 12-month cleaning interval
- Total Light Loss Factors – 0.658

For the Gallery corridor, the IES recommendation is 15fc as determined by the transition spaces definition. As seen below in Figure 57, this lighting layout reflects that of the original design in Figure 55 shown previously. Overall, the luminaires have been spaced 11ft. x 8ft., and the calculated average illuminance for this design is 21.47fc. While this output may be slightly higher than recommended, it will provide the appropriate amount of light for this particular space. Additionally, these LED luminaires in conjunction with the photocell design will allow each corridor to be adequately lit throughout the day.

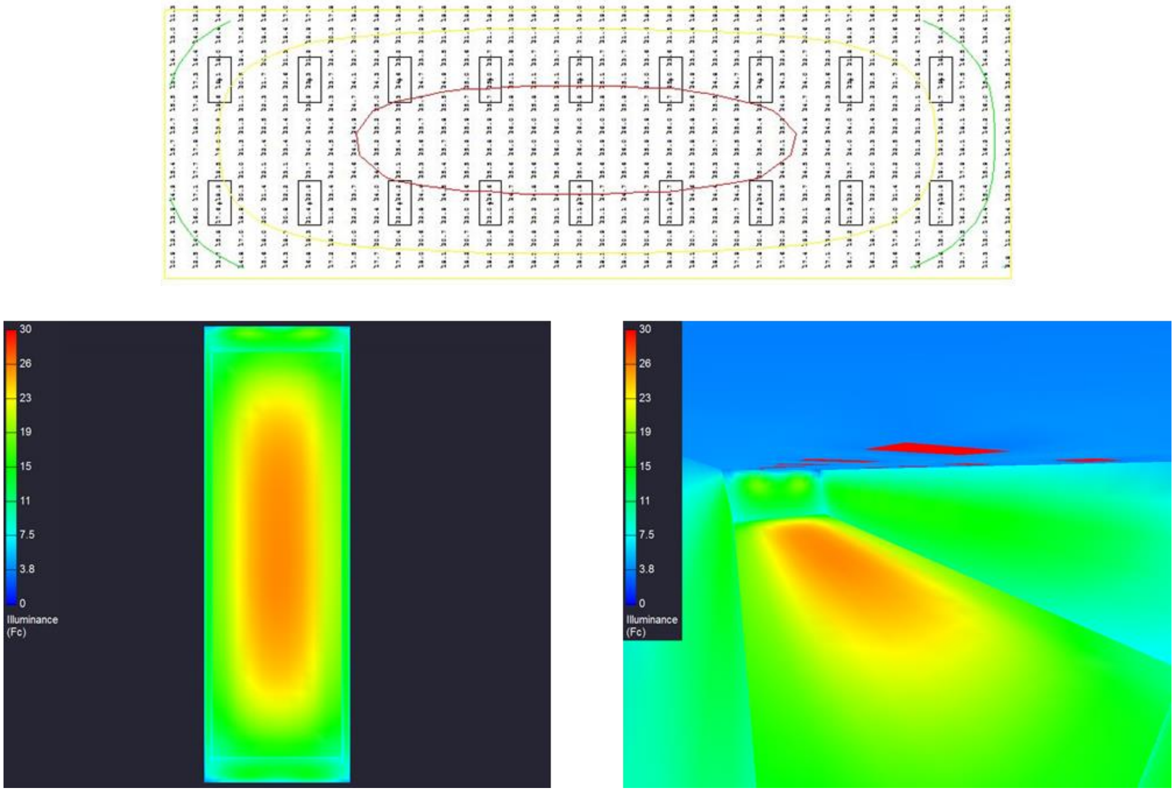

Figure 57: Gallery Corridor AGi Output

With regards to the Seminar room, the IES recommendation is 30fc based on the reading and writing definition. From the original lighting design, the Sylvania RLL24s were spaced as shown in Figure 58 on the following page. The average illuminance that was calculated using AGi was 23.48fc, which does not meet the target illuminance outlined previously. However, taking a look at the contour images at the bottom of the page, the illuminance is in the low 30s in the middle of the room. Given that this is a seminar or conference space, another luminaire may be necessary to accommodate for the appropriate light levels, but overall this luminaire layout is an acceptable replacement.

