Hunter's Point South

Intermediate School & High School

Long Island City, NY

M E C H A N I C A L O P T I O N

Final Thesis Report

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HUNTER'S POINT SOUTH INTERMEDIATE SCHOOL & HIGH SCHOOL

Project Information:

Location: Long Island City, NY

Construction: Jan. 2011 – Oct. 2013

Size: 153,769 square feet

Cost: $61 million construction cost

Levels: 5 stories, no cellar

Delivery: Lump Sum Bid

Function: Educational

Height: 73 feet

Project Team:

Owner:

NYC Department of Education

Architect:

FXFWOLE Architects

General Contractor/CM:

Skanska

Structural:

Ysreal A. Seinuk, PC

MEP/Fire Protection:

Kallen & Lemelson, LLP

Lighting Designer:

Tillotson Design Associates

Architecture:

- Exterior Façade: grey brick, slate stone veneer, perforated steel panels, low-e coated windows, and ITSPS
- Design fits into urban community redevelopment plan

Structural:

- Load transferred to soil through 14 inch diameter cassions
- Floor system is a 3 ¼" lightweight concrete on top of a 3" metal deck
- Lateral force resisting system is concentric braced frames

Electrical/Lighting:

- 4000 Amp Main Switchboard
- 400 kW Diesel Generator
- Building Voltage is 208Y/120V
- Fluorescent lighting with MR16 track and spotlights for auditorium

Mechanical:

- 3 CAV and 3 VAV custom made AHU's each equipped with a vfd, wrap around heat pipes for dehumidification, and 0-100% oa intake for economizer mode
- (2) 276 ton air cooled water chillers with scroll compressors
- (4) gas fired condensing boilers each capable of producing 1860 MBH
- Heat transfer fluid for building is a 30% and 35% propylene glycol water used for cooling and heating, respectively

Sustainability:

- Striving for LEED Silver Certification
- Utilizes local materials, recycled steel, low voc emitting finishes, occupancy sensors for lighting, and solar shading
- Abides by the NYC Green Schools Guide

http://www.engr.psu.edu/ae/thesis/portfolios/2012/BAK5101/index.html

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Executive Summary

One alternative was considered in this analysis because all the changes made were linked to one another and depended upon the previous change of work. In this analysis, the existing mechanical system in Hunter's Point South School was compared against the institution of a dedicated outdoor air system with fan-powered inductions units for the terminals. With the changes made to this DOAS/FPIU design, a secondary chilled water loop was created to distribute a higher temperature chilled water to the FPIU's cooling coils. Total energy recovery wheels were used in both DOAS's to recover energy from the room exhaust air. Lastly, with the clearing of roof space a 68.99 kW photovoltaic solar system was installed on the roof. It was found that minor structural upgrades would have to be made to strengthen the roof deck/slab and girders under the solar array.

In comparing the costs, it was found that the new alternative would save $1,273,311 in upfront mechanical cost. This is more than enough to front the costs for the photovoltaic solar array and structural upgrades. When throwing these two items in, the new alternative saved $958,143 in initial costs. The new alternative also managed to save on electricity and natural gas usage. Electricity usage was reduced by 7% and natural gas by 41%. This led to a decrease in total energy costs of 13%. The natural gas had a huge decrease in use due to the addition of the total energy recovery wheels in the DOAS's being used to preheat the OA during the winter months. The wheels were able heat the OA so much that preheat coils were not needed in the DOAS's except as a backup for safety. With the energy and upfront savings, a 25 year life cycle-cost analysis was performed. Bringing both the costs back to a net present value found that the new proposed designs would save $2,018,185 over the existing design.

With the changing of the terminal units and air distribution to the rooms, a computational fluid dynamics (CFD) study was performed on a common classroom. This was done to determine if the new system's air distribution to the space would create a thermally comfortable and draft free environment for the students during the winter design peak. The current variable air volume box design was also tested for full flow and 30% turndown. The analysis focused on the area of the room occupied by the students because this was felt to be the most critical zone. In the new FPIU layout, it was found that the room had a uniform temperature gradient right at the setpoint temperature of 72°F with no drafts being caused in the student section. The two VAV layouts produced problematic results. It was found that the space was being overheated in both scenarios and a huge draft problem occurred in the 30% turndown case. From the results of the CFD analysis, it was determined that the new FPIU layout would create a thermally comfortably, draft-free environment for the occupants.

A big objective of the redesign of the mechanical system was to create a more sustainable, green building with increased comfort control. Temperature control of rooms will be greatly increased because the FPIU's allow for extra heating and cooling to be accomplished at each space. The new FPIU system will provide each room with the correct amount of ventilation air, something that is problematic when VAV boxes are turned down. The emissions of the new design reduced greatly. There was a 16% reduction in CO_2 equivalent. The photovoltaic solar array will produce emission free electricity for years. It can also serve as an educational function for students in teaching green technologies. Through all the changes proposed to Hunter's Point South School, a new cheaper, healthier schoolhouse will be created.

Acknowledgements

Throughout the process of writing and performing the below analyses for my thesis, I was blessed with a lot of help and support along the way. I would like to take this page to express my gratitude and appreciation for all the guidance I received. Though not everyone may be listed, I wanted to take a moment to share the names of those that took the time out of their busy schedules to lend me a hand.

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Dr. Stephen Treado	Thesis Advisor, Penn State

Also, I would like to especially thank the whole AE Department, faculty, staff, and my fellow peers. Lastly, thanks to all my family and friends. I can't express how daunting this task would have been if not for the support from everyone along the way.

Building Overview

Hunter's Point South Intermediate School & High School is a public school for grades 5 through 12 serving the PS 287 Queens School district. Hunters Point is a five story school that will house over 1,000 students. It consists of 26 classrooms, 8 special education classrooms, library, gym, assembly space, cafeteria with open terrace seating, kitchen, and support spaces. The building is a part of the Hunter's Point South Project, a redevelopment of the 30 acre Queens area to become a more sustainable, middle income urban community along the waterfront park. This redevelopment in Queens also includes residential housing, apartments, retail space, community/cultural facilities, parking, and a new 11 acre waterfront park.

Mechanical System Overview

Conditioned air is served to Hunter's Point South Intermediate School & High School via the six rooftop air handling units. Units 1, 2, and 3 are variable air volume (VAV) systems that service the classrooms, offices, corridors, and non-public spaces. Units 4, 5, and 6 are constant air volume (CAV) systems that serve the gymnasium, cafeteria/kitchen, and auditorium, respectively. All air handling units have variable frequency drives, wrap around heat pipes for dehumidification, and economizer controls. Preheat coils in the AHU's use a 35% propylene glycol – water mixture while the cooling coil utilizes a 30% propylene glycol – water mixture. This heat-transfer fluid has low toxicity and volatility. It poses little harm to humans in case of a leak.

Four natural gas fired, condensing boilers are used for Hunter's Point South School's heating needs. These boilers are located in the mechanical penthouse's boiler room. Each boiler can produce 1860 MBH worth of 35% propylene glycol – water mixture which is used for the AHU's, perimeter fin tube radiators, unit heaters, and cabinet heaters. All heating hot water and secondary pumps are located in the boiler room along with the hot and chilled water expansion tanks. Two 276 ton air cooled chillers with scroll compressors are also located on the roof. A 30% propylene glycol – water mixture is cooled by the R-410a refrigerant which is used for the AHU's cooling coils.

Cabinet and unit heaters are used to heat the building's entrances, locker rooms/showers, and stairwells. Split heat pumps are utilized in the telecom rooms on each floor, food storage, and elevator machine room. The outdoor section of each heat pump is located on the roof. Fin tubed radiators are used along the perimeter walls to heat the space in conjunction with AHU's. Upblast and mushroom fans are located on the roof where they exhaust air from the science lab's fume hoods and kitchen.

Design Objectives, Requirements, and Conditions

Hunter's Point South School is a schoolhouse for grades 5 through 12 which is located in Queens, New York. It is part of the Hunter's Point South Project which is a process to redevelop the 30 acre area in Queens to become a more sustainable, middle income urban community. Hunter's Point South School's architecture as well as building maintenance was designed with this idea in mind. The school is also held to the requirements of the New York City Green School Guide which further reinforces the strive for a green, efficient building.

The classrooms house a large number of occupants which consumes a huge amount of energy. Since the classrooms have a fluctuating number of occupants throughout the day, it would be costly and inefficient to run the rooms at full load all day for ventilation and lighting. This was considered in the design so to help reduce energy consumption, VAV boxes were used to vary the flow of conditioned air to the spaces. Occupancy sensors for lighting control were also included to save electricity.

Hazardous chemicals are used in the laboratories and science classrooms. This inherent concern was accounted for in the design phase. Fume hoods with exhaust fans are used to help flush out potentially harmful chemicals. Strict standards were imposed on the quality of duct used for the chemical exhaust and the inside of the ducts are negatively pressurized to prevent leakage of the chemical exhaust to surrounding spaces.

Hunter's Point South School was commissioned under the New York City Board of Education. All new schoolhouses in New York City must abide by the New York City Green School Guide. The NYC Green School Guide is a document that outlines standards that new schools must follow. The standards outlined are geared towards making these new schoolhouses more energy efficient and sustainable. Since Hunter's Point South School must follow this, no emphasis was put forth to go for LEED certification (even though the NYC Green School Guide is fairly similar to the USGBC's LEED rating system).

The NYC Board of Education has commissioned many school houses as well as created ties with power companies in the area. This has led to beneficial relations between the board and power companies. Hunter's Point South School receives their electricity from the New York Power Authority (NYPA). The rates for energy prices can be seen below in Table 1 for Hunter's Point South School.

Energy Prices	
Type	Price
Electricity (from NYPA)	$0.19/kWh
Natural Gas (based on National Grid firm charges)	$1.542/therm

Table 1 – Energy Prices

Hunter's Point South School is located in Long Island City, New York in the Queens borough. It sits in the Mixed-Humid Climate Zone according to ASHRAE Standard 90.1 and has roughly 5,400 heating degree days or fewer. Below in Table 2 are the outdoor design conditions for the school.

ASHRAE HoF 2009 Chapter 14 Appendix: Climate Data	
JFK Airport, NY	dB Temp
0.4% Cooling	89.7°F
99.6% Heating	12.8°F

Table 2 – Outdoor Design Air Conditions

Table 3 below shows the room design conditions for the spaces in Hunter's Point South School.

Room Design Temperatures	
Winter	72°F Dry Bulb
Summer	75°F Dry Bulb

Table 3 – Indoor Design Conditions

Design Ventilation

Appendix C contains the excel spreadsheets of each air handler's results for minimum outdoor air intake using the calculations from ASHRAE Standard 62.1-2007 Section 6 for ventilation. For AHU's 4, 5, and 6, the minimum ventilation supplied to each room is contrasted against the design condition. The NYC Green Schools Guide requires all new schools, such as Hunter's Point South Intermediate School & High School, to be designed to use above 30% minimum ventilation air calculated in ASHRAE Standard 62.1. This is outlined in Q1.1R Minimum IAQ Performance/Increased Ventilation in the NYC Green Schools Guide. Compliance with this increase in air has also been added to the analysis and can be seen Table 4 below.

	Type	Min OA Intake	Vot	Compliant?	30% Above Vot	Above 30% Compliant?
AHU-1	VAV	14945	12218	Yes	15883	No
AHU-2	VAV	19445	18971	Yes	24662	No
AHU-3	VAV	13210	10954	Yes	14240	No
AHU-4	CAV	13360	7085	Yes	9211	Yes
AHU-5	CAV	11840	6259	Yes	8488	Yes
AHU-6	CAV	6325	2657	Yes	3454	Yes

Table 4 – Air Handling Units' Section 6 of ASHRAE Standard 62.1 Compliance

Since Hunter's Point South School is located in Queens, New York ventilation requirements must be checked against both the ASHRAE Standard 62.1-2007 Section 6 and the New York

State Mechanical Code 2007 using values from Section MC 403. The zone primary outdoor air fraction (Z_p) values found using the NYS Mechanical Code are slightly higher than the ASHRAE ones. However, these values are not shown because they are irrelevant in the end. They are irrelevant because the above 30% outside air calculated from ASHRAE Standard 62.1 dominates the New York State Mechanical Code values. This 30% increase makes the ASHRAE required outside air the driving factor in this comparison.

Design Building Load Estimates

To evaluate the heating and cooling loads of Hunter's Point South School, Trane TRACE 700 was used. The results generated can be seen below in Table 5.

	Conditioned Space (sf)	Supply Air per unit area (cfm/sf)		Area per Cooling Capacity (sf/ton)	Cooling Capacity per Area (tons/sf)	Heating Capacity per Area (Btuh/sf)	Total Heating (Btuh)	Total Cooling (tons)
		Cooling	Heating					
AHU-1	30637	0.65	0.37	296.6	0.0034	52.91	1,621,100	103.3
AHU-2	29722	0.89	0.5	218.5	0.0046	52.58	1,562,800	136
AHU-3	22567	0.89	0.52	213.1	0.0047	50.38	1,136,900	105.9
AHU-4	12735	2.08	2.08	99.0	0.0101	74.54	949,300	128.6
AHU-5	11449	1.69	1.69	182.3	0.0055	59.28	678,700	62.8
AHU-6	4341	3.63	3.63	93.0	0.0108	98.76	428,700	46.7
Unit Heaters	6963	n/a	0.42	n/a	n/a	24.82	172,800	n/a
Total Building	118414	1.081	0.865	203.9	0.0049	55.32	6,550,300	583.3

Table 5 – TRACE Loads

Load calculations were also provided by the design engineer for comparison. This can be seen below in Table 6. For this project, the design loads calculated in TRACE were used.

	Conditioned Space (sf)	Supply Air per unit area (cfm/sf)	Area per Cooling Capacity (sf/ton)	Cooling Capacity per Area (tons/sf)	Heating Capacity per Area (Btuh/sf)	Total Heating (Btuh)	Total Cooling (tons)
AHU-1	28115	0.98	286.5	0.0035	37.82	1,063,259	98.12
AHU-2	27690	1.04	232.5	0.0043	48.83	1,351,976	119.1
AHU-3	21646	1.14	234.6	0.0043	43.36	938,642	92.25
AHU-4	12527	1.48	113.8	0.0088	70.87	887,731	110.1
AHU-5	9833	1.62	144	0.0069	80.1	787,669	68.27
AHU-6	4341	2.01	110.7	0.009	84.01	364,697	39.21
Stairs	1080	2.91	186.3	0.0054	65.47	70,713	5.8
South Entrance	800	0.72	0	0	31.29	25,034	0
Total Building	106032	1.20	201	0.005	51.77	5,489,721	532.85

Table 6 – Designer's Load Calculations

Design Energy Usage

The energy usage for Hunter's Point South School was found by doing an energy model in Trane TRACE 700. It was calculated that the current design uses 1,614,418 kWh per year and 42,285 therms of natural gas a year. This equates to a total energy bill of $371,941 dollars a year ($304,739 electric and $65,202 natural gas). A comparison between the designer engineer's values and the ones calculated in TRACE can be seen below in Table 7.

	Electricty (kWh per year)	Natural Gas (BTU x 10^6 per year)	Electricity Cost per year	Natural Gas Cost per year	Total Cost per year	Cost per Square Foot of Building
Design Engineer	1,720,210	6,740	$ 290,640	$ 104,066	$ 394,706	$ 2.58
Existing Building (TRACE)	1,614,418	4,228	$ 306,739	$ 65,202	$ 371,941	$ 2.43
Difference	105,792	2,511	$ (16,099)	$ 38,864	$ 22,765	$ 0.15
% Difference	6%	37%	-6%	37%	6%	6%

Table 7 – Energy Usage TRACE vs. Design Engineer

The energy cost found using TRACE is much higher for electricity. This would come down some if the occupancy sensors for lighting were able to be modeled in TRACE. Even though the TRACE values are much different than the design engineer's numbers, the values found in the TRACE model were used for comparison later on with the proposed design changes because both use the same basic TRACE model.

The energy usage of the school can be seen broken down month by month for electricity in Figure 1 and natural gas in Figure 2.