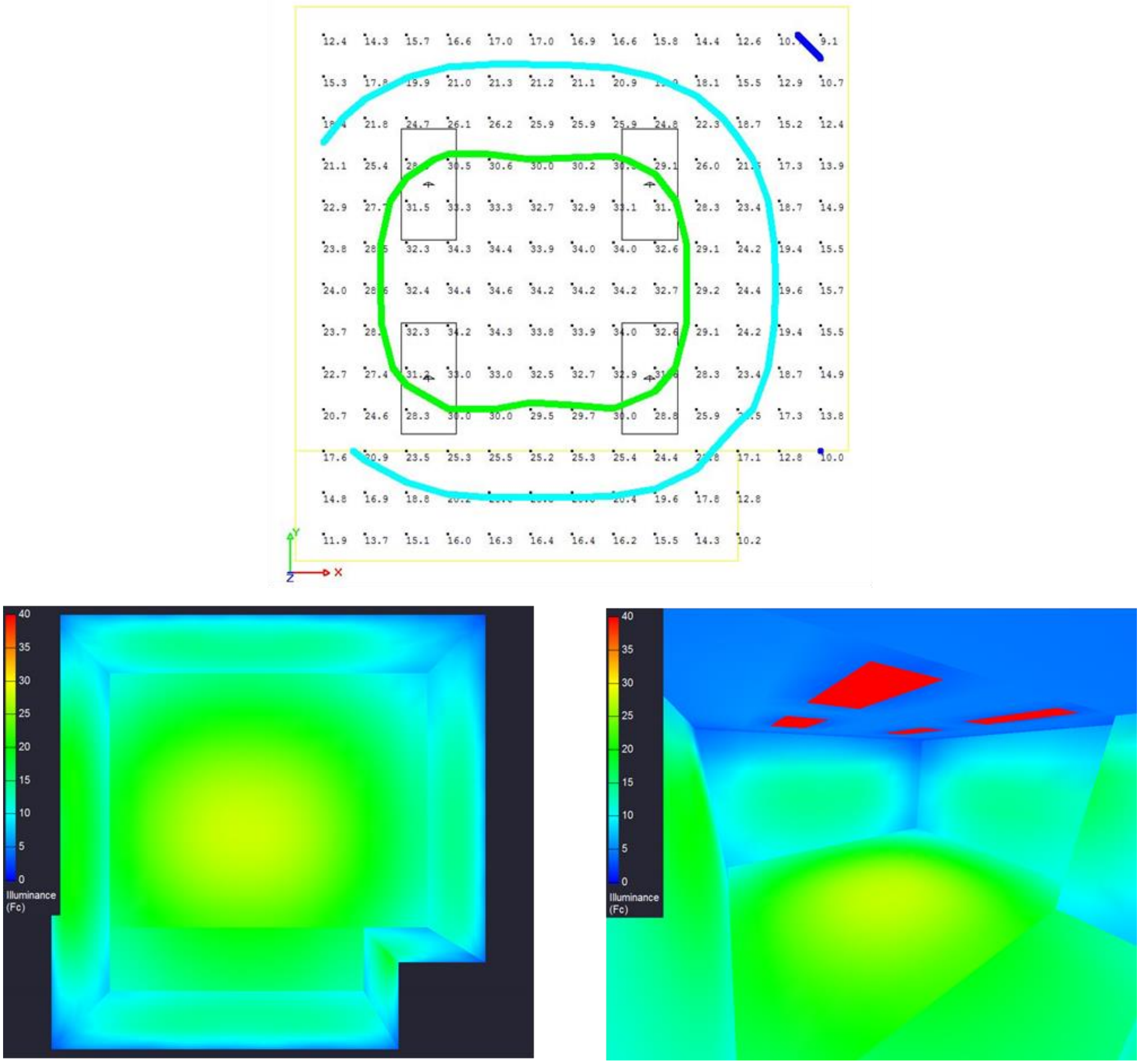

Figure 58: Seminar Room AGi Output

Breadth Analysis 2 | Construction

General Overview

As a whole, this report has discussed different design proposals that could potentially save the Northeast Education Building energy and utility costs on an annual basis. From the original Depth Study, there were several redesign implications for each hydronic system as these two technologies were compared with the current VAV air-driven system. Now, taking the energy savings potential into consideration, this study will dive into more of a realistic business perspective of implementing each system. More often than not, when handling energy audits and design alternatives, the main concern with building owners and designers alike are the cost implications. Furthermore, this section will detail the relative payback period when implementing each system and fully analyze the feasibility of each proposal.

Redesign Implications

Both of the proposed designs in the original depth study are hydonic systems, and therefore, both operate differently than the original air-driven design. To start, one of the initial discussions in the original analysis was the airflow consideration of the chilled beams and fan coil units, and the ability to drastically reduce each system's airflow requirements. What this also means for the overall system is a reduction in ductwork, air handling units, VAV terminal boxes, and any additional equipment that these water-driven systems may not need to operate. However, as just stated, because these are water-driven systems, this also introduces new design changes that may require additional piping to be installed. For example, 4-pipe chilled beams and fan coils need both chilled water supply/return and hot water supply/return piping, and the current design may not include chilled water supply/return piping throughout the whole building. While these are some of the basic design implications, all three systems were analyzed with these building factors in mind.

Building System Analysis

Ductwork Calculations

From the original drawing set provided by the design team, each respective office space that would be affected by the chilled beam or fan coil design was analyzed to acquire the amount of ductwork the current VAV system needed to operate. (See Appendix A for the full layout of office spaces)

Assumptions:

- The amount of ductwork in the north and south ends of the west wing offices was assumed to be identical because the space layouts from Levels 3-5 are almost identical.
- Only the south end of Level 5 was accounted to be different because the layout did not follow the typical design as described in point 1.
- Each ductwork calculation is tabulated in sheet metal weight from a provided spreadsheet (see Appendix B for details).

On the following page, Table 27 shows the original amount of ductwork that the VAV system was designed for using the calculated airflows for an air-driven system. In total, there was about 8,225.24 lbs. of sheet metal required for this design. To calculate the overall weight, each respective duct was measured from the appropriate VAV box with its height, width, and total length that were then input into a calculation spreadsheet. These calculations for the original design can be found in Appendix B with the overall sheet metal weights as well.

Table 27: Original Ductwork Total

Building Level	Sheet Metal Weight [lbs.]
Level Three Totals	2,902.77
Level Four Totals	2,902.77
Level Five North Totals	1,550.12
Level Five South Totals	869.58
Total	8,225.24

Table 28 outlines the total sheet metal necessary for each chilled beam design. Option A, requires approximately 5,817.42 lbs. of sheet metal and Option B about 6,559.74 lbs. – a 30% and 20% reduction from the original design respectively. From the original analysis, this is what was to be expected because of the 75% (Option A) and 62% (Option B) reduction in airflow through the ducts. Similarly, Table 29 also outlines the overall duct reduction in the fan coil design, which accurately reflects the original 32% reduction in airflows. In total, the fan coil redesign accounts for 7,954.79 lbs. of sheet metal, which is a 3% reduction for all of the ductwork.

Table 28: Chilled Beam Ductwork Total

Building Level	Sheet Metal Weight [lbs.]	
	Option A	Option B
Level Three Totals	2,096.46	2,313.94
Level Four Totals	2,096.46	2,313.94
Level Five North Totals	1,073.88	1,176.96
Level Five South Totals	550.62	754.90
Total	5,817.42	6,559.74

Table 29: Fan Coil Ductwork Total

Building Level	Sheet Metal Weight [lbs.]
Level Three Totals	2,809.83
Level Four Totals	2,809.83
Level Five North Totals	1,485.85
Level Five South Totals	849.28
Total	7,954.79

Piping Calculations

Similar to the analysis of each duct system involved in the previous calculations, the piping was calculated in a similar fashion. By analyzing each respective office space and the current piping design, there were certain assumptions made in order to accurately portray each mechanical system. To start, as stated in the design implications section above, the original design does not include chilled water piping on Levels 3-5. There is a general 8" chilled water supply/return in a centralized location between the north and south ends of the west wing, and that is where the hypothetical piping design will be connected.

Assumptions:

- The new pipe design that was created for this analysis is based solely off of the current drawings and the most accurate portrayal of the necessary piping to accommodate each system. (For full calculation and piping take-offs, see Appendix B).
- Again, all piping in the north and south ends of the west wing offices was assumed to be identical because the space layouts from Levels 3-5 are almost identical.
- Only the south end of Level 5 was accounted to be different because the layout did not follow the typical design as described in point 2.
- The chilled beam (Option A) and fan coils were assumed to require the same amount of piping because both systems require 4-pipe and 2-pipe equipment depending on the location of the office space.
- All additional piping was assumed to be 1" and ¾" to supply each system

Continuing the above discussion, all of the necessary piping was measured from this centralized location to make sure that the appropriate length of piping would be calculated. Different than the ductwork analysis, there is not a current piping layout in which the chilled beams and fan coils can connect into. Therefore, Table 30 shows all of the additional piping, in linear feet, which would need to be added to the building design in order to accommodate for the 4-pipe systems.