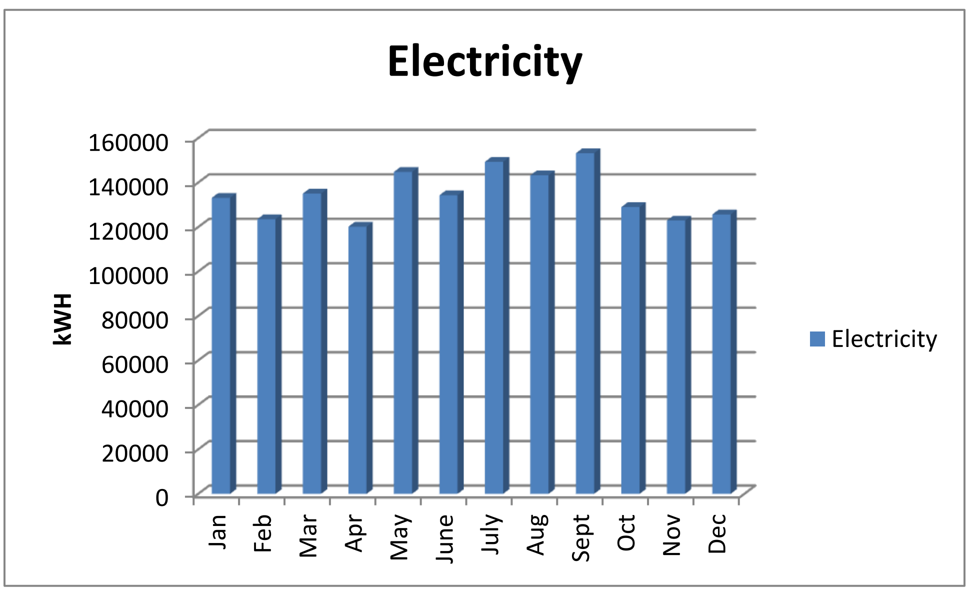


Figure 1 – Electricity Usage by Month

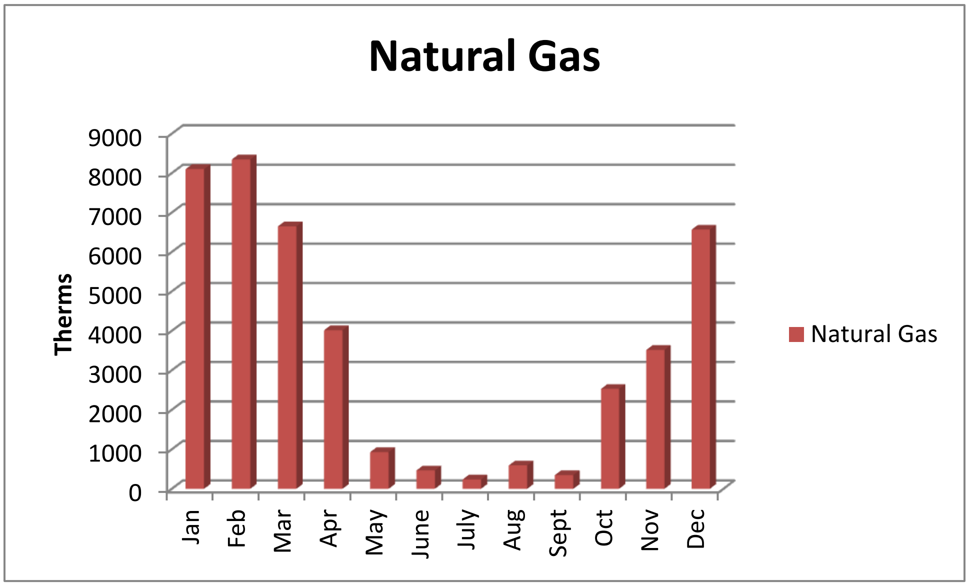


Figure 2 – Natural Gas Usage by Month

The energy consumption breakdown for Hunter's Point South School can be seen below in Figure 3.

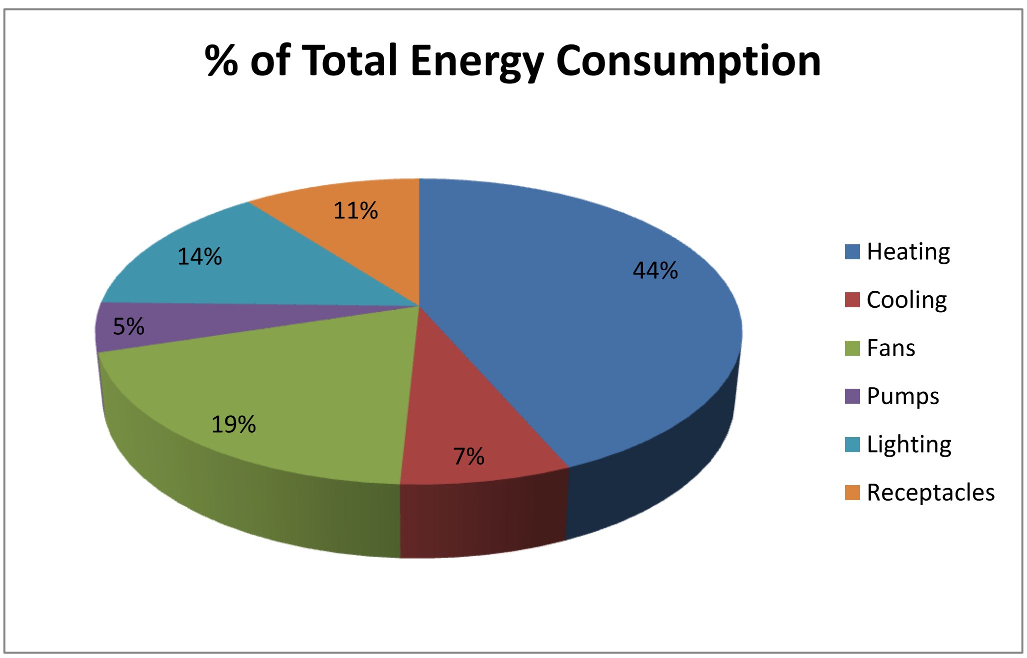


Figure 3 – Energy Usage Breakdown of Existing Building

Emissions

The emissions created by electricity, on site combustion, and transportation for fuel to the building can be seen below in Tables 8 through 10 for the current design of Hunter's Point South School.

Pollutant	lb of pollutant per kWh of electricity	lb of pollutant per year due to electricity
CO_{2e}	1.03E+00	1,662,850.54
CO_2	9.61E-01	1,551,455.70
CH_4	2.59E-01	418,134.26
N_2O	1.68E-05	27.12
NO_x	1.72E-03	2,776.80
SO_x	6.23E-03	10,057.82
CO	1.75E-03	2,825.23
TNMOC	6.38E-05	103.00
Lead	5.59E-08	0.09
Mercury	3.99E-08	0.06
PM10	6.87E-05	110.91
Solid Waste	6.18E-02	99,771.03
kWh/year =	1,614,418	

Table 8 – Base Building Electricity Emissions

Pollutant	lb of pollutant per 1000 cubic ft of natural gas	lb of pollutant per year due to on-site combustion
CO_{2e}	1.23E+02	520,093.20
CO_2	1.22E+02	515,864.80
CH_4	2.50E-03	10.57
N_2O	2.50E-03	10.57
NO_x	1.11E-01	469.35
SO_x	6.32E-04	2.67
CO	9.33E-02	394.51
VOC	6.13E-03	25.92
Lead	5.00E-07	0.00
Mercury	2.60E-07	0.00
PM10	8.40E-03	35.52
cubic feet of natural gas =		4228400

Table 9 – Base Building Emissions On-Site Combustion

Pollutant	lb of pollutant per 1000 cubic ft of natural gas	lb of pollutant per year due transportation to site
CO_{2e}	2.78E+01	117,549.52
CO_2	1.16E+01	49,049.44
CH_4	7.04E-01	2,976.79
N_2O	2.35E-04	0.99
NO_x	1.64E-02	69.35
SO_x	1.22E+00	5,158.65
CO	1.36E-02	57.51
TNMOC	4.56E-05	0.19
Lead	2.41E-07	0.00
Mercury	5.51E-08	0.00
PM10	8.17E-04	3.45
PM-unspecified	1.42E-03	6.00
Solid Waste	1.60E+00	6,765.44
cubic feet of natural gas =		4228400

Table 10 – Base Building Emissions Fuel Transportation

The total pollutants generated in a year by the school can be seen in Table 11 below and Figure 4.

Pollutant	Total Pollutants (lb of pollutant)
CO_{2e}	2,300,493.26
CO_2	2,116,369.94
CH_4	421,121.63
N_2O	38.69
NO_x	3,315.50
SO_x	15,219.14
CO	3,277.25
TNMOC	103.19
VOC	25.92
Lead	0.09
Mercury	0.07
PM10	149.88
PM-unspecified	6.00
Solid Waste	106,536.47

Table 11 – Total Emissions

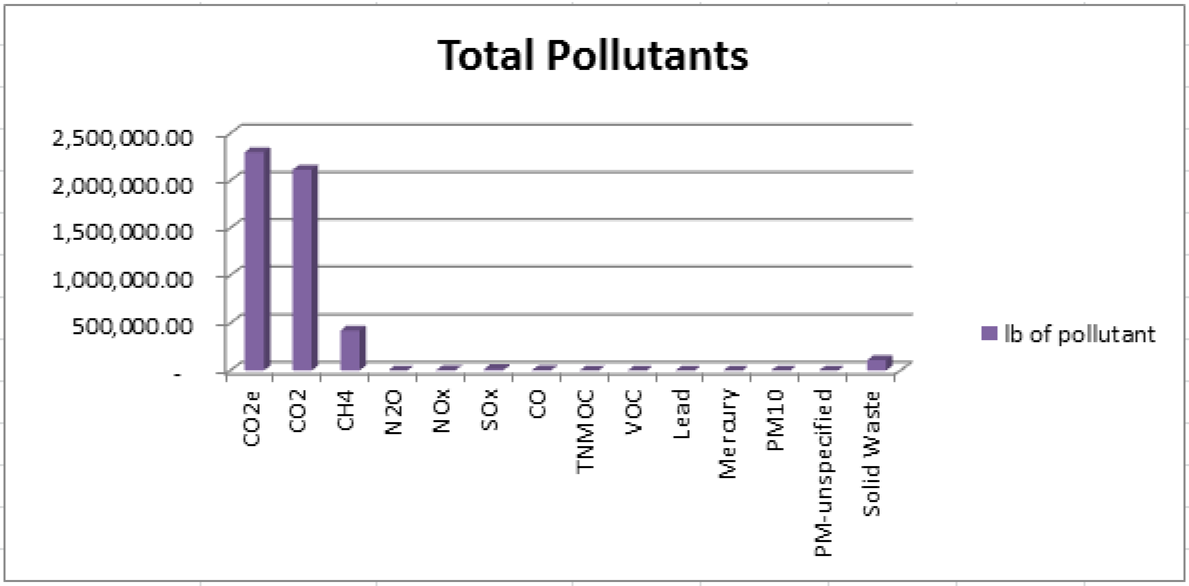


Figure 4 – Total Emissions

Mechanical Equipment Summary

The mechanical systems in Hunter's Point South School are primarily located on the roof. Two air cooled chillers and six air handling units are located here along with the outdoor sections of each of the heat pumps and many of the exhaust fans. The mechanical penthouse on the roof houses the four condensing boilers along with their pumps and the expansion tanks. The emergency generator is also located in a room in the penthouse. The roof space is mainly used for the mechanical equipment because no basement exists for Hunter's Point South School. Due to direct exposure to the elements on the roof, a propylene glycol – water mixture has been used instead of water to prevent freezing in the pipes and coils. Below in Tables 12 through 15 is the breakdown of information for the boilers, chillers, heat pumps, and exhaust fans, respectively.

Boiler Schedule							
Unit No.	Location	Type	Heating Capacity (MBH)	Efficiency (minimum)	EWT	LWT	Horsepower
B-1, B-2, B-3, or B-4	Boiler Room (on roof)	Gas Fired Condensing Boiler	1860	85.3%	120°F	140°F	56

Table 12 – Boiler Schedule

Chiller Schedule							
Unit No.	Location	Type	Capacity (tons)	COP/ EER	EWT	LWT	GPM
ACH-1 or ACH-2	Roof	Air cooled with scroll compressors	276	3.25/11.1	54°F	44.4°F	710

Table 13 – Chiller Schedule

Heat Pump Schedule					
Unit No.	Service	Air Flow (CFM)	Heating Capacity (MBH)	Cooling Capacity (MBH)	System EER
AC-1	Telecom Room	790	45	42	15.8
AC-2	Telecom Room	425	0	12	13.8
AC-3	Telecom Room	425	0	12	13.8
AC-4	Telecom Room	425	0	12	13.8
AC-5	Telecom Room	425	18	12	13.8
AC-6	Food Storage	425	18	12	13.8
AC-7	Elevator Machine Room	425	0	12	13.8

Table 14 – Heat Pump Schedule

Exhaust Fan Schedule					
Unit No.	Service	Location	Type	Capacity (cfm)	Motor HP
Ke-1	Kitchen Gneral Exhaust (5th Flr)	Roof	Upblast	3000	1.5
Ke-2	Kitchen Hood Exhaust (5th Flr)	Roof	Upblast	7050	5
Ke-3	Can Wash Room Exhaust (5th Flr)	Roof	Mushroom	320	1/4
EF-1	Fume Hood Exhaust	Roof	Nozzle	1300	1.5
EF-2	Fume Hood Exhaust	Roof	Nozzle	1300	1.5
EF-3	Science Lab General Exhaust	Roof	Mushroom	700	1/3
EF-4	Fume Hood Exhaust	Roof	Nozzle	1300	1.5
EF-5	Main Toilets & Locker Room Exhaust	Roof	Mushroom	5910	3
EF-6	I/S Boy's & Girl's Locker Room Exhaust	Roof	Mushroom	1060	1/2
EF-7	H/S Boy's & Girl's Locker Room Exhaust	Roof	Mushroom	1440	3/4
EF-8	Copy Room Exhaust	Roof	Mushroom	300	1/4
EF-9	Kitchen Men's & Women's Toilet	Roof	Mushroom	400	1/6
EF-10	General Exhaust	Plumbing Room (1st Flr)	In-Line	1310	1/2
EF-11	Electric Service Room Exhaust	Equipment Room (1st Flr)	In-Line	1000	1/3
EF-12	Fuel Oil Tank Room Exhaust	Fuel Oil Room (1st Flr)	In-Line	220	1/4
EF-13	Emergency Generator Room Exhaust	Generator Room	In-Line	650	1/4
EF-14	Elevator Machine Room	Equipment Storage (1st Flr)	In-Line	220	1/4
EF-15	Gas Meter Room	Gas Room (1st Flr)	In-Line	220	1/4
EF-16	Kitchen Detergent Room	Roof	Mushroom	100	1/6
EF-17	Kiln Unit	Roof	Mushroom	150	1/6
EF-18	Acid Storage Cabinets	Roof	Mushroom	150	1/6
SF-1	Boiler Room Supply	Boiler Room	In-Line	850	1/4

Table 15 – Exhaust Fan Schedule

AHU-1, AHU-2, and AHU-3 are all part of a variable air volume system. VAV boxes are used to manage the flow of air to the spaces served by these air handlers in an attempt to save energy costs. Each air handler (AHU-1 through 6) has variable frequency drives, wrap around heat pipes for dehumidification, and the ability to run in economizer mode. Temperature drops across the heating coils and heating terminal units is 20°F. The cooling coils in the air handlers have a 10°F temperature drop across them. Table 16 below shows the AHU's breakdown.

Air Handler Unit Schedule											
Unit No.	Service	Location	Type	Supply/Return CFM	Minimum OA/Exhaust CFM	Heating Capacity (MBH)	Cooling Capacity (MBH)	Supply Fans	Supply Fan HP (each)	Return Fans	Return Fan HP (each)
AHU-1	Classrooms, Offices, Corridors, and Non-Public	Roof	VAV	30,000/27,000	14,945/11,945	1,266.8	1,389.7	2	30	2	15
AHU-2	Classrooms, Offices, Corridors, and Non-Public	Roof	VAV	31,700/27,100	19,445/14,845	1,367.7	1,562.8	2	30	2	15
AHU-3	Classrooms, Offices, Corridors, and Non-Public	Roof	VAV	27,000/24,300	13,210/10,510	1,111.4	1,270.9	2	25	2	10
AHU-4	Gymnasium	Roof	CAV	20,860/18,560	13,360/11,060	1,232.5	1,222.9	2	20	2	7.5
AHU-5	Café/Kitchen	Roof	CAV	18,700/12,500	11,840/5,640	1,096.5	916.2	1	40	1	10
AHU-6	Auditorium	Roof	CAV	9,600/9,200	6,325/5,925	443.8	492.0	1	20	1	10

Table 16 – Air Handler Unit Schedule

Information for the pumps used in Hunter's Point South School can be seen below in Table 17. Note that pumps P-1, P-2, and P-3 distribute a 35% propylene glycol water mixture while P-4 through P-6 distribute a 30% propylene glycol water mixture. FOP-1 and FOP-2 both pump fuel oil for the emergency generator.

Pump Schedule					
Unit No.	Service	Location	Capcaity (GPM)	Head (ft)	Motor Size (HP)
P-1	Heating Hot Water	Boiler Room (on roof)	330	110	20
P-2	Heating Hot Water (Stand-By)	Boiler Room (on roof)	330	110	20
P-3	Heating Hot Water	Boiler Room (on roof)	330	110	20
P-4	Secondardy Chilled Water (ACH-1)	Boiler Room (on roof)	710	100	30
P-5	Secondary Stand By for P-3 or P-5	Boiler Room (on roof)	710	100	30
P-6	Secondardy Chilled Water (ACH-2)	Boiler Room (on roof)	710	100	30
FOP-1 or 2	Emergency Generator on Roof	Plumbing Room (1st Flr)	2	18	1/2

Table 17 – Pump Schedule

Mechanical Equipment First Cost

The total cost of the mechanical equipment for Hunter's Point South School is $7,750,000. This equates to $50.40 per square foot of the building. The price includes furnish and installation of all the outlined equipment. Table 18 below has a breakdown of the cost for the different mechanical systems. To further clarify what each system encompasses, read below the table.

Mechanical Cost Breakdown		
Type	Cost ($)	Cost per square foot ($/sf)
AHU's	1,190,000	7.74
Chillers	820,000	5.33
Boilers	260,000	1.69
Heat Pumps	49,000	0.32
Fin Tube Radiators	300,000	1.95
Unit/Cabinet Heaters	143,000	0.93
VAV Boxes	216,000	1.40
Fan Powered Boxes	16,000	0.10
HVAC Piping	1,250,000	8.13
Ducts	1,479,500	9.62
HVAC Controls	910,000	5.92
Pumps	32,000	0.21
Convectors	14,000	0.09
Fans	80,000	0.52
Dampers	55,000	0.36
Diffusers/Grills	100,000	0.65
Emergency Generator/Fuel Oil	182,000	1.18
Glycol	35,000	0.23
Miscellaneous	38,500	0.25
Overhead	580,000	3.77
Total	**7,750,000**	**50.40**

Table 18 – Mechanical Cost Breakdown

- The Boilers cost includes the chemical treatment as well as the boilers.
- The HVAC Piping includes all piping for the HVAC equipment. This includes piping to and from the equipment, anchors/guides, and insulation. The plumbing piping is not included in this number.
- Ducts cost include insulation, silencers, and all supply and return duct runs.
- The HVAC Controls include all the controls needed to run the different mechanical equipment and systems. Pressure valves are also included here.
- Fans include the 12 rooftop and 10 in-line exhaust fans. The fans in the AHU's and chillers' condensers are not included here, rather in their respective tab.
- The Emergency Generator/Fuel Oil includes all costs associated with this system. This includes piping, controls, pump set, tank, generator, and ducts.
- Miscellaneous includes the cost of the seismic restraint, hot water pumps' inertia pads, and the hot and cold make up water.

- Overhead includes the cost of the site project supervisor, project management, commissioning/punch lists, shop drawings, and submittals.

Lost Usable Space

Mechanical equipment as well as duct runs require floor space and detract from the overall usable building area. Below in Table 19 is a breakdown of the floor space used by the mechanical equipment.

The Fuel Oil Room feeds the emergency generator and the Gas Room supplies the boilers with natural gas. Space is lost on each floor from ducts that run between floors. This lost area is found under the "Shafts" breakdown. The "Penthouse" is located on the roof and includes the emergency generator, boiler, and mechanical storage rooms. Pumps and expansion tanks are located in the Boiler Room. "Penthouse" area is not included in the overall lost usable space because it is not considered usable space. This information was included to reflect how much actual space the mechanical systems occupy. Furthermore, lost usable space is saved by the air handlers and chillers being located on the roof. Hunter's Point South School has no basement.

The floor area lost to electrical and plumbing systems is not included in this breakdown. Further floor area is lost to these two systems.

Lost Usuable Space		
Space Type	Location (Floor)	Floor Area (square feet)
Fuel Oil Room	1st	132
Gas Room	1st	120
Shafts	2nd-5th	1429
Mechanical Penthouse	Roof	1924*
	Total	1681
	*Note: Not included in total.	

Table 19 – Lost Usable Space

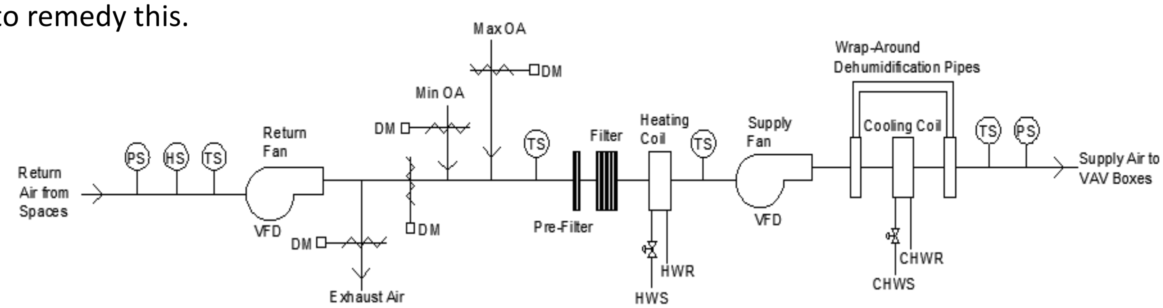
System Operations and Schematics

Air Side

AHU's 1, 2, and 3

Below in Figure 5 is a schematic for a typical VAV AHU (AHU 1, 2, or 3) as well as a terminal VAV box. This AHU serves the classrooms, offices, corridors, and non-public areas with the necessary heating, cooling and ventilation needed. The return fan and supply fan are both equipped with variable frequency drives (VFD) so air can be modulated to the spaces or from them depending upon the needs. The minimum outside damper is opened whenever the AHU is in use. All AHU's have the ability to run in economizer mode so the controls operating the damper motors of the minimum outside air, maximum outside air, and exhaust air dampers are all linked together. As much as 100% outside air can be supplied. A temperature sensor (TS) and humidity sensor (HS) measure the return air conditions. A TS and HS are also located outside the AHU to measure the outdoor conditions. The readings from the return air sensors and outdoor air sensors work in conjunction with the space requirements to run the economizer mode which modulates the dampers. Both the heating coil and cooling coils use two way valves to modulate the amount of the propylene glycol – water mixture flow. The heating coil performs the function of a preheat coil as well as having the ability to serve as a regular heating coil.

The dehumidification of the supply air is accomplished by the wrap-around heat pipes (which wraps around the cooling coil). A precool heat pipe is upstream of the cooling coil while a reheat heat pipe is downstream. The precool heat pipe brings the warm air temperature down bringing it closer to its dew point. Dehumidification can then occur across the cooling coil and the reheat heat pipe then brings the supply air back up to its appropriate temperature. A solenoid control valve is used to modulate the flow through the heat pipes which is controlled by the outdoor and return humidity sensors. Finally a pressure sensor on the return and supply side checks to make sure the pressure is balanced. If the pressure is off, the fans will vary flow to remedy this.



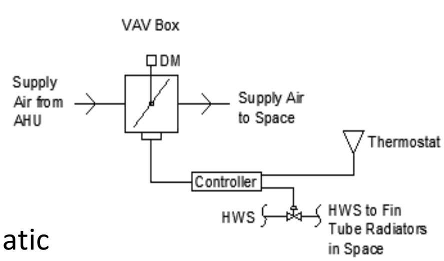


Figure 5 – VAV AHU and VAV Box Schematic

The VAV box modulates based upon the space's need. The controller is run by the thermostat in the room and controls the damper motor and hot water supply to the fin tube radiators. Each VAV box has a minimum turndown so each space will still receive minimum ventilation.

AHU's 4, 5, and 6

AHU's 4, 5, and 6 are constant air volume systems. These AHU's serve the gymnasium, cafeteria/kitchen, and auditorium, respectively. Each fan motor in the AHU's has a VFD and the ability to run in economizer mode. A VFD is provided on the fans to ensure that the proper CFM will be maintained when the filters get dirty. A schematic for AHU 4, 5, or 6 can be seen below in Figure 6. Essentially the AHU's work like the VAV AHU's above except that there are no VAV terminal boxes and a constant volume of air is supplied.

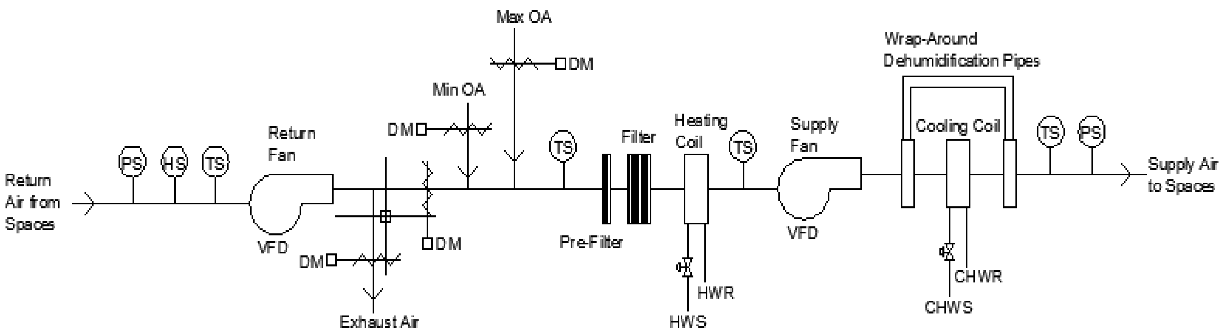


Figure 6 – CAV AHU

Water Side

Chilled Water System

The chilled water system is composed of two packaged air-cooled water chillers in parallel that serve the cooling coils of the AHU's. This system can be seen below in Figure 7. The chilled water loop is a primary-only variable flow design. The flow thorough the chillers' evaporators shall vary with the load. The bypass valve is used to maintain the minimum flow through the chillers' evaporators (when they are on). The flow to the terminal loads vary depending upon the amount of gpm required. The chilled propylene glycol – water mixture is supplied at a temperature of 44.4°F and sent to the AHU's cooling coils. The return temperature is designed to be 54°F, giving an approximate ΔT of 10°F for cooling. The chilled propylene glycol – water mixture supplied from the chillers can bypass the cooling coils through the low flow bypass. This bypass is controlled by a differential pressure sensor across it. When the load at the terminals can no longer be met by one chiller, the second chiller will modulate on as well as the pump. An air separator and expansion tank are located on the return side of the chilled water.

Temperature sensors are located on the upstream and downstream of the chillers to determine the loads needed to be produced by the evaporators and that the chillers are operating properly. A flow sensor (GPM in schematic) is used to measure flow from the chillers and to check that the system is functioning properly.

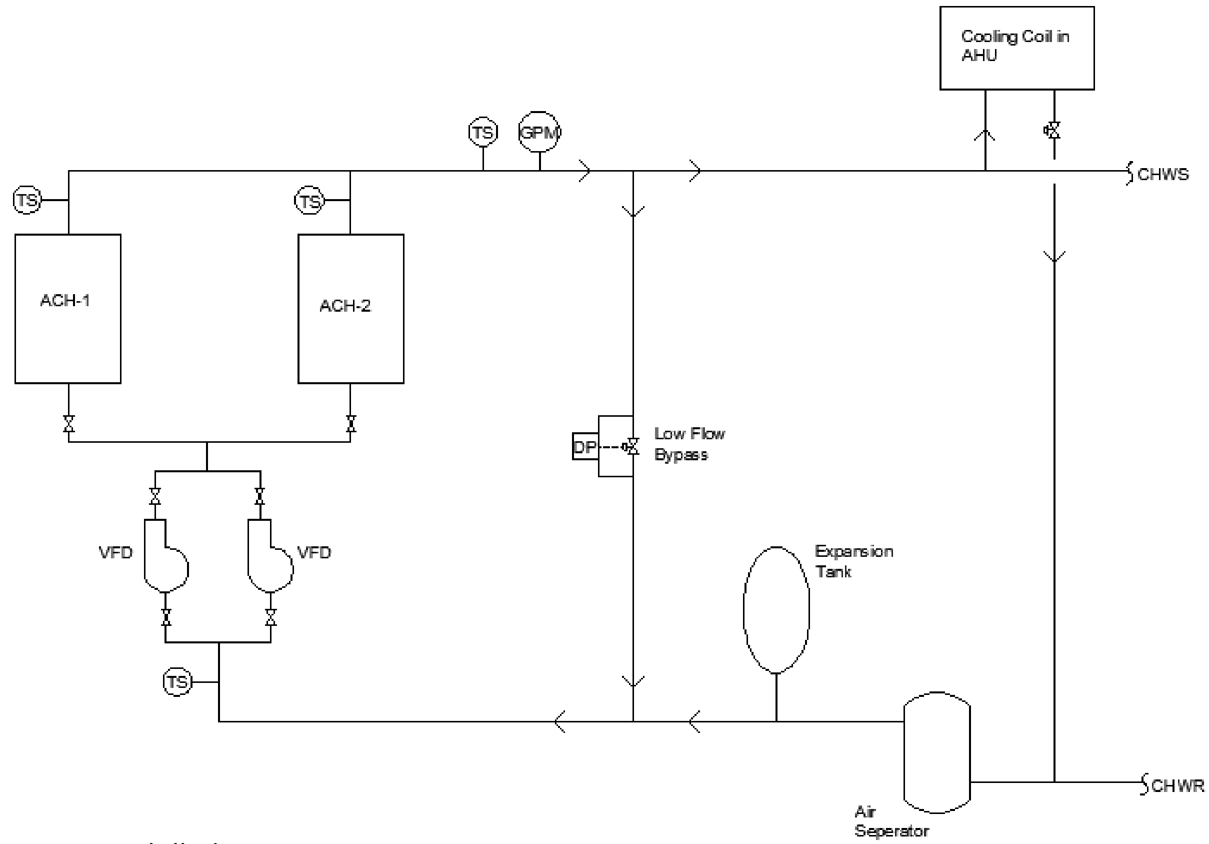


Figure 7 – Chilled Water System

Hot Water System

Natural gas is piped in through the gas meter in the Gas Room on the first floor. It is then piped up through the building to the boilers in the mechanical penthouse. The boilers, air separator, expansion tank, and pumps for the hot water system are all located in the mechanical penthouse. The four natural gas fired, condensing boilers can produce 1860 MBH each of 35% propylene glycol – water mixture. The three hot water circulating pumps have variable frequency drives (one pump is used for standby). The pumping system is variable primary flow with a bypass line. The bypass line is controlled by a differential pressure sensor. The hot propylene glycol – water mixture is supplied at 140°F to the AHU's heating coils, fin tube radiators, cabinet heaters, and unit heaters. The solution is returned at 120°F giving a ΔT of 20°F for heating. Check valves control flow through the boilers and pumps. An air separator and expansion tank are located on the supply side. The hot water system can be seen below in Figure 8.

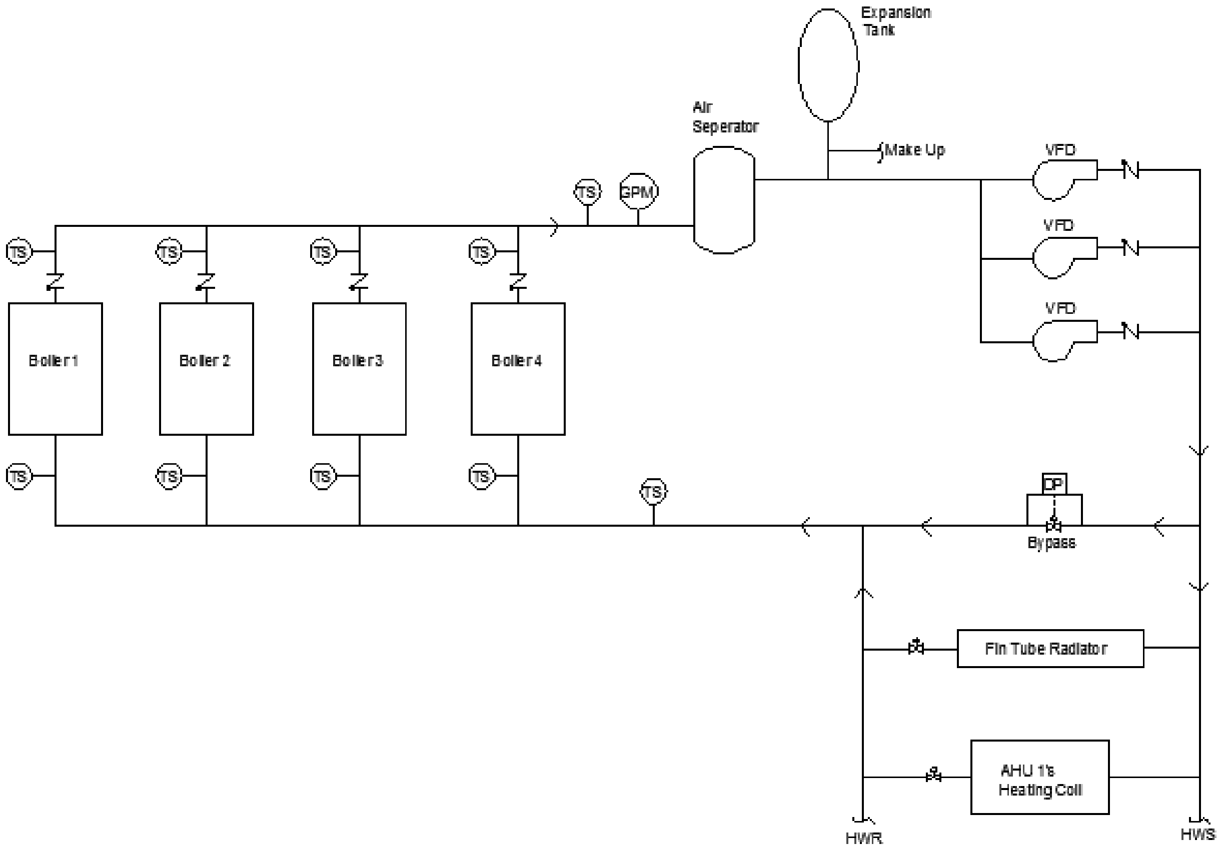


Figure 8 – Hot Water System

ASHRAE Standard 62.1-2007 Analysis

Section 5 Analysis

5.1 Natural Ventilation

Perimeter rooms have manually operable windows but the building spaces are mechanically ventilated. Natural ventilation is not used.

5.2 Ventilation Air Distribution

Hunter's Point South Intermediate School & High School was designed to comply with Q 1.1R Minimum IAQ Performance/Increased Ventilation from the NYCSA's Green School Guide. It meets minimum ventilation standards set forth in Section 6 of ASHRAE Standard 62.1-2007.

5.3 Exhaust Duct Location

Fume hoods/acid cabinets located in the science classrooms and kitchen hoods each have their own separate ducting for exhaust. The main bathrooms and some locker rooms share common exhaust ducting. All exhaust ducts are negatively pressured to the surrounding spaces to prevent leaks.