Table 30: Additional Piping Total

Building Levels	Piping [LF]	
	Option A/ Fan Coils	Option B
Level Three Totals	1,687.00	1,511.00
Level Four Totals	1,687.00	1,511.00
Level Five North Totals	1,589.00	1,413.00
Level Five South Totals	504.00	276.00
Total	5,400.00	4,608.00

Cost Data

Following the initial system analysis and calculating the decreasing ductwork or additional piping necessary for the hydronic systems, the next step taken was to gather the most relevant cost data. As displayed in Tables 31 and 32, all of the cost data was gathered from the most up-to-date RS Means catalogues (to see catalogue information reference Appendix B). There were several catalogues analyzed during this portion of the data collection because some of the systems and equipment were specifically included in one book. All of the relative data was collected from these references except for the chilled beam and fan coil unit estimations. This particular equipment data was referenced from a Price sales representative to obtain the most accurate data.

Table 31: Cost Analysis – Air Distribution Equipment

Type	Unit Size	Cost			
		Material	Labor	Total	Total O&P
Supply Diffuser	9x9	$161.00	$32.00	$193.00	$226.00
FPB-2	600 CFM	$1,375.00	$89.50	$1,464.50	$1,650.00
FPB-4	1,500 CFM	$1,675.00	$161.00	$1,836.00	$2,075.00
VCV-4	200 CFM	$790.00	$73.00	$863.00	$980.00
VCV-6	400 CFM	$800.00	$80.50	$880.50	$1,000.00
VCV-8	600 CFM	$800.00	$80.50	$880.50	$1,000.00
VCV-10	1,000 CFM	$820.00	$101.00	$921.00	$1,050.00
VCV-12	1,500 CFM	$900.00	$134.00	$1,034.00	$1,200.00
ACBM	2-Pipe	-	-	-	$735.00
FCHCP	Size 3	-	-	-	$760.00
FCHCP	Size 6	-	-	-	$815.00
FCHCP	Size 12	-	-	-	$1,485.00
ACBM	2-Pipe	-	-	-	$735.00
Piping	Per LF	$3.70	$8.10	$11.80	$11.80
Ductwork	Per lb.	$1.96	$5.35	$7.31	$10.55

Table 32: Cost Analysis – Air Handling Units

Type	Unit Size [CFM]	Cost			
		Material	Labor	Total	Total O&P
AHU	20,000	$66,500.00	$3,425.00	$69,925.00	$77,900.00
AHU	25,000	$84,075.00	$4,150.00	$88,225.00	$98,325.00
AHU	30,000	$101,650.00	$4,875.00	$106,525.00	$118,750.00
AHU	35,000	$109,012.50	$5,675.00	$114,687.50	$128,012.50
AHU	40,000	$116,375.00	$6,475.00	$122,850.00	$137,275.00
AHU	55,000	$151,240.00	$8,100.00	$159,340.00	$170,525.00
AHU	60,000	$152,498.75	$8,900.00	$161,398.75	$177,146.25
AHU	65,000	$153,757.50	$9,700.00	$163,457.50	$183,767.50
AHU	75,000	$156,275.00	$11,300.00	$167,575.00	$197,010.00

Individual System Costs

Taking the cost data above, this information was applied to each system in comparison to the original. The following tables will outline the different aspects of each system design and the respective costs of each component.

Original Design

As can be seen in Table 33, the base cost, or what has been deemed the base cost for this analysis is ~$170,000 for the VAV air system. Realistically, this system would include piping cost and other necessary components as well. However, this analysis has been simplified to look at the discrepancies in each system, and therefore, the base cost of the piping in the original system is $0.00 because no additional piping was necessary to implement this design. The VCV boxes are the necessary terminal boxes to regulate each mechanical zone and similar the ‘FPB’ designation are fan powered terminal boxes.

Table 33: Original Design Costs

Type	Quantity	Cost
Supply Diffuser	157.00	$35,482.00
FPB-2	10.00	$16,500.00
FPB-4	1.00	$2,075.00
VCV-4	-	-
VCV-6	-	-
VCV-8	9.00	$9,000.00
VCV-10	17.00	$17,850.00
VCV-12	1.00	$1,200.00
Piping	-	-
Ductwork	8,225.24	$86,776.28
	Total Cost	$168,883.28

Chilled Beam Design

For both chilled beam design options, there are no additional supply diffusers that are needed, and along the same lines, air diffusers are not necessary for this design. Therefore, as seen on the following page, the diffusers are actually taken as a deduction in the lifecycle cost analysis. Similarly, there are no fan powered VAV boxes necessary for Option A and the overall VAV terminal boxes are able to be downsized significantly as well. Compared to the original design where the terminal boxes ranged from VCV-8 to 12, Option A does not need higher than VCV-6. On the other hand, Option B still needs the fan powered VCV boxes because these are used on the exterior office spaces to condition the rooms effectively. Seen with Option A, the overall VCV terminal boxes can be downsized, and the only other addition to both chilled beam designs are the chilled beams themselves. Option A, having both interior and exterior spaces to condition, includes both 4-pipe and 2-pipe units while Option B only includes 2-pipe units.

Table 34: ACB – Option A Design Costs

Type	Quantity	Cost
Supply Diffuser	-	-
FPB-2	-	-
FPB-4	-	-
VCV-4	28.00	$27,440.00
VCV-6	10.00	$10,000.00
VCV-8	-	-
VCV-10	-	-
VCV-12	-	-
ABCL-HE	26.00	$23,660.00
ACBM	131.00	$96,285.00
Piping	5,400.00	$63,720.00
Ductwork	5,817.42	$61,373.78
	Total Cost	$282,478.78

Table 35: ACB – Option B Design Costs

Type	Quantity	Cost
Supply Diffuser	26.00	$5,876.00
FPB-2	10.00	$16,500.00
FPB-4	1.00	$2,075.00
VCV-4	18.00	$17,640.00
VCV-6	9.00	$9,000.00
VCV-8	-	-
VCV-10	-	-
VCV-12	-	-
ABCL-HE	-	-
ACBM	131.00	$96,285.00
Piping	4,608.00	$54,374.40
Ductwork	6,559.74	$69,205.26
	Total Cost	$270,955.66

Analyzing the overall cost of each system and the implied design features, the chilled beam options appear to be the most expensive. Much of the associated cost with this technology is the actual chilled beam units because it is a newer technology and not as easily available as the standard VAV boxes. From a first cost analysis, it is evident that the chilled beams are an expensive building technology; however, it will be the annual energy savings that determine whether or not it is worth the additional upfront costs.

Fan Coils

The fan coil redesign is very similar to the chilled beams in that it includes additional piping as discussed before and also reduces the overall VAV terminal box size. Unfortunately, it is not able to downsize the VAVs as significantly as the chilled beams; however, there is certainly some improvement from the original design. One of the design elements that must remain in the fan coil design and not the chilled beam design are the supply diffusers. Different than the chilled beam design, fan coils monitor the offices inside the plenum space and circulate the air through a ducted system. Therefore, the supply diffusers must remain in each room in order for the fan coils to distribute the air appropriately. And again, the only other addition to this system that is included in Table 36, are the fan coils units and their associated cost.

Table 36: Fan Coil Design Costs

Type	Quantity	Cost
Supply Diffuser	157.00	$35,482.00
FPB-2	-	-
FPB-4	-	-
VCV-4	-	-
VCV-6	23.00	$23,000.00
VCV-8	14.00	$14,000.00
VCV-10	-	-
VCV-12	1.00	$1,200.00
FCHCP - 3	13.00	$9,880.00
FCHCP - 6	24.00	$35,640.00
FCHCP - 12	1.00	$1,485.00
Piping	5,400.00	$63,720.00
Ductwork	7,954.79	$83,923.03
	Total Cost	$268,330.03