5.4 Ventilation System Controls

All six air handling units have two intake dampers for outside air. One is dedicated for minimum outside air while the other is modulated to help reduce energy costs. Variable air volume boxes have minimum turn down for dampers so airflow into the spaces complies with minimum outside air from Section 6 of ASHRAE Standard. 62.1-2007.

5.5 Airstream Surfaces

Duct work is made from sheet metal; aluminum, galvanized steel, and stainless steel with metal fasteners. Therefore duct work complies with the mold growth and erosion resistance outlined in this section. Fiberglass lining for ducts is in compliance with ASTM C1338 (to prevent mold) and UL 181 (to resist erosion). Flexible ducts are made from spiral-wound steel or corrugated aluminum and comply with UL 181.

5.6 Outdoor Air Intakes

All outdoor air intakes for AHU's are over 30 feet away from lab fume hood exhaust vents. AHU's have intake and exhaust outlets on opposite sides, each of which have stormproof louvers or hoods to prevent entrainment of rainwater and an aluminum bird screen. Access doors to AHU's are easily accessible and have as much as an eight foot clearance around them.

The only questionable aspect to the compliance for Hunter's Point South School to this section is a shaft smoke vent which is located eight feet from AHU-2's intake. If AHU-2 is designed to turn off in the event of a fire, then the school is in compliance. However, no information could be found on the controls logistics that would incur during a fire for AHU-2's intake.

5.7 Local Capture of Contaminants

All noncombustion equipment (ex. fume hoods, kitchen equipment, etc.) have separate ducting to the roof with their own dedicated fans. The diesel oil storage tank located on first floor exhausts vapors through a vent brick in the wall.

5.8 Combustion Air

The emergency generator and boilers have direct venting to the atmosphere for their flue gas through the roof and wall louvers of the mechanical roof penthouse. Adequate air is provided to the four gas fired condensing boilers for combustion.

5.9 Particulate Matter Removal

All six AHU's have a set of two filters located upstream of the cooling coil that comply with UL 900-1994. The first filter is a 2" thick, pleated type pre-filter that has a minimum efficiency of MERV 7. The second filter is a 12" thick cartridge filter that has a minimum efficiency of MERV 13.

5.10 Dehumidification Systems

Dehumidification is accomplished by the wrap-around dehumidifier heat pipes in each AHU. Relative humidity is limited below 65 percent by these heat pipes. The minimum outdoor air intake is greater than the minimum exhaust for each air handler, so a positive pressure in the building may be contained during dehumidification processes.

5.11 Drain Pans

The drain pans in the six AHU's extend 1" upstream and 3" downstream of the cooling coils. The pans consist of one-piece seamless stainless steel that is pitched towards the drain outlet. Drain pans for the wrap around dehumidification heat pipes have the same specifications as the ones outlined above for the AHU's cooling coils. All drain pans comply with this section.

5.12 Finned-Tube Coils and Heat Exchangers

Split heat pumps have drain pans with integrated condensate pumps to distribute condensate to the nearest sanitary drain with air gap. The finned tube radiators have 48 fins per foot. The number of coils varies per radiator, being either 1 or 2 coils. There is no mention of the 18" intervening access space, however the pressure drop is less than 0.75 in wg so the equipment outlined in this section complies.

5.13 Humidifiers and Water-Spray Systems

No humidifiers or water-spray systems are used in Hunter's Point South School. This section does not apply.

5.14 Access for Inspection, Cleaning, and Maintenance

Hunter's Point South School complies with this section. All six AHU's have multiple access doors measuring 24" wide (some 30") by 72" in height. The doors are situated so all required equipment may be serviced, including the wrap-around heat pipes. There is an eight foot clearance around access doors to allow workers plenty of space for inspection and maintenance.

5.15 Building Envelope and Interior Surfaces

The exterior walls of Hunter's Point South contain an air/vapor barrier and crystalline waterproofing which is applied to the CMU blocks. The face brick façade has weeping holes at its base to drain accumulated water. The roof and foundation both use a rubberized asphalt sheet membrane to prevent water infiltration. Ductwork and piping that has the potential to fall below the local dew point will have adequate preventative insulation.

5.16 Buildings with Attached Parking Garages

There is no attached parking garage to Hunter's Point South Intermediate School & High School. This section does not apply.

5.17 Air Classification and Recirculation

The majority of air in Hunter's Point South School is Class 1 air. Class 1 air is returned through the ceiling plenum and recirculated back to the rooftop AHU's where it can be reused or exhausted. Class 1 air is also used to supply the restrooms in the building. Class 2 air from the restrooms and locker rooms is ducted separately and exhausted on the roof. Grease hoods and laboratory hoods exhaust the Class 4 air through their own separate ducts and vents on the roof.

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

No ETS Areas exist in Hunter's Point South School. This section is irrelevant.

Section 6 – Procedures

The six air handling units used in Hunter's Point South Intermediate School & High School were tested to verify their compliance with ASHRAE Standard 62.1-2007 Section 6 Ventilation Rate Procedure. The individual AHU's service multiple floors which have a variety of spaces. Due to this it was beneficial to break up the zones into single rooms (or grouped rooms when multiple similar occupancy type rooms existed) when analyzing the minimum required ventilation needed. Below are the equations and tables used from ASHRAE Std. 62.1-2007 to complete the Section 6 analysis, along with their variable definitions.

Ventilation Rate Procedure

Breathing Zone Outdoor Airflow (V_{bz}):

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

Where:

V_{bz} = breathing zone outdoor airflow – the design outdoor airflow required in the breathing zone of the occupiable space or spaces in a zone

R_p = outdoor airflow rate required per person (cfm/person), determined from Table 6-1

P_z = zone population – the number of occupants in the space, this can be estimated based on the occupant density in Table 6-1

R_a = outdoor airflow rate required per unit area (cfm/ft^2), determined from Table 6-1

A_z = zone floor area (ft^2)

Zone Air Distribution Effectiveness (E_z):

$$E_z = \# \qquad \text{(From Table 6-2)}$$

Where:

E_z = 1 for ceiling supply of cool air.

All AHU's serve conditioned air to zones through ceiling diffusers. It was assumed that all interior spaces would only need cooling and exterior rooms' heating needs would be supplied by the fin tubed radiators. Therefore an E_z value of 1 was used for all rooms.

Zone Outdoor Airflow (V_{oz}):

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

Where:

V_{oz} = zone outdoor airflow, the outdoor airflow that must be provided to the zone by the supply air distribution system

Zone Primary Outdoor Air Fraction (Z_p):

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

Where:

V_{pz} = zone primary airflow, the primary airflow to the zone from the air handler including outdoor air and recirculated return air

System Ventilation Efficiency (E_v):

Use Table 6-3 to determine E_v, however if max Z_p is greater than 0.55 than Appendix A must be used to compute E_v.

Zone Ventilation Efficiency (E_{vz}) for Single Supply Systems:

$$E_{vz} = 1 + X_s - Z_d \qquad \text{(Eq. A-1)}$$

Where:

X_s = average outdoor air fraction at the primary air handler
$X_s = V_{ou}/V_{ps}$

V_{ou} = uncorrected outdoor air intake

V_{ps} = system primary airflow, the total primary airflow supplied to all zones served by the system from the air handling unit at which the outdoor air intake is located

Z_d = discharge outdoor air fraction

$Z_d = V_{oz}/V_{dz}$

V_{dz} = zone discharge airflow, the expected supply airflow to the zone that includes primary airflow and locally recirculated airflow

Uncorrected Outdoor Air Intake (V_{ou}):

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

Where:

D = occupant diversity

Occupant Diversity (D):

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

Where:

P_s = system population, the total population in the area served by the system

Outdoor Air Intake (V_{ot}):

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

Appendix A contains the excel spreadsheets of each air handler's results for minimum outdoor air intake using the above calculations for ventilation. For AHU's 4, 5, and 6, the minimum ventilation supplied to each room is contrasted against the design condition. The NYC Green Schools Guide requires all new schools, such as Hunter's Point South Intermediate School & High School, to be designed to use above 30% minimum ventilation air calculated in ASHRAE Standard 62.1. This is outlined in Q1.1R Minimum IAQ Performance/Increased Ventilation in the NYC Green Schools Guide. This is also a requirement for a LEED point that Hunter's Point South School is pursuing. Compliance with this increase has also been added to the analysis and can be seen in Table 4 on page 8.

Occupant density (from Table 6-1) was not used to determine the number of people per space because exact occupant numbers were given in the design. Some assumptions were made based on the occupancy type for rooms where no similar match could be found. These assumptions for occupancy type can be seen in the excel spreadsheets.

For VAV systems, V_{pz} is equal to the minimum turn down for the VAV box. Hs Special Education Room 517 (AHU-2) has a very low turndown for its VAV box. It is so low that the minimum outside air needed will not be met when it is turned down fully, even if supply air is 100% outside air. The Z_p and E_{vz} values calculated for it were disregarded because they created an unrealistic strain on the system's necessary ventilation. The VAV box can supply up to 660 cfm to Room 517. This cfm is more than sufficient for the minimum ventilation. This means that the damper on the VAV box will rarely ever be turned down low for this room, perhaps it will just be turned down during the night when there is no occupancy so as to save on energy costs.

Table 4 on page 8 contains the minimum outdoor air intakes and calculated V_{ot} for each AHU. Each AHU surpassed the corresponding calculated V_{ot}. However, AHU's 1 through 3 do not supply the above 30% minimum ventilation required for the LEED's point. This is fairly alarming considering the high priority given to meeting the standards set by the NYC Green Schools Guide and LEED's criteria. AHU's 1 through 3 are all VAV systems with VAV boxes. The minimum outside air intakes were all calculated with the VAV boxes turned down to their minimum supply position (worst case scenario). AHU's 1 through 3 do have the ability to supply up to 100% outside air. The ability to supply up to 100% outside air with the combination of a good controls system should allow AHU-1, AHU-2, and AHU-3 to meet the above 30% minimum ventilation.

Summary of Analysis for ASHRAE Standard 62.1-2007

Hunter's Point South Intermediate School & High School complied with all the requirements in Section 5. There was only one area that caused concern which was the smoke vent located in close proximity to AHU-2's intake. The requirements for minimum ventilation were greatly surpassed in Section 6 for all AHU's. Three of the AHU's even met the above 30% minimum ventilation for a LEED's credit; the other ones may too depending upon the control system logistics. Hunter's Point South was designed to meet the guidelines set forth by the New York City Green Schools Guide. This governing body has helped push the envelope for the efficiency and HVAC design in Hunter's Point South School.

ASHRAE Standard 90.1-2007 Analysis

Section 5 – Building Envelope

5.1.4 Climate Zone

From Figure B-1 and Table B-1 in ASHRAE Standard 90.1-2007 it was determined that Hunter's Point South Intermediate School & High School is located in climate zone 4A. This climate zone is named Mixed-Humid and has roughly 5,400 heating degree days or fewer.

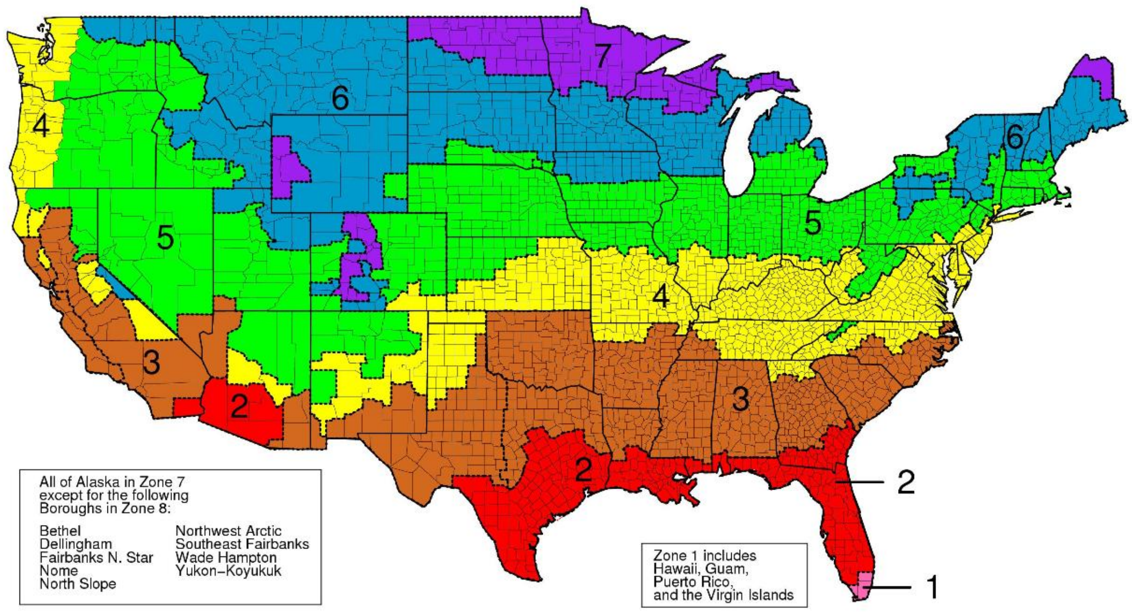


Figure 9 – Climate Regions in the United States

5.4 Mandatory Provisions

Hunter's Point South has two enclosed vestibules located directly across from each other on the north and south side. All the doors open inwards toward the vestibule and have self-closing devices. The closest doors are located roughly eight feet apart so the doors need not be opened at the same time.

5.5 Prescriptive Building Envelope Option

Hunter's Point South School has nonresidential conditioned spaces. Below in Table 20, the compliance for Hunter's Point South School's opaque elements is shown and tested against the corresponding U-values, C-values, and F-values. Fenestration is also shown in Table 20. Note that Hunter's Point South has no basement and thus no walls below grade. No skylights exist in Hunter's Point South either. The Insulated Translucent Sandwich Panel System (ITSPS) and typical windows have both been represented under fenestration. The total building glazing area is calculated and compared in Table 21.

Building Envelope Requirements for Zone 4A					
		Assembly Maximum	Insulation Min. R-Value	Hunter's Point	Standard 90.1-2007 Compliance?
Exterior Opaque Elements:					
Roofs - Insulation Entirely above Deck		U-0.048	R-20.0 c.i.	U-0.05	No
Walls, Above Grade Mass		U-0.104	R-9.5c.i.	U-0.056	Yes
Slab-On-Grade Floors - Unheated		F-0.73	NR	F-0.49	Yes
Fenestration:					
Vertical Glazing - Metal Framing					
	Typical Window	U-0.50	SHGC-0.4	U-0.30, SHGC-0.38	Yes
	ITSPS	U-0.50	SHGC-0.4	U-0.28, SHGC-0.23	Yes

Table 20 – Building Envelope Requirements

	Glazing Area (sf)	Façade Area (sf)	Percent Glazing	Standard 90.1-2007 Compliance?
Hunter's Point South School	16,978	70,080	24.2%	Yes

Table 21 – Vertical Fenestration Area

All exterior features of Hunter's Point South School complied with the maximum assembly values except for the roof, which barely missed compliance. The glazings used in the typical low e-coating windows and insulated translucent sandwich panel system (ITSPS) greatly surpassed the threshold needed. Since Hunter's Point School must follow the NYC Green Schools Guide, it is held too much higher constraints for energy efficiency than the ASHRAE Standard 90.1-2007 contains. The total glazing area of the façade is well under 40% of the building's exterior area. Though some facades are composed of mainly glazing, the all brick façades on the southeast corners balanced this out.

Section 6 – Heating, Ventilating, and Air-Conditioning

6.2 Compliance Path

Hunter's Point South Intermediate School & High School cannot use the Simplified Approach for HVAC Systems because it does not meet the requirements. The school is 153,769 square feet and five stories tall. This is much greater than the 25,000 square feet and two stories restraint needed for Section 6.3. The Mandatory Provisions method shall be used for Hunter's Point South School.

6.4 Mandatory Provisions

Minimum equipment efficiencies are met for the HVAC equipment in Hunter's Point South School. Below in Table 22 are a few examples of the equipment characteristics. The systems used in Hunter's Point South School must abide by the NYC Green School Guide, which is based off of ASHRAE requirements but contain more stringent goals. The values used in Table 3 were pulled from Table 6.8.1A through 6.8.1G in ASHRAE Standard 90.1-2007.

	Required Minimum Efficiency	Hunter's Point South School	ASHRAE 90.1-2007 Compliant?
Air Cooled Water Chiller (with condenser and electrically operated)	COP 2.8	COP 3.25	Yes
Gas-Fired Boiler (hot water)	75%	85.3-93%	Yes
Split Heat Pump (air cooled, cooling mode)	SEER 10.0	EER 13.8	Yes

Table 22 – System Efficiencies

Thermostats in each zone control the heating and cooling needs for the space. For rooms serviced by both VAV boxes and radiators or convectors, the two shall work integrally to control the room conditions. Spaces are maintained at a temperature of 72°F when occupied, with a cooling set point of 78°F and a heating set point of 65°F. Carbon dioxide sensors are used for demand controlled ventilation in the auditorium and gymnasium. All AHU's are equipped with air-side economizers to further save on energy costs. A night time setback temperature of 55°F (heating) or 86°F (cooling) is used so energy is not wasted conditioning the spaces at night.

Table 23 below shows the insulation needed for the different pipes. All ductwork requires 2" rigid fiberglass or flexible fiberglass insulation except for exposed ductwork (with 55°F duct temperature in cooling mode) in finished spaces that they serve and exhaust.

Pipe Insultion Thickness				
	Material	≤1.5"	2"-4"	>4"
Cold Water	Fiberglass	1.0	1.5	1.5
Hot Water	Fiberglass	1.0	2.0	2.0
Refrigerant (-32 to 0°F)	Fiberglass	1.5	2.0	2.0
Refrigerant (0 to 39°F)	Fiberglass	1.0	1.5	1.5

Table 23 – Pipe Insulation Thickness

All duct sealant and their adhesives comply with the South Coast Air Quality Management District (SCAQMD) Rule #1168 and the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA). This complies with ASHRAE Standard 90.1-2007.

6.5 Prescriptive Path

Dampers in the all the AHU's provide 0-100% modulation of outside air, exhaust air, and return air for economizer operation. The air-side economizers are run by dry bulb and relative humidity control of outside and return air dampers. The high-limit shutoff controls meet the requirements in Table 6.5.1.1.3B for the economizers.

The compliance with Table 6.5.3.1.1A Fan Power Limitations in ASHARAE Standard 90.1-2007 is shown below in Table 24. All fans in the AHU's have variable frequency drives. The majority of other fans in the building are centrifugal fans. Due to the controls in the building and spaces, every fan has the ability for variable volume control except FPB-1 and FPB-4, which service the Science Preparation Rooms. These two fans are constant air volume (CAV) due to the nature of the Science Preparation Rooms. These two rooms are used for instructors' to prepare chemicals for student use. They have very low occupancy needs but when in use the chemicals must be flushed out through the fume hoods. From values calculated, all fans comply except for the supply fans in each AHU.

Fan Power					
Unit	# of Fans	HP	CFM (each)	VAV (CFM x 0.0015)	Compliant with ASHRAE Standard 90.1-2007?
AHU-1	2	30	15000	22 1/2	No
	2	15	13500	20 1/4	Yes
AHU-2	2	30	15850	23 7/9	No
	2	15	13550	20 1/3	Yes
AHU-3	2	25	13500	20 1/4	No
	2	10	12150	18 2/9	Yes
AHU-4	1	20	10430	15 2/3	No
	1	7 1/2	9280	14	Yes
AHU-5	1	40	18700	28	No
	1	10	12300	18 4/9	Yes
AHU-6	1	20	9600	14 2/5	No
	1	10	9200	13 4/5	Yes
KE-1	1	1 1/2	3000	4 1/2	Yes
KE-2	1	5	7050	10 4/7	Yes
KE-3	1	1/4	320	1/2	Yes
EF-1	1	1.5	1300	2	Yes
EF-2	1	1.5	1300	2	Yes
EF-3	1	1/3	700	1	Yes
EF-4	1	1 1/2	1300	2	Yes
EF-5	1	3	5910	8 6/7	Yes

Fan Power					
Unit	# of Fans	HP	CFM (each)	VAV (CFM x 0.0015)	Compliant with ASHRAE Standard 90.1-2007?
EF-6	1	1/2	1060	1 3/5	Yes
EF-7	1	3/4	1440	2 1/6	Yes
EF-8	1	1/4	300	4/9	Yes
EF-9	1	1/6	400	3/5	Yes
EF-10	1	1/2	1310	2	Yes
EF-11	1	1/3	1000	1 1/2	Yes
EF-12	1	1/4	220	1/3	Yes
EF-13	1	1/4	650	1	Yes
EF-14	1	1/4	220	1/3	Yes
EF-15	1	1/4	220	1/3	Yes
EF-16	1	1/6	100	1/7	Yes
EF-17	1	1/6	150	2/9	Yes
EF-18	1	1/6	150	2/9	Yes
SF-1	1	1/4	850	1 2/7	Yes
FPB-2	1	1/3	560	5/6	Yes
FPB-3	1	1/3	925	1 2/5	Yes
				CAV (CFM x 0.0011)	
FPB-1	1	1/2	1200	1 1/3	Yes
FPB-4	1	1/2	1200	1 1/3	Yes

Table 24 – Fan Power

6.7 Submittals

A 100% Construction Document Submission was made to the NYC Green School Guide shortly after the start of construction to make sure the requirements of the guide were upheld in design. The New York City School Construction Authority (NYC SCA) has approved the building of Hunter's Point South School through design and system submissions. Hunter's Point South School is also design intended to be LEED Silver so an application for LEED certification will be submitted at completion. Commissioning shall take place at the completion of construction. Records of Hunter's Point South Intermediate School & High School shall be kept by the NYC SCA.

Section 7 – Service Water Heating

7.4 Mandatory Provisions

The four condensing gas fired boilers in the boiler room are used to condition spaces' thermal needs. They need not be reviewed in this section because they do not supply potable water; they supply a 35% propylene glycol – water mixture only for heating purposes. One gas fired water heater is used to supply domestic hot water to Hunter's Point South School. The water heater was specified to comply with all efficiency guidelines set up in ASHRAE Standard 90.1-2007. The water heater tank has insulation with a minimum value of R-13.4 and a designed E_t of no less than 81%. It complies with all requirements of Section 7.

7.5 Prescriptive Path

The gas fired water heater is not used to heat spaces. This section is irrelevant for it.

Section 8 – Power

Hunter's Point South School is governed by the 2005 National Electric Code (NEC). The feeder conductors' and branch circuit voltage drops that must be met in the NEC surpass the requirements set up in ASHRAE Standard 90.1-2007. Therefore, Hunter's Point South School is compliant with this section. Construction drawings contain the necessary single–line diagrams and locations/areas served for the electrical distribution systems. On completion, the needed manuals and maintenance manuals shall be provided to the building operators.

Section 9 – Lighting

9.2 Compliance Path

The Building Area Method has been chosen for analysis for Hunter's Point South School.

9.4 Mandatory Provisions

Occupancy sensors that control lighting have been installed in all classrooms and some offices for Hunter's Point South School. They are set to turn the room lighting off 15 minutes after no occupants have been detected. These sensors combined with room switches control the lights in the areas. Hunter's Point South School uses a lighting control system clock that automatically turns lights off/on based upon the schedule. A separate schedule is used for interior and exterior lights. The system has an eight year back-up and automatically adjusts for daylight savings.

9.5 Building Area Method Compliance Path

Exterior lights have been included in these calculations. For a school, the max lighting power density is 1.2 W/ft^2. Hunter's Point South School has a LPD of 0.844 W/ft^2 which is well below the mandated maximum. Below, Table 25 has the breakdown of the lighting fixtures and fixture wattage by floors which led to the calculated value.

Lighting Power Density								
Fixture	1st	2nd	3rd	4th	5th	Penthouse	W/fixture	Total W
A	1						100	100
C	2	2	2	2			25	200
TA	63	118	215	226	86		64	45312
TA-1		11	18		4		96	3168
TB	29				2		32	992
TB-1	15				3	9	32	864
TC	19	69	57	53	36		64	14976
TC-1	44	5	5	5	13		64	4608
TD		32					256	8192
TF	15	21	10	8			32	1728
TF-1	48	39	3	6	5		32	3232
TF-2	11	9	6	10	20		32	1792
TG	10						32	320
TL	53	12	5	34	14	21	64	8896
TL-1		24					32	768
TM				30			128	3840
TN			41	36			3	231
TR				29			100	2900
TS	50						36	1800
TT	22	17	11	3	93		64	9344
TU	5						26	130
TAA-1			6	4	9		50	950
TAA-2				4			50	200
TAB	12	15	20	20	14		64	5184
TAB-1	1	4			4		128	1152
TAC	2	1					64	192
TAC-1	1		2	2	2		32	224
TAD					17		64	1088
TAE					38		64	2432
TTB				3			100	300
TTH				8			575	4600
Exit Sign	15	7	12	10	9	1	2	108
							Total Watts =	129823
							Building Area =	153796
							W/SF =	0.844

Table 25 – Lighting Power Density

Section 10 – Other Equipment

Minimum efficiencies for electrical motors are defined in this section based upon their horsepower and revolutions per minute. Below in Table 26, the evaluation of the pumps in Hunter’s Point South School is shown. None of the pumps comply with the minimum efficiencies outlined in this section. The centrifugal fan motors are designed to meet the 2007 New York State Energy Conservation Construction Code and ASHRAE 90.1. All the centrifugal fans therefore meet or exceed the requirements.

Electric Motors					
Pumps	Efficiency	HP	RPM	Minimum Efficiency	ASHRAE Standard 90.1-2007 Compliance
P-1	74.8	20	1750	91	No
P-2	74.8	20	1750	91	No
P-3	74.8	20	1750	91	No
P-4	81.4	30	1750	92.4	No
P-5	81.4	30	1750	92.4	No
P-6	81.4	30	1750	92.4	No

Table 26 – Electric Motors

Summary of Analysis for ASHRAE Standard 90.1-2007

Overall Hunter’s Point South Intermediate School & High School did very well in its comparison to the requirements for ASHRAE Standard 90.1-2007. It passed all requirements except for the U-value for roof assembly; the supply fans in the AHU’s did not meet the fan power limitations, and the motor efficiency for the pumps. The U- and R-values for the building enclosure all far surpass the minimum standards. The glazing especially stands out and will greatly help save energy on the thermal loads induced on the building. The supply fans in the AHU’s may not comply with the fan power limitations but they do have variable frequency drives which will help save on fan energy. The majority of electric motors in the building do comply; it is only the pumps that fall short. The least efficient pump is only off by roughly 16% to meet efficiency.

It is no surprise Hunter’s Point South School did so well in this evaluation. The school was designed under the strict energy conscious standards set forth by the NYC Green Schools Guide.

LEED Rating System

The LEED rating system is not followed by Hunter's Point South School. This is because it follows the New York City Green School Guide. This guide is outlined very similar to LEED and is required for new schools in New York City. The attempt is to make these school houses more sustainable and green. Thus, Hunter's Point South School is very environmentally conscious but will not strive for any LEED status or even certification.

The NYC Green School Guide is based very much on the USGBC's LEED rating system. Many of the points for both systems overlap. Because of this, the analysis of the LEED rating system was still done and is outlined below for the mechanical systems of Hunter's Point South School.

Energy & Atmosphere

EA Prerequisite 1: Fundamental Commissioning of the Building

(Required)

Intent – Verify that the building's energy related systems are installed, calibrated and perform according to the owner's project requirements, basic of design, and construction documents.

Execution – Upon completion of work, a test shall be conducted in the presence and under direction of a licensed professional engineer or registered architect (retained by the contractor) who is qualified to run such tests. These tests shall show compliance with the code requirements for ventilation and proper operation of the HVAC devices.

EA Prerequisite 2: Minimum Energy Performance

(Required)

Intent – Establish the minimum level of energy efficiency for the proposed building and systems.

Execution – Hunter's Point South School complies with Sections 5.4, 6.4, 7.4, 8.4, 9.4, and 10.4 of ASHRAE Standard 90.1-2007 and from the building model ran by the design engineers there is a 28.3% reduction in yearly energy cost from the baseline building of ASHRAE Standard 90.1-2007 Appendix G.

EA Prerequisite 3: Fundamental Refrigerant Management

(Required)

Intent – Reduce ozone depletion.

Execution – No CFC-based refrigerants are used. The chillers and heat pumps use R-410a as a refrigerant.

EA Credit 1: Optimize Energy Performance

(6 of 10 Points)

Intent – Achieve increasing levels of energy performance above the baseline in the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use.

Execution – Following Appendix G of ASHRAE Standard 90.1-2007, Hunter’s Point South School will save 28.3% in yearly energy cost over the base building. Since Hunter’s Point South School is a new building it has stricter requirements and will only receive 6 out of the possible 10 points.

EA Credit 2: On-Site Renewable Energy

(0 of 3 Points)

Intent – Encourage and recognize increasing levels of on-site renewable energy self-supply in order to reduce environmental and economic impacts associated with fossil fuel energy use.

Execution – No energy is generated from on-site renewable energy sources.

EA Credit 3: Enhanced Commissioning

(0 of 1 Point)

Intent – Begin the commissioning process early during the design process and execute additional activities after systems performance verification is completed.

Execution – The commissioning for Hunter’s Point South School does not begin until the construction phase. No input is gathered from the commissioners during the design phase.

EA Credit 4: Enhanced Refrigerant Management

(1 of 1 Point)

Intent – Reduce ozone depletion and support early compliance with the Montreal Protocol while minimizing direct contributions to global warming.

Execution – Following Option 2, a value of 44.4 was calculated for the weighted average atmospheric impact due to the chillers and heat pumps. This is lower than the bar set at 100 by LEED and therefore complies.

EA Credit 5: Measurement & Verification

(0 of 1 Point)

Intent – Provide for the ongoing accountability of building energy consumption over time.

Execution – No plans could be found to outline such a program being set forth.

EA Credit 6: Green Power

(1 of 1 Point)

Intent – Encourage the development and use of grid-source, renewable energy technologies on a net zero pollution basis.

Execution – Hunter's Point South will use 360,703 kWh per year of allocated green power for 2 years. This is above the 35% building's electricity from renewable sources required by this credit.

Indoor Environmental Quality

EQ Prerequisite 1: Minimum IAQ Performance

(Required)

Intent – Establish minimum indoor air quality (IAQ) performance to enhance indoor air quality in buildings, thus contributing to the comfort and well-being of the occupants.

Execution – Hunter's Point South School follows both ASHRAE Standard 62.1 Section 6 and the New York City Mechanical Code for minimum ventilation.

EQ Prerequisite 2: Environmental Tobacco Smoke (ETS) Control

(Required)

Intent – Minimize exposure of building occupants, indoor surfaces, and ventilation air distribution system to Environmental Tobacco Smoke (ETS).

Execution – No smoking is allowed in Hunter's Point South School and smoking areas outside of the building are located far enough away as to comply with this prerequisite.

EQ Credit 1: Outdoor Air Delivery Monitoring

(1 of 1 Point)

Intent – Provide capacity for ventilation system monitoring to help sustain occupant comfort and well-being.

Execution – CO_2 sensors are located in spaces of high occupancy. VAV boxes are controlled to distribute at least the minimum amount of outside air required. This credit is attainable.

EQ Credit 2: Increased Ventilation

(0 of 1 Point)

Intent – Provide additional outdoor air ventilation to improve indoor air quality for improved occupant comfort, well-being and productivity.

Execution – From technical report one, all constant air volume AHU's meet the above 30% minimum rates. However, the variable air volume AHU's do not meet this requirement. This credit is not attainable unless the minimum supplied fraction on the VAV boxes is ramped up.

EQ Credit 3.1: Construction IAQ Management Plan: During Construction

(1 of 1 Point)

Intent – Reduce indoor air quality problems resulting from the construction/renovation process in order to help sustain the comfort and well-being of construction workers and building occupants.

Execution – The construction methods comply with the SMACNA (Sheet Metal and Air Conditioning National Contractors Association) and filters are required to have a MERV of 8 during construction for return air grilles.

EQ Credit 3.2: Construction IAQ Management Plan: Before Occupancy

(1 of 1 Point)

Intent – Reduce indoor air quality problems resulting from the construction/renovation process in order to help sustain the comfort and well-being of construction workers and building occupants.

Execution – Through Option 1, a flush-out of Hunter's Point South School will occur prior to occupancy. It is up to the owner to determine which type of flush-out to use.

EQ Credit 4.1: Low-Emitting Materials: Adhesives & Sealants

(1 of 1 Point)

Intent – Reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

Execution – Adhesives and sealants used fall below the VOC limits outlined in this credit. Hunter's Point South School was designed with low VOC emission in mind.

EQ Credit 4.2: Low-Emitting Materials: Paints & Coatings

(1 of 1 Point)

Intent – Reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

Execution – Paints and coatings used fall below the VOC limits outlined in this credit.

EQ Credit 4.3: Low-Emitting Materials: Carpet Systems

(1 of 1 Point)

Intent – Reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

Execution – Carpets installed meet the necessary requirements and adhesives used fall below the VOC limits outlined.

EQ Credit 4.4: Low-Emitting Materials: Composite Wood & Agrifiber Products

(1 of 1 Point)

Intent – Reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

Execution – Composite wood and agrifiber products do not use any urea-formaldehyde resins. This credit is attainable.

EQ Credit 5: Indoor Chemical & Pollutant Source Control

(1 of 1 Point)

Intent – Minimize exposure of building occupants to potentially hazardous particulates and chemical pollutants.

Execution – Vestibules are used at all the main entrances to Hunter's Point South School which have dimensions greater than six feet in the direction of travel. Fume hoods are used to control any pollutant sources created in the laboratories.

EQ Credit 6.1: Controllability of Systems: Lighting

(1 of 1 Point)

Intent – Provide a high level of lighting system control by individual occupants or by specific groups in multi-occupant spaces (i.e. classrooms or conference areas) to promote the productivity, comfort and well-being of building occupants.

Execution – Over 90% of the lights in Hunter's Point South School are controllable by building occupants. Thereby this credit is attainable.

EQ Credit 6.2: Controllability of Systems: Thermal Comfort

(1 of 1 Point)

Intent – Provide a high level of thermal comfort system control by individual occupants or by specific groups in multi-occupant spaces (i.e. classrooms or conference areas) to promote the productivity, comfort and well-being of building occupants.

Execution – Operable windows and accessible thermostats are provided in the majority of rooms. VAV boxes specifically serve one space each for better comfort control.

EQ Credit 7.1: Thermal Comfort: Design

(1 of 1 Point)

Intent – Provide a comfortable thermal environment that supports the productivity and well-being of building occupants.

Execution – The HVAC systems and building envelope of Hunter's Point South Building were designed to meet ASHRAE Standard 55. This credit shall be earned.