Lifecycle Costs

To follow the initial analysis above, the following lifecycle cost analyses were performed to show the simple payback period for each technology. As seen above in Table 34, there were several benefits to implementing the chilled beam design such as downsizing the overall ductwork from the initial system and additionally reducing the VAV terminal boxes associated with each zone. Similarly, the supply diffusers were deemed unnecessary with this new technology, and shown in Table 37 is the full cost analysis of these savings as well as additional costs outlined above. The most expensive and crucial addition to this system would be the chilled beams themselves. Because this is still a newer technology in the U.S., the market has not fully developed a competitive price in comparison to the typical air system equipment. Therefore, seen in the table, the additional cost of the beams in addition to the required piping would increase the initial costs by about $185,000. However, as stated previously, there are additional cost savings associated with this technology as well which can be seen in the adjustment section. The air handling units that are referenced below are directly related to Table 32 above. Because the chilled beams require a dedicated outdoor air system (DOAS), there must be an adjustment of which system would be conditioning the respective air. From the original design, the offices were conditioned by the 75,000 CFM AHU-W-2. With the appropriate adjustment of airflow reduction and reallocation to the AHU-W-1, 100% OA system, there are some cost savings as well as cost increases based on the systems needed. Ultimately, AHU-W-2 would be decreased from a 75,000 CFM unit to one that is rated for 55,000 CFM. Similarly, AHU-W-1 would be increased from 25,000 CFM unit to 30,000 CFM.

Table 37: Cost Analysis ACB – Option A

ACB Option A	
Additional Costs	
Material Cost: Chilled Beams	$119,945.00
Material Cost: Piping	$63,720.00
Total	**$183,665.00**
Adjustments	
AHUs	
AHU-W-2	$(26,485.00)
AHU-W-1	$20,425.00
Ductwork Downsizing	$(25,402.50)
Diffusers	$(35,482.00)
VAV Terminal Boxes	$(9,185.00)
Total	**$(76,129.50)**
Annual Savings	
Energy Savings ACB	$7,723.99
Conclusion	
Initial Total Costs	**$107,535.50**
Payback Period (Years)	**14**

All in all, with the cost savings from the discussed adjustments and the additional costs associated with this specific technology, there is about $110,000 of added cost to the original air-driven system. With the energy savings that were shown above in Depth Study Overview | Cost Analysis, there are approximately14 years to payback the additional costs of this system.

Similar to the previous analysis of the chilled beam Option A, Table 38 outlines the additional costs and potential savings of the second layout utilizing chilled beams. With fewer beams involved in this system, there are less additional costs such as piping, but likewise there are also less cost savings or adjustments shown as well. Going down the list of adjustments, each component is able to decrease less and less, and AHU-W-1 must increase from the initial 25,000 CFM to 35,000 CFM. Ultimately, based on the additional costs and associated adjustments, this version of the chilled beam technology actually costs about $11,000 more than Option A. These additional costs in conjunction with the energy savings presented above in the Depth Study Overview allow this proposed design to be paid off in about 18 years.

Table 38: Cost Analysis ACB – Option B

ACB Option B	
Additional Costs	
Material Cost: Chilled Beams	$96,285.00
Material Cost: Piping	$54,374.40
Total	**$150,659.40**
Adjustments	
AHUs	
AHU-W-2	$(13,242.50)
AHU-W-1	$29,687.50
Ductwork Downsizing	$(17,571.03)
Diffusers	$(29,606.00)
VAV Terminal Boxes	$(1,410.00)
Total	**$(32,142.03)**
Annual Savings	
Energy Savings	$6,586.00
Conclusion	
Initial Total Costs	$118,517.38
Payback Period (Years)	18

Lastly, Option C is outlined in Table 39, and the most notable factor of this design option is that the material costs of the actual units are not comparable to that of the chilled beam system. From solely a base equipment standpoint, the fan coils require about 40% of the cost of the chilled beams. As seen in each table and stated previously, the additional piping for each design was assumed to be the same because realistically each system would need a similar layout. Therefore, with the lowest additional costs of the three options, the fan coils are a promising design. However, shown in the adjustments section of the table, there is a drastic difference in the cost savings of about $76,000 with Option A and paying an additional $7,800 with Option C. This system, shown in the airflow comparison, does not save nearly as much on the associated ductwork, VAV terminal boxes, or air handling units. Likewise, this system requires all of the original supply diffusers and therefore does not benefit from this savings either.