EQ Credit 7.2: Thermal Comfort: Verification

(0 of 1 Point)

Intent – Provide for the assessment of building thermal comfort over time.

Execution – Verification of thermal comfort is not needed in the NYC Green School Guide. Therefore there this credit will not be obtained.

EQ Credit 8.1: Daylight & Views: Daylight 75% of Spaces

(1 of 1 Point)

Intent – Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.

Execution – Through the calculation of Option 1, Hunter's Point South School will obtain this credit.

EQ Credit 8.2: Daylight & Views: Daylight 90% of Spaces

(1 of 1 Point)

Intent – Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.

Execution – The majority of rooms in Hunter's Point South School are located along the exterior and thus have direct views outside. The rooms congregated in the middle of the school that don't have views are generally unoccupied rooms or rooms of short occupancy duration. Because of this, Hunter's Point South School has views in at least 90% of all regularly occupied spaces.

Overall Mechanical System Evaluation

The mechanical system for Hunter's Point South School meets the requirements outlined for design. The total mechanical system cost was $7,750,000 which is approximately $50.40 per square foot. Two of the biggest cost factors were the ductwork and custom made air handling units. Operating the building would cost $371,943 a year or $2.43 a square foot. Space was saved by placing the mechanical equipment on the roof but extensive ductwork was still required. A total of 1,681 square feet were lost to the mechanical system, the most of it being shafts for ducting from floor to floor.

The variable and constant flow AHU's meet the ventilation requirements outlined in ASHRAE Standard 62.1. The VAV terminal boxes further help to save energy costs, however at times of full turndown ventilation requirements may not be met. Since the ductwork and AHU's consume such a huge percent of the total mechanical system cost, perhaps a hydronic system with a dedicated outside air system could be used instead. This would use smaller ductwork and ventilation requirements would be more easily met. In using smaller ducts, floor area would be saved because the vertical shafts would not need to be as big.

The evaluation for maintenance for the mechanical systems is mixed. Huge clearances are given around the AHU's as well as access doors. Chillers are easily reachable on the roof. All proponents of the system are very accessible but no elevator goes up to the mechanical penthouse or roof. Replacement of larger parts would be difficult. The only way to access the chillers, AHU's, boilers, and generator is by using the stairs.

Fume hoods do an excellent job to remove hazardous chemicals from the laboratories and science classrooms. However this energy is wasted. No heat recovery is used in Hunter's Point South School for any of the exhaust fans. Recovering exhausted heat can help save building energy costs.

Moving forward, the mechanical system designed for Hunter's Point South School is very good but not flawless. Heat recovery is not present at all. The use of roof space for mechanical equipment saves usable floor space but the use of a 100% outside air system with hydronic heating and cooling could potentially save more floor space. From reviewing the construction site, a large body of water is nearby but it is probably not close enough to be used effectively for geothermal. Looking forward there are a few promising leads to improve the efficiency of the mechanical systems of Hunter's Point South School.

Proposal

Alternatives Considered

Several alternatives were considered to improve the efficiency and operating costs of the mechanical systems in place in Hunter's Point South School. These alternatives are described more in depth below.

Geothermal Heat Pumps

Geothermal heat pumps use the Earth's constant temperature for heating or cooling purposes. No combustion is needed and it has a relatively long life. Geothermal is an excellent design idea and once the initial costs are paid off, the costs for heating or cooling is a fraction of the original. The implementation of a geothermal heat pump was a favored topic to use but due to the nature of the site it is not feasible.

Geothermal closed-loop systems require extensive excavating for the piping to be placed. Excavating for Hunter's Point South School is very costly and the footprint of the building is not big enough to support the number of wells needed. Also, since Hunter's Point South School is located in the city, sewage lines and electrical wires could run right under the building. Open-loop systems could not be used either because no body of water is located close enough to the schoolhouse.

Reheat Recovery on Fume Hoods

No heat recovery has been used for the fume hoods. Using wrap around heat pipes and using the exhaust to precondition the supply air would be a quick fix and simple solution. This idea was highly considered but ultimately due to the sporadic use of the fume hoods and fear of corrosive properties from the chemicals exhausted, it was abandoned.

Chilled Beam System

Chilled beam systems are an up and coming technology in the U.S. They can be used for both heating and cooling purposes and are traditionally coupled with dedicated outdoor air systems to supply a reduced amount of air to spaces. Chilled beams have the potential to have a huge cost savings when combined with dedicated outdoor air systems. However, the use of chilled beam systems is very limited in the U.S. Owners are skeptical if they run properly. Since chilled beam systems have a cooling coil in the unit, people worry about water condensing on the coil and it "raining" in the space. When properly designed this should not happen but still many owners are skeptical in the U.S. so topic has been avoided.

Cooling Tower

The two chillers located on the roof of Hunter's Point South School are air-cooled. A possible investigation into whether water cooled chillers would be more efficient would be a great thesis topic. This would include designing a cooling tower and comparing the savings on compressor energy while having to pay for makeup water versus the current air-cooled chillers. This idea alone would not be enough and seems to be a stand-alone consideration. This was considered but a more encompassing idea was preferred.

Mechanical Proposal

After looking through all the alternatives and some new ideas, the following changes were proposed to the design of Hunter's Point South School.

Dedicated Outdoor Air System (DOAS)

A dedicated outdoor air system will be used for ventilation air instead of AHU's 1, 2, and 3. To receive a point in the New York City Green Schools Guide, Hunter's Point South should supply above 30% outside air according to ASHRAE Standard 62.1. The CAV systems do meet this requirement but the existing VAV system is problematic at times when the VAV boxes are fully turned down.

The use of a DOAS is a simple solution to meet the ventilation needs. The air supplied by the DOAS will be constant and sized to 30% of the minimum ventilation standard in ASHRAE Std. 62.1. This will insure that Hunter's Point South will receive the Q1.1R Minimum IAQ Performance/Increased Ventilation credit.

Another goal of using a DOAS, is that it will reduce the amount of ductwork needed in the building. The ductwork was the biggest mechanical cost (excluding emergency generator/fuel oil) and can be seen in Table 18 on page 17. Less ductwork will save on costs and should increase the usable floor space by restricting the size of the floor to floor duct chases and runs.

The AHU's currently used by Hunter's Point South School are the third biggest cost (seen above in Table 18). A single DOAS can potentially replace AHU's 1, 2, and 3. This will result in a smaller system and more roof space. It will also lower the cost of the system and make the operating system much simpler. Since all return air from spaces will be exhausted, the use of a total energy recovery wheel will be beneficial so energy is not "thrown away".

Total Energy Recovery Wheel

ASHRAE Standard 90.1 requires any mechanical system that uses 100% outside air to have some form of energy recovery. Currently, no heat recovery is used in the mechanical design for Hunter's Point South School. A total energy recovery wheel would be able to transfer sensible and latent properties from the exhausted air of the DOAS to the incoming outdoor air. This will bring the outside air closer to the supply air conditions and would greatly lower energy costs. The dehumidification wrap around coils used in the original VAV AHU's would not be needed in the DOAS because of the wheel. A purge section in the wheels would help ensure no cross contamination from the exhaust to the incoming outdoor air. In case there ever is a discharge of chemicals in a lab room to the regular exhaust, this purge section can transfer energy to the incoming outdoor air without spreading contaminants. Below, Figure 10 shows a how a purge section is used with a wheel.

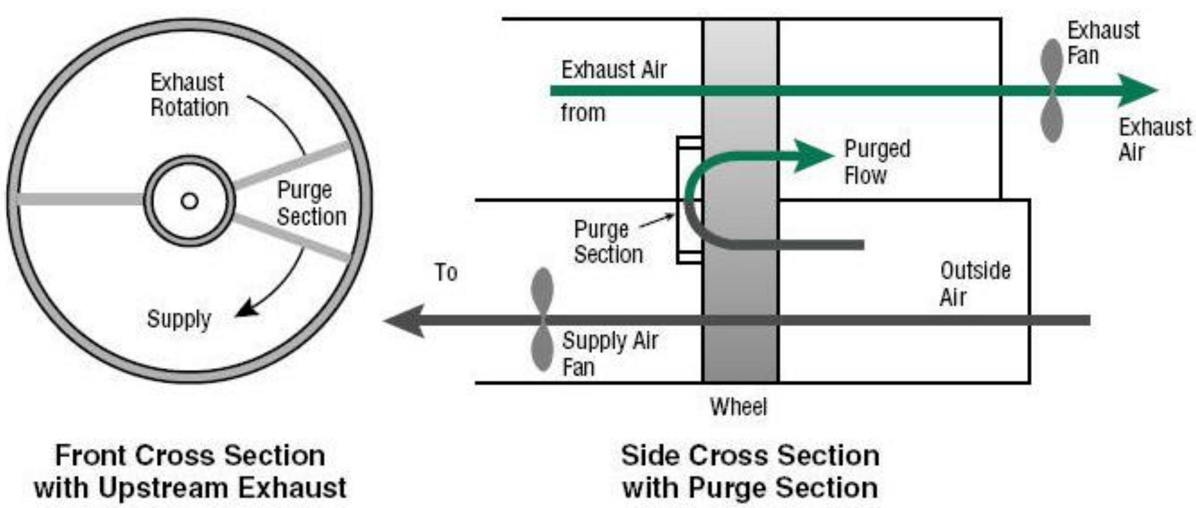


Figure 10 –Total Energy Recovery Wheel with Purge Section

Fan-Powered Induction Units (FPIU)

The classrooms, offices, lab rooms, corridors, and non-public spaces are served by the VAV AHU's 1, 2, and 3 which have VAV boxes as the terminal units. These spaces require the most cost to condition. VAV's systems are well suited to help lower energy costs but as explained before, they are problematic in reaching the minimum ventilation requirements when fully turned down. Using fan-powered induction units would work well in place of the VAV boxes. FPIU's have a dedicated outdoor air supply so minimum ventilation can always be met. Since only minimum outside air is ducted to the rooms, duct sizes will be dramatically reduced. Additional air is recirculated from the plenum and mixed with the outside air. The FPIU's allow for easy control of temperatures in spaces since both a cooling coil and heating coil can be placed in the unit. This increases the comfort level for occupants in space and allows for turn down when the space isn't occupied. Each different space is more easily controlled to exactly the thermal needs it has. It is important to mention that the FPIU's have drip pans under the cooling coils incase air would condense. This is will prevent the internal "rain" that makes owner's wary of chilled beams. Also, the chilled water supplied to these cooling coils will be of a much higher temperature so no condensing will occur.

Though duct sizes may be reduced, piping will have to be provided to the FPIU's for cooling and heating coils. This will increase piping costs but hopefully not enough to overcome the savings from the smaller ducts. Using fan-powered induction units will hopefully help save on energy costs while allowing for an increase in thermal comfort. Below in Figure 11 is a picture of the Krueger KLPS-D FPIU (the one chosen to be used). Note that an optional MERV 8 Filter can be put on the recirculated plenum air. Adding this filter, will allow for the addition of a LEED point.

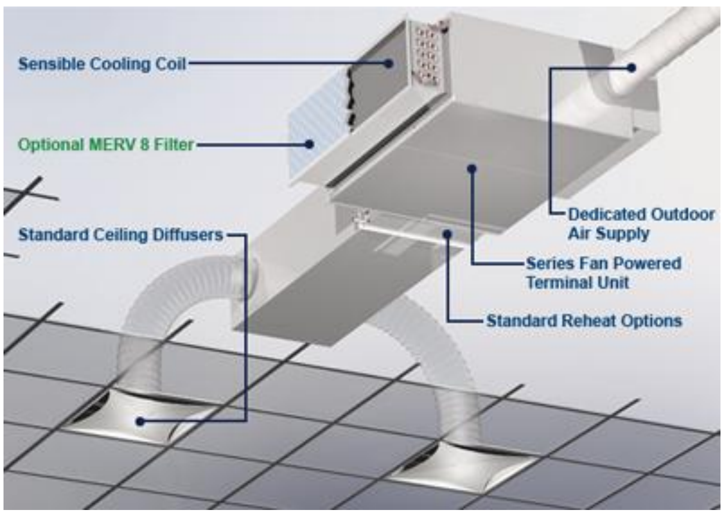


Figure 11 – Fan-Powered Induction Unit

Chilled Water System

Since fan powered induction units will be used as the new terminal device, the sensible loads for each space will be met at the zone through recirculated plenum air. The plenum air will run through a cooling coil above the served spaces. A new chilled water system will have to be designed to supply chilled water at a high enough temperature so that air will not condense on the cooling coils and cause mold or water damage above the served spaces. A drip pan is included in the FPIU's but this should be used as a last line of defense. A chiller system supplying two different temperature chilled waters should suffice, meaning atleast two different chillers with two different chilled water loops. The AHU's and DOAS will be supplied with the current 44°F propylene glycol – water mixture while a new chiller will supply the FPIU's cooling coils with a higher temperature propylene glycol – water mixture, which is high enough to ensure no condensation.

Benefits of the Proposed Design

Indoor air quality should be greatly increased through the proposed mechanical redesign. The correct amount of outside air used in the spaces will always be met and the thermal comfort of the rooms shall be easier to control. Free up of the rooftop space will allow for an area for photovoltaic solar panels to be installed. Finally the integration of a total energy recovery wheel and FPIU's should increase efficiency and lower economic costs.

Breadth Topics

Solar Photovoltaic Panels (Electrical Breadth)

Through all the proposed mechanical changes, extra space will be created on the roof. Figure 12 on the next page shows the proposed open area. This open area on the roof is south facing, making it a great source for solar power generation. A parapet currently exists all along the roof. The parapet can be reduced in size along the southern walls to allow for sun light to reach the panels. Though the space is not enough to generate a large chunk of Hunter's Point South School's electricity needs, solar photovoltaic panels can cut cost and have a reasonable payback time with the current rebates in New York. In the long run, the solar panels will offset enough electricity costs to make money for the school. Energy generated from these panels is also clean and will not pollute the environment. This will further add to the schools sustainable footprint. The design and integration of tying a solar system into the existing electrical system of Hunter's Point South School shall be included in this breadth. The sizing of the inverter(s) and breaker(s) will be calculated as well as the feeders. An economic analysis on the payback period and energy generated by the panels shall also be performed.

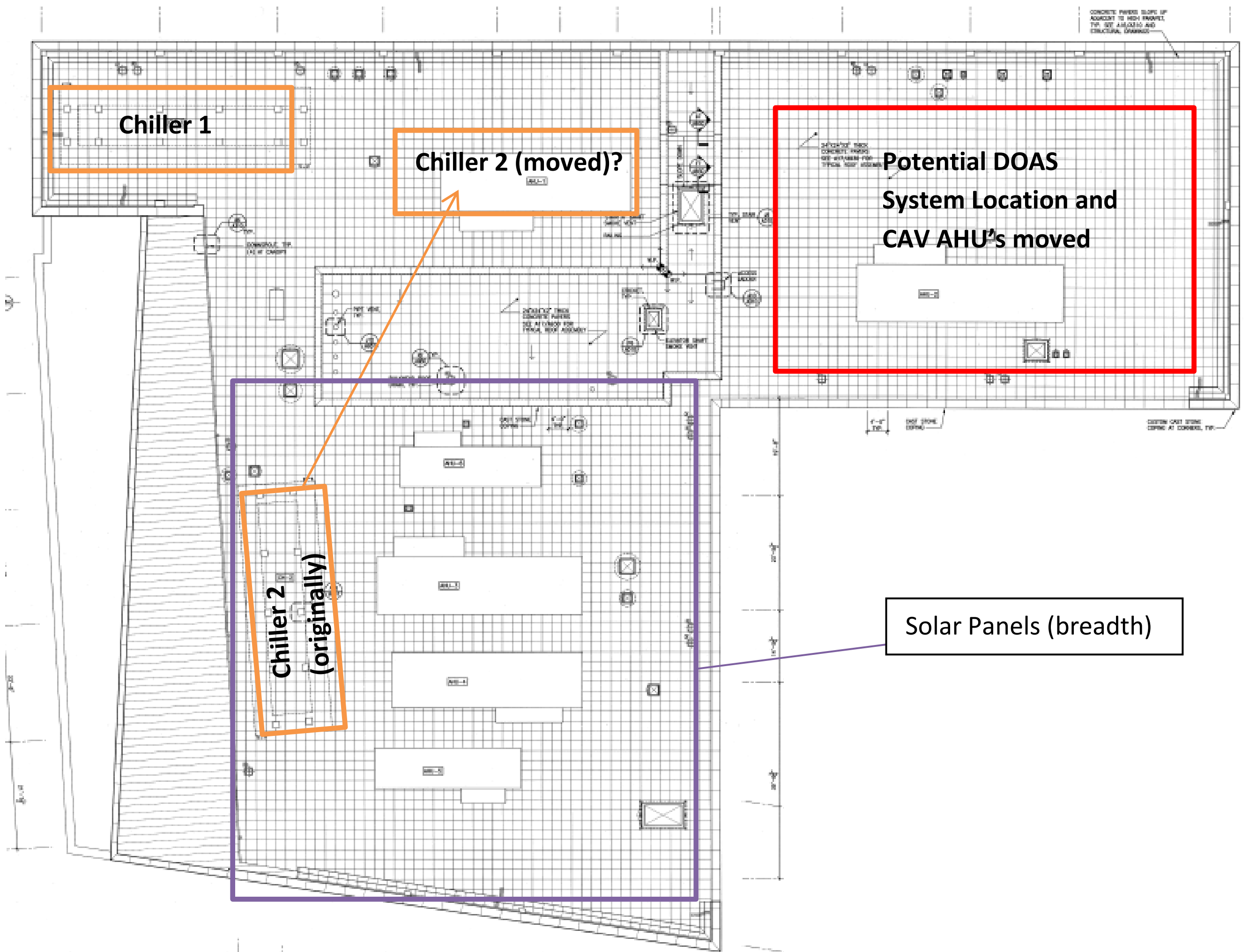


Figure 12 – Proposed Roof Layout

Analysis of the Roof System (Structural Breadth)

With all the moving around of AHU's, chillers, and adding solar photovoltaic panels, an analysis of the roof of Hunter's Point South School is in order. Whenever solar photovoltaic panels are installed on a roof, a structural analysis must first be performed. The analysis set up will test whether the existing roof system for the schoolhouse can support all these changes. The roof deck, beams, girders, and columns that have increased loads on them due to the adding/moving around of equipment will be tested. Calculations for strength and deflection will be performed by hand and if the structure fails, a new one that can hold the loads will be specified.

MAE Course Relation

Since the terminal units are being changed, it is necessary to make sure that the air in spaces is still well circulated. With the information gained in AE 559 Computational Fluid Dynamics, a study may be conducted into how well air is supplied and mixed within the rooms through the FPIU's. This shall show if any dead zones/drafts may exist and give a better picture of how thermally comfortable the spaces will be to occupants. The air distribution and circulation of the new fan powered induction units will be compared against the old VAV box systems.

Tools for Analysis

Below is a list of a few programs that shall be used for the integration of the above proposed designs.

Trane TRACE 700

This program will be used to run load calculations on spaces so the FPIU's can be sized properly as well as the DOAS system. An energy analysis will also be performed using TRACE to see the feasibility and life cycle costs of these systems.

Engineering Equation Solver (EES)

EES is an advanced equation solving software. Coupled with excel, problems not easily solved by hand can be made much quicker.

AutoCAD

AutoCAD can be used to take measurements and areas for the different rooms. It is also an excellent tool to use to draw diagrams for the systems and outline proposed piping/duct layouts.

Codes and Standards

Codes and standards for design as well as safe practice will need to be investigated throughout the redesign work. Compliance with the 2007 New York State Mechanical Code, New York City Green Schools Guide, and ASHRAE Standards 62.1 and 90.1 will be checked periodically.

Mechanical Depth

DOAS Sizing

The first step in sizing the DOAS units was to calculate the amount of ventilation air needed for each space supplied by the DOAS. Since Hunter's Point South School is located in New York City, it must follow the New York City Mechanical Code. The school also abides by the guidelines set up in the New York City Green Schools Guide. The Q1.1R Minimum IAQ Performance/Increased Ventilation point that Hunter's Point South is striving to receive requires above 30% minimum ventilation as calculated in ASHRAE Standard 62.1 Section 6. Therefore, the amount of outside air needed to be supplied to each room is determined by the highest constraint between the NYC Mechanical Code, NYC Green Schools Guide, and the latent load for the space. The latent load for each space was determined using the equation:

$$Q_{latent} = 0.69 \times CFM \times \Delta w$$

Q_{latent}: The latent load in the space (Btu/hr).

CFM: The outside air (cubic feet per minute) supplied to the room. Only the ventilation air to the room is used here because the DOAS does the entire latent load for each space served.

Δw: The difference in the room humidity ratio to the supply humidity ratio (grains of moisture per pound of dry air).

The room set point for Hunter's Point South School is 75°F and 50% relative humidity. This gives a value of 65 grains/lb in each room. Outside air with a lower grains/lb will be needed to be supplied to each room to offset the latent load generated by the occupants. A supply grains/lb of 45 was chosen for the outside air. This would generate a Δw of 20. The latent load given off by occupants was found in the 2009 ASHRAE Fundamentals Handbook on page 18.4. 250 and 200 Btu/hr was used for walking and sitting occupants, respectively. No appliances in any of the spaces served by the DOAS gave off a latent load (so the latent load was only determined by occupants). Also, since the building is positively pressurized it was assumed no outside air leaks in which would further complicate the latent load calculations. Rearranging the above equation to solve for CFM gives:

$$CFM = Q_{latent} \div (0.69 \times \Delta w)$$

The calculation for latent load can be seen in Appendix D. The calculation for minimum ventilation air for the New York State Mechanical Code and for 30% above ASHRAE Standard 62.1 can be seen in Appendix E and C, respectively. Once all the ventilation needs were found, the largest was chosen as the amount of outside supply air to the space. This can be seen in Appendix F.

This led to a total outside air supply of 36,865 CFM for the DOAS. This is a 23% reduction in ventilation air and 58% reduction in air supplied to the terminal units supplying the rooms from the rooftop units.

The next process was determining the amount of exhaust air needed by the DOAS. Less air is needed to be exhaust than supplied to allow for building pressurization and exfiltration to occur. Since the building will be positively pressurized to the outside, approximately 0.025 CFM/SF-façade will be lost to exfiltration (so you can exhaust this much less). The locker rooms and bathrooms have their own dedicated exhaust system (8,410 CFM). This CFM exhausted by the dedicated exhaust system can be subtracted from the amount of CFM needed to be exhausted by the DOAS. The total amount of air exhausted will then be:

$$36{,}865\ \text{CFM} - \left(0.025\frac{\text{CFM}}{\text{SF Facade}} \times 70{,}515\ \text{SF Facade}\right) - 8{,}410\ \text{CFM} = 26{,}292\ \text{CFM}$$

This means that the DOAS will have to exhaust 26,292 CFM to keep building pressurization. Art classrooms require 0.7 cfm/sf exhaust according to Table 6-4 in ASHRAE Standard 62.1. This means that 105 Is Art and 552 Hs Art rooms will need to exhaust 762 and 736 cfm, respectively. Since the supply outside air cfm is much greater than these exhaust needs, exhausting the correct amount of air will not be a problem. Other rooms with minimum exhaust rates are shown below in Table 27.

Room Type	Minimum Exhaust Rates (cfm/sf)
Art Classrooms	0.70
Copy/Printing Rooms	0.50
Educational Science Laboratories	1.00
Janitor Closets	1.00
Dressing Rooms	0.25
Locker Rooms	0.50
Toilets - public	50 cfm/toilet

Table 27 – Minimum Exhaust Rates

The external static pressure (esp) for the fan in the DOAS had to be calculated next. Early in the process of laying out the new duct runs, it was determined that it would be better to use two

DOAS rather than one. This would allow for shorter duct runs and allow the system to run more smoothly (since you don't have all the rooms hooked up to one unit). DOAS 1 would be placed in AHU 3's current position and DOAS 2 would be placed in AHU 1's spot. This new arrangement can be seen in Figure 13 below. Note also, this means that the east roof will now be used as the area for solar panel installation although some exhaust runs may need to be moved. Table 28 below shows the restrictions on air velocity through the ducts based on noise criteria. Ducts were sized using these requirements along with a ductulator (duct calculator).

Run Type	Air Velocity (fpm)	Design RC (NC)
Riser	1700	25
Main	1500	25
Branch	1000	35
After FPIU	500	25
Diffuser	350	25
Return	425	25

Table 28 – FPM for Duct Runs

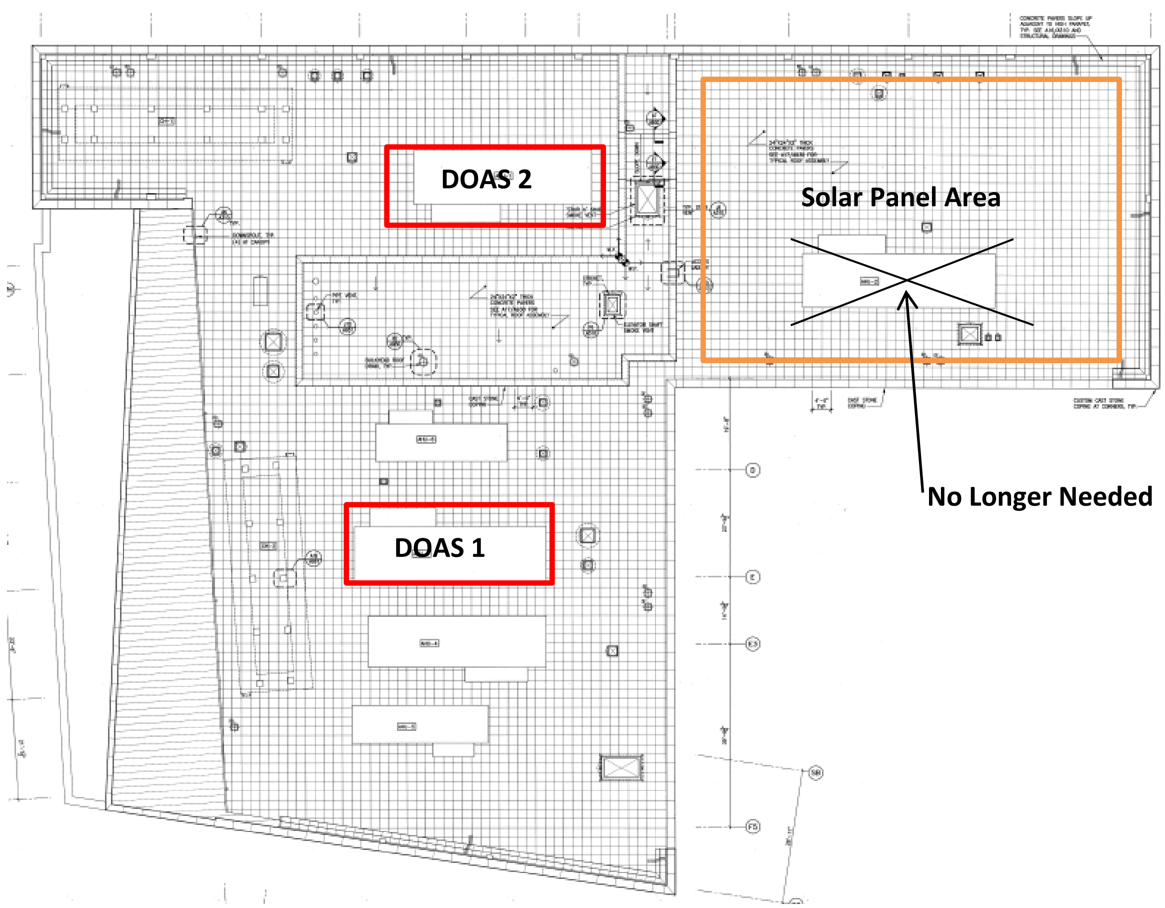


Figure 13 – DOAS 1 and DOAS 2 Positioning

The new Air Flow Diagrams can be seen below in Figure 14 for DOAS 1 and Figure 15 for DOAS 2.

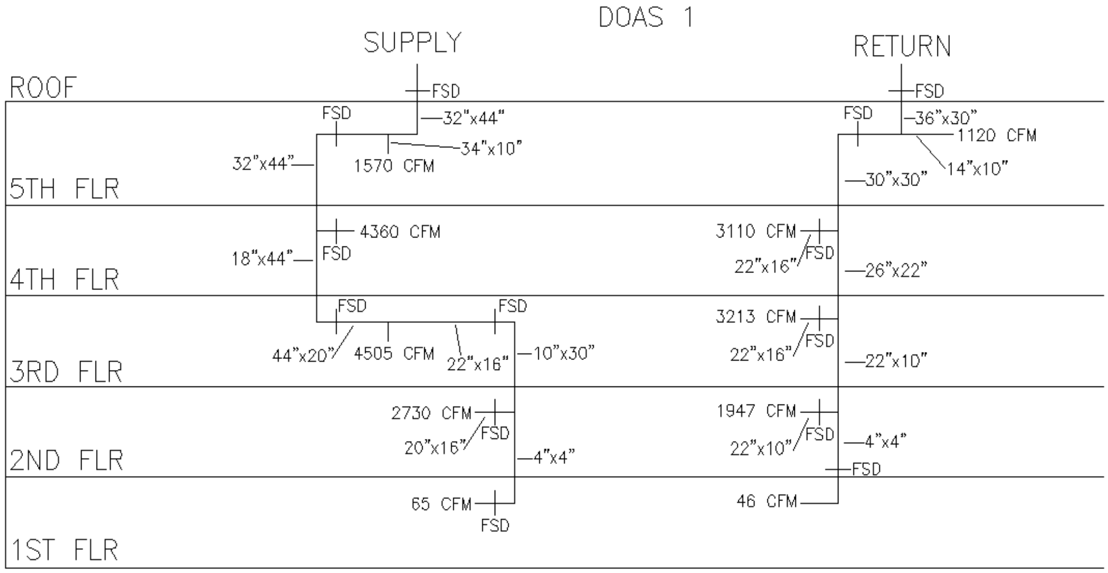


Figure 14 – Air Flow Diagram DOAS 1

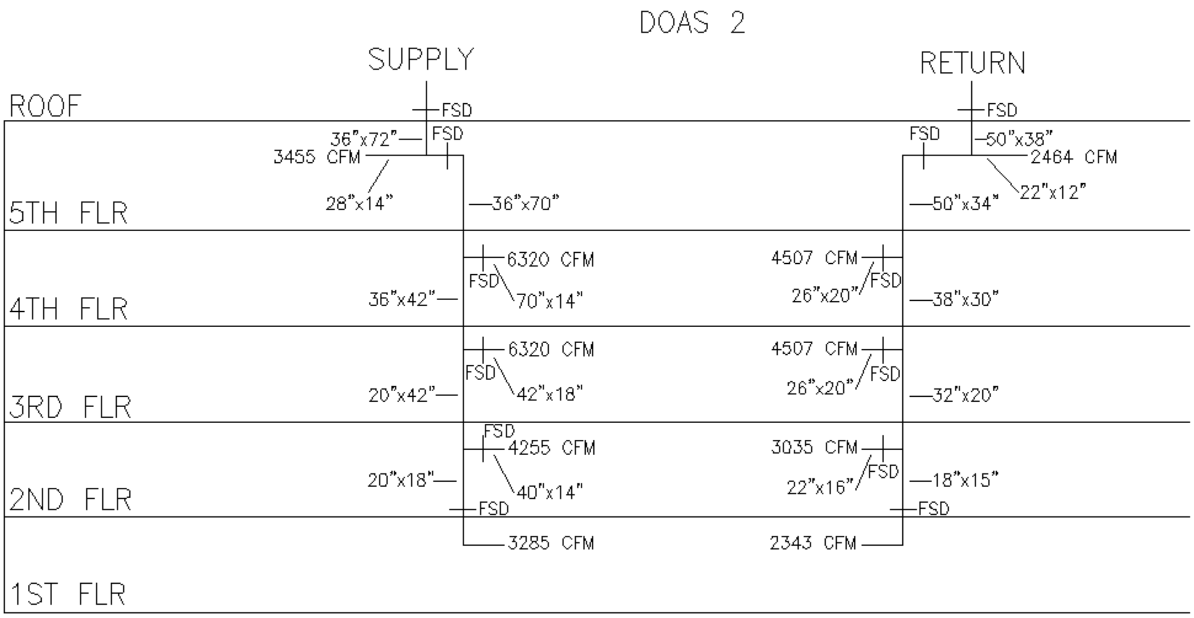


Figure 15 – Air Flow Diagram DOAS 2

The complete new duct layouts can be seen in Appendix G. The ducts are actually oversized due to an early error in oversizing the ventilation air needed for the two DOAS's. An oversizing of the ducts will cause the air to flow smoother through the ducts causing less noise so this early error is not a problem. Note that FSD refers to fire smoke damper in the layouts.

The fan external static pressure (esp) could then be calculated once all the new ducts had been laid out and sized. The fan esp is the pressure drop along the longest duct run from the discharge of the DOAS to the FPIU serving the room (no internal drops from the DOAS). The reason the esp is not calculated to the diffuser in this case is because the FPIU has a fan in it which can raise the pressure of the air to the space. The longest run for DOAS 1 was from the supply fan discharge to the library on the second floor. The longest run for DOAS 2 was from the supply fan discharge to the Vault W. Anteroom on the first floor. The return fans' longest run for both DOAS were from a return on the first floor up through the plenum to the return fan. Pressure drop in the duct runs occur due to friction losses and dynamic losses. The friction losses are the pressure drop associated with friction between the air and the duct. Friction loss is calculated by:

$$\Delta P_f = \text{Length of Run} \times \text{Friction Loss} \div 100$$

ΔP_f: Friction Loss (inches water gauge)

Length of Run: Distance of the duct run (feet)

Friction Loss: Pressure drop in inches water gauge per 100 feet of duct run

The dynamic losses are caused by bends, turns, and other impediments along the run. Dynamic loses are calculated by:

$$\Delta P_j = C \times P_v$$

ΔP_j: Dynamic Loss (inches water gauge)

C: Local loss coefficient (dimensionless)

P_v: Velocity pressure (inches water gauge)

The friction loss (inches water gauge per 100 feet of run) and velocity pressure were found using a ductulator. The local loss coefficient C was calculated using the charts at the end of chapter 21 in the 2009 ASHRAE Handbook of Fundamentals and interpolation/extrapolation. A list of all the pressure drops that occurred in the runs can be seen in Appendices H through K. Below in Table 29 is the esp calculated for each of the DOAS's supply and return fans.