Table 39: Cost Analysis Fan Coils – Option C

Fan Coils Option C	
Additional Costs	
Material Cost: Fan Coils	$47,005.00
Material Cost: Piping	$63,720.00
Total	**$110,725.00**
Adjustments	
AHUs	
AHU-W-2	$(19,863.75)
AHU-W-1	$38,950.00
Ductwork Downsizing	$(2,853.25)
Diffusers	-
VAV Terminal Boxes	$(8,425.00)
Total	**$7,808.00**
Annual Savings	
Energy Savings	$1,047.01
Conclusion	
Initial Total Costs	$118,533.00
Payback Period (Years)	**113**

So, from the analysis shown to the right, there is evidently a price difference in the fan coil versus chilled beam capital costs. From the originally designed system, the chilled beam Option A design is calculated to be less expensive than the fan coil design. There is also a significant difference between the associated energy savings with each technology, and unfortunately, the fan coils receive little improvement over the original design. With just over $1,000 savings per year, the technology would take about 113 years to pay back.

Chapter 4 | Final Conclusions

Water vs. Air

There is a lot to be drawn from the analysis presented in this study. Of the three proposed designs, the main question at hand is whether or not the technology is worth the additional costs. Do the pros outweigh the cons that are associated with each design? If they do and the design requirements are met by each system, then it does not matter which technology is used in the Northeast Education Building. However, from the analysis presented throughout this entire report, there are two design options that do not meet the specified criteria. From a business and engineering standpoint alike, the chilled beam Option B redesign and the fan coil redesign do not benefit the academic space in an economic or significant energy-saving manner. While both design options offer reduction in the respective airflow and utility usage throughout the office spaces, the cost payback period of both seems to be unrealistic in today's market. From the overall analysis, the fan coils have proven to be an unrealistic consideration in this building. Although this technology presents similar benefits to that of the chilled beams, the associated fan energy with each unit actually prevents energy costs from being reduced. It was stated previously in the report that the fan coils are taking the main energy away from the air handling units and dispersing amongst the building units. This certainly has its benefits when air handling units are able to be decreased; however, in this particular design, the benefits were not seen.

Therefore, this leaves the chilled beam Option A redesign as the only potentially beneficial system when compared to the original air-driven system. First and foremost, the inclusive analysis has shown that as studied, Option A is the best choice of the three proposals. While it is deemed as the best choice, this does not mean that this design is the most beneficial decision for the building owner to consider. Realistically, given today's economy and the associated government regulations with green buildings, owners are becoming more aware of the technology available as well as a realistic payback on their initial investment. While 14 years is not unrealistic for a building's lifespan, there are components within the associated chilled beam design that would potentially need to be replaced over the course of that cost cycle. Ultimately, there is potential for the chilled beam system to save the Northeast Education Building energy and utility costs over time. However, there are certain modifications in the initial design proposal that would need to be considered and studied if this chilled beam system was to be approved.

Potential Considerations

Chilled beams work on a higher operating temperature as discussed in the original analysis section. In doing so, the benefit of utilizing chilled beams is a higher temperature for the desired chilled water and less demand on the associated chiller. Unfortunately, with the current design proposal mixing both the air-driven system with the chilled beams, the chiller does not recognize these benefits. With both systems on one unit, the chiller still operates to produce 45F water whereas if there was a dedicated chiller for the beams, it could be a smaller unit and produce water that was 60F instead. To improve this system and see the potential cooling coil benefits that chilled beams offer, there would have to be an additional study conducted in which a chiller was dedicated to the beams.

Similar to the previous point made, the two studies shown in this report compared the quantity of chilled beams used in the project. While the beams have a higher capital cost, the overall energy benefit and annual cost savings were proven to be more beneficial in Option A. This analysis showed that beams can be placed on interior and exterior spaces to offer more cost savings, and this type of analysis should be carried throughout the building. One of the potential studies could show a complete overhaul of the current air system to replace all of the appropriate spaces with the current chilled beam design. With drastic decreases in ductwork and an increase in piping to accommodate for the new design, there would still be a cost savings for overall material. To prove the potential benefits, all seminar, lounges, meeting spaces, and conference rooms should be added to the initial Option A design. This could show much more energy savings than was realized in the initial design proposal and allow the dedicated chiller to be utilized appropriately. Unfortunately, not all of the corridor and lecture hall spaces can be designed with chilled beams because of restrictions on the technology. However, these spaces can be designed with their own chiller that cools to the appropriate temperature for air systems, and both the hydronic and air system could be conditioned using DOAS air handling units.

Lastly, the proposed overhaul of the original mechanical system should also be coupled with the photocell technology that was discussed above. Each of these systems operate on completely different principles and do not directly benefit one another because they are designed for different spaces in the building. This technology, as shown previously in the report, allows electrical costs to be decreased with more control over the lighting system. Additionally, this system could show potential benefits in saving hot water energy throughout the circulation spaces and conference rooms on the exterior. Ultimately, this is how the two systems could benefit one another because chilled beams require an exterior heating source such as baseboard heating to help condition the room effectively. Therefore, by allowing the photocells to track the amount of daylight in these spaces and the corridors as well, this system could also determine how much heat is being generated in these spaces from the natural light. With more daylight being utilized to save electrical energy, this would also help heat the building in the winter months when hot water energy is increased. The conjunction of these two technologies was discussed previously; however, the study could be furthered to realize the full potential of these systems working together.

Appendix A

Building Drawings

Typical Office Layout Levels 3 – 5

Typical Photocell Layout Levels 1 – 5

Proposed Thesis Schedule

LEED Master Scorecard

Appendix B

Calculations

Cost Analysis Data

Distribution Equipment

Air Handling Units

Typical Ductwork Take-Off Calculation

Typical Piping Take-Off Calculation

Airflow Redesign Calculations

Lighting Calculations

Energy Analysis Graphics

Utility Cost Calculation

Original Design

Chilled Beam Option A

Chilled Beam Option B

Fan Coil Option C

Room 4225-E Trane TRACE Output

Appendix C

Equipment Specifications

Price ACBM: Modular Active Beam (2-Pipe System)

Price ACBL-HE: Linear High Efficiency Active Beam (4-Pipe System)

Price Fan Coil

Sylvania OCTRON 800 XP Lamps

LED T8 Lamps Commercial Grade

Electronic Fluorescent Ballasts

OSRAM Ceiling Mounted Wireless Sensor with Photocell

Electronic Fluorescent Ballasts – Dimming Systems

Sylvania RLL24 Fixture and Retrofit Kit

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Academic Vita

Andrew S. Koffke

koffke@psu.edu

EDUCATION

Master of Architectural Engineering | Mechanical Focus
Bachelor of Architectural Engineering
Schreyer Honors College
The Pennsylvania State University, University Park, PA
Anticipated Graduation: Spring 2015

The Pantheon Institute, Rome, Italy
7 week, 12 credit Study Abroad May-June 2014

WORK EXPERIENCE

Engineering Intern
BR+A Consulting Engineers   Watertown, MA   Summer 2013, 2014

- Calculated total airflow and pressure drops to size correct piping and ductwork
- Used Revit MEP to analyze and fix any clash issues between mechanical equipment
- Calculated and adjusted VAV box schedules to create the correct building pressurization
- Laid out preliminary ductwork system for pharmaceutical and educational buildings

Engineering Intern
Michael Norris & Assoc.   State College, PA   Sep 2013 – May 2014

- Performed energy simulations using eQuest to find the most economical mechanical system for current projects
- Researched building code to ensure that new projects were up to date and being implemented correctly
- Used AutoCAD to coordinate mechanical systems with other employees

Engineering Intern
John Schade Engineering   Chalfont, PA   May 2011 – Dec 2012

- Trained in AutoCAD to reproduce schematics, details, and floor plans
- Used AutoCAD to model MEP floor plans for residential and commercial buildings

SPECIAL SKILLS   Revit MEP | Revit Architecture | AutoCAD | eQuest | Trane TRACE | MS Office | Bluebeam

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LEADERSHIP & ACTIVITIES

OPPerations Director
Penn State IFC/Panhellenic Dance Marathon 2015

- Actively communicate on behalf of THON with the Bryce Jordan Center Managerial Staff in preparation for the year's events
- Oversee 21 OPPerations Captains and 750 Committee volunteers in their efforts to collectively plan and execute the logistics of the THON 5K, Family Carnival, and THON Weekend
- Collaborate with the Executive Committee to ensure professionalism of THON both internally and externally

OPPerations Captain: Supply Logistics Liaison
Penn State IFC/Panhellenic Dance Marathon 2014

- Communicated with the OPPerations Director to coordinate supply requests for all events
- Worked with the Supply Logistics Committee to request and acquire all supply needs
- Logistically planned and managed transportation of all supplies to and from each event