	Fan External Static Pressure (inches water gauge)	
	DOAS 1	DOAS 2
Supply Fan	2.77	1.84
Return Fan	1.50	1.18

Table 29 – ESP Fans

With this last piece of information, the data was given to a manufacture at Havtech to size two DOAS units that could meet the following criteria seen below in Table 30.

	DOAS 1	DOAS 2
Supply Air (cfm):	13230	23635
Return Air (cfm):	9436	16856
OA design Conditions:		
Winter:	12.8 DB, -5.4 dew point	
Summer:	89.7 DB, 72 dew point	
Supply air conditions:		
Winter:	55 DB, 48 dew point	
Summer:	45 DB, dew point 45	
Room Setpoints:		
Winter:	72 DB, 30% rh	
Summer:	75 DB, 50% rh	
Supply Fan E.S.P.:	2.77	1.84
Return Fan E.S.P.:	1.5	1.18
Chilled Water Entering (F):	44.4	44.4
Chilled Water Leaving (F):	54	54
Hot Water Entering (F):	140	140
Hot Water Leaving (F):	120	120
Units outside:	Yes	Yes

Table 30 – DOAS Information

The specifications for the two DOAS units chosen can be seen in Appendices L and N as well as their physical dimensions in Appendices M and O. In this analysis, dehumidification wrap around heat pipes were considered but were advised against according to the manufacturer. A total energy wheel was chosen for both DOAS instead. More on this feature can be seen in the next section. An important point to notice is that both the new systems weigh less than the current systems that sit in their place. This is very helpful because it means a structural analysis will not be needed for these two units.

Total Energy Recovery Wheel

Once the conditions for the two DOAS units were found, the energy recovery wheel could be chosen. An energy recovery system of some type is required for air handlers using 100% outside air as supply. The energy recovery wheel was not only given consideration because of this guideline but also because the exhaust airflow has a lot of useful energy that can be utilized. Currently, Hunter's Point South School has no energy recovery devices for the air handlers. This is a bit strange considering it must abide by the New York City Green Schools Guide. An energy recovery wheel would be a great way to make the building more efficient because it could then recover both sensible and latent energy from the exhaust air stream. Recovering energy for both sensible and latent will allow for maximum savings. The wheel was placed in the typical spot for a preheat coil since in the winter it can do the job of the coil. It is usually a good idea to include a preheat coil even though the wheel will heat the air above the dew point of the cooling coil because the wheel could fail. For this report it was assumed the wheel would not break down. Also, adding a preheat coil with the wheel would create too great of a static pressure drop for the fan.

Below in Figure 16 is the energy recovery wheel in cooling mode at worst case scenario in the summer.

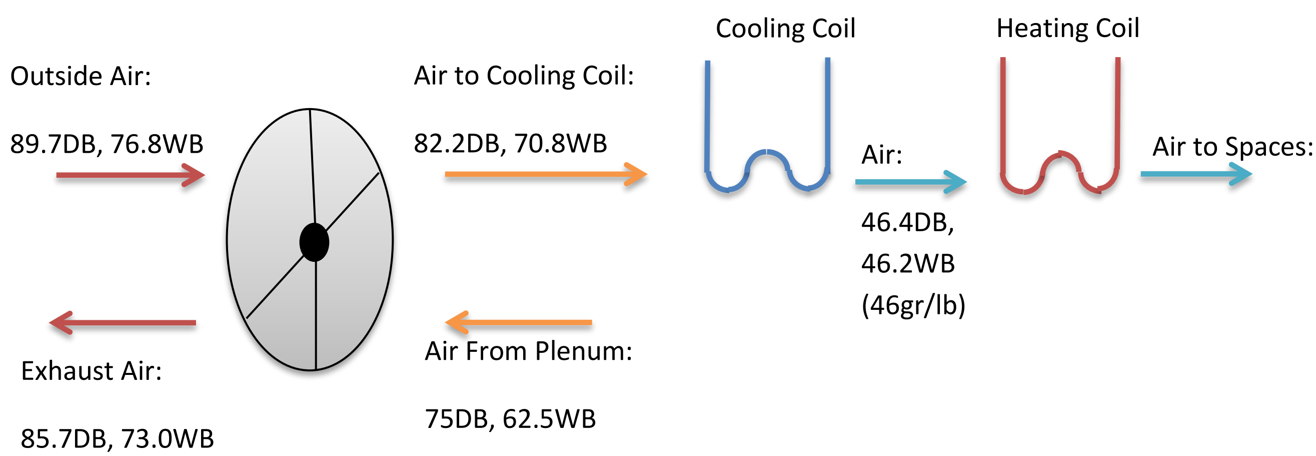


Figure 16 – Energy Recovery Wheel Cooling Mode

The cooling coil specified by the manufacturer can't actually get the supply air down to the correct gr/lb of 45 (can get down to roughly 46 gr/lb). This means that for a few days a year the space humidity may be a bit higher than the set point but it should still fall within the thermal comfort level specified in ASHRAE Std. 55. The other days of the year for cooling the gr/lb of the supply air will be 45 as designed. Note that an added heating coil is downstream of the cooling coil for temperature reset. Figure 17 is the energy recovery wheel in heating mode at worst case scenario in the winter.

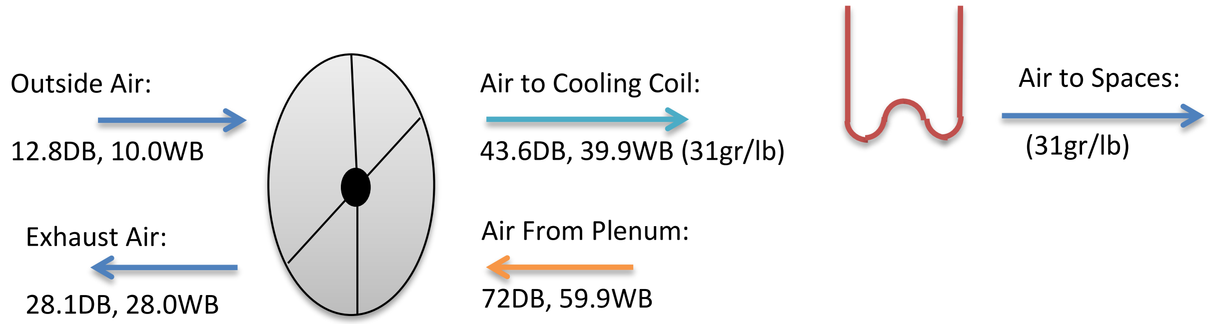


Figure 17 – Energy Recovery Wheel Heating Mode

The total energy recovery wheel does the majority of the heating of the air in the winter. The cooling coil is neglected from the above diagram because it is not needed since the latent load is met by the moisture of the outside air. In this scenario the heating coil will be used to bump up the supply air temperature to the lowest temperature required by the served spaces.

The effectiveness of the total energy recovery wheels can be seen below in Table 31 for the worst case summer and winter design days.

	Summer Worst Case				Winter Worst Case			
	Latent Effectiveness	Sensible Effectivness	Total Effectiveness	Total Energy Recovered (Btu/hr)	Latent Effectiveness	Sensible Effectivness	Total Effectiveness	Total Energy Recovered (Btu/hr)
DOAS 1	68.62%	75.30%	70.75%	345,881	70.81%	77.20%	74.55%	675,484
DOAS 2	68.67%	75.34%	70.80%	618,195	70.86%	77.24%	74.59%	1,207,247
			Total:	964,076			Total:	1,882,731

Table 31 – Effectiveness of Wheel

The biggest savings for the total energy recovery wheel is from heating. The wheels save a total of 14,817 therms of natural gas a year. This equates to an energy savings of $22,848. This is due to the fact that the wheels can do the complete heating of the OA during the winter. Electricity usage also decreases by 17,159 kWh per year, a savings of $3,260 a year. The wheel requires electricity to run but saves enough energy by displacing the energy needed to run pumps to serve the heating coils a typical AHU or DOAS would have. This gives a total savings of $26,108 a year for using total energy recovery wheels. The wheels cost (including labor/installation) $23,875 and $42,652, respectively for DOAS 1 and DOAS 2.

Fan Powered Induction Units

The chilled water supplied to the FPIU's cooling coils must be warm enough so that the return plenum air does not condense on them. The cooling coil's temperature can be assumed to be the same as the chilled propylene-glycol water mixture running through it. The summer and winter air conditions are 75°F and 72°F, respectively with 50% relative humidity. Since relative humidity readings can fluctuate +/- 5%, the worst case scenario will be plenum air in the summer. This worst case condition can have the air be 75°F DB with 55% relative humidity. The dew point for air at this condition can be seen below in Figure 18.

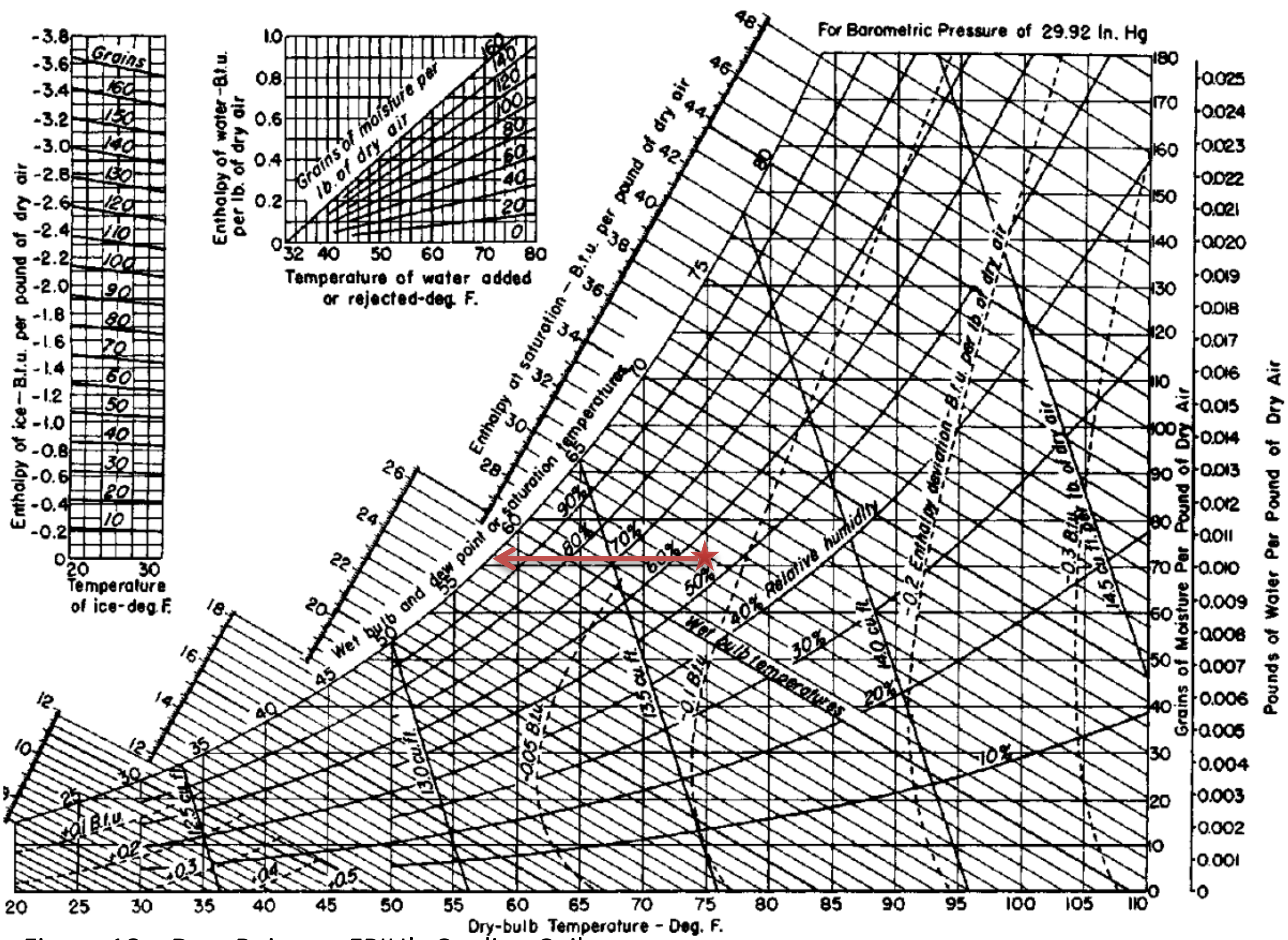


Figure 18 – Dew Point on FPIU's Cooling Coil

The star in the figure shows the 75°F DB with 55% relative humidity air. For this condition, the dew point of the air will be slightly lower that 58°F. This means that the CHW supply must not be any lower than 58°F or else the air may condense on the cooling coil. Since this is worst case scenario and the supplied CHW will heat up a bit due to friction, 58°F CHW supply from the chiller should prevent condensing on the coils.

Once the supply chilled water temperature was chosen, the cooling coils for each FPIU could be sized. The room peak sensible cooling loads were taken from TRACE. When the max cooling occurs in a room, the DOAS will be supply the room with 47°F air (46°F air comes off the coil so add one degree for friction). This primary air in conjunction with the recirculated cooled plenum air will take care of the room's sensible cooling. First the amount of cooling the primary air does for the space was calculated using:

$$Q_{sensible} = 1.1 \times CFM \times \Delta T$$

$Q_{senible}$: Cooling applied to space (Btu/hr)

CFM: Supply primary air to space

ΔT: Temperature difference of room and supply air. The max cooling will occur in the summer when the room set point is 75°F and the supply air is 47°F. This gives a ΔT equal to 28°F.

The excess cooling needed for each room and the cooling coil sizing can be seen in Appendix P. For spaces were a negative excess cooling value is shown, means that the space is overcooled. Therefore no cooling coil is needed. In fact, if a space is overcooled than a heating coil must be used. Since the fin tube radiators are being replaced by heating coils in the FPIU's, these heating coils can be used for this purpose.

Some rooms require further cooling than just the primary air. The coiling coil sizing for each room was based on the manufacture's specifications in Appendix Q (cooling coil size) for 75°F plenum air and 58°F entering 30% propylene glycol – water mixture. The coil sizing had to take into account the max deliverable fan CFM to the space as well as the primary air CFM. This can be seen in Table 32 below or Appendix R.

Unit Size	Max Primary CFM	Max Fan CFM	Dimensions		
			L	W	H
3	920	1100	40"	26"	11"
5	1430	1660	46"	36"	17"

Table 32 – FPIU's Fan CFM

Some spaces were able to share FPIU units. These spaces needed the same ventilation requirements as well as similar cooling needs. In general, each classroom received its own FPIU (sometimes two if the cooling load was too great for one). Spaces that were able to share FPIU's were generally very small interior offices (ex. 308, 308A, and 308B) or small offices along the same exterior wall (ex. 551A and 551B).

FPIU's have the ability to include heating coils. Since the fin tube radiators will be removed for the rooms, heating coils in the FPIU's will be used to heat the spaces. The calculation for the heating coil sizes can be seen in Appendix S. In sizing the heating coils, both the room loses (due to walls, windows, etc.) and the cooling done by the primary air flow to the room had to be accounted for. Appendix T has the manufacturer's heating coil size specifications used in this analysis.

FPIU's supply a constant volume of air to the room. The heating and cooling coils both require different amounts of air to generate their capacity. The FPIU will use the bigger air volume so the full load for cooling or heating can both be provided. The FPIU could switch between flows for the two scenarios but this would cause added noise and is not ideal.

Below are the price calculations for the FPIU's in Table 33. The total install cost including labor and a location factor was found to be $241,809. This is an increase from the original design cost of the VAV boxes (which can be seen in the results section).

Number of FPIU's	Unit Size	Cooling Coil Rows	Heating Coil Rows	Cost per Unit	Total Cost of Units
22	3	0	1	$ 738.00	$ 16,236.00
16	3	0	2	$ 970.00	$ 15,520.00
33	3	2	1	$ 1,027.00	$ 33,891.00
7	3	2	2	$ 1,185.00	$ 8,295.00
7	3	4	1	$ 1,375.00	$ 9,625.00
5	3	4	2	$ 1,415.00	$ 7,075.00
12	5	0	2	$ 1,090.00	$ 13,080.00
14	5	2	2	$ 1,355.00	$ 18,970.00
2	5	4	1	$ 1,360.00	$ 2,720.00
13	5	4	2	$ 1,410.00	$ 18,330.00
2	5	6	1	$ 1,655.00	$ 3,310.00
11	5	6	2	$ 1,700.00	$ 18,700.00
				Total =	$133,996.00
		Total (with installation/labor/LF)=			$241,809.18

Table 33 – FPIU's Cost

Once all the FPIU's were sized and the DOAS units chosen, the new alternate ductwork could be finalized. The new duct work was calculated to be $227,498. This was done by finding the pounds of steel for the new duct work and using the 2012 RS Means Mechanical Data. A sample of this calculation can be seen in Appendix U and explained more below.

The galvanized rectangular steel ducts must be in accordance with SMACNA HVAC Duct Construction Standards. For simplification, it was assumed that all ductwork was of 26 gauge (both rectangular and circular ducts). The duct cost estimation was done using the RS Means Mechanical Cost Data 2012. Since the cost is given in pounds for galvanized rectangular ductwork in the RS Means, the weight per linear foot of ductwork was first calculated. 26 gauge duct weighs 0.906 pounds per square foot. An example of calculating the pounds per foot of duct can be seen below for a 32"x44" duct.

$$\text{Perimeter} = 2 \times 32 + 2 \times 44 = 152 \text{ inches}$$

$$\frac{\text{lb}}{\text{ft}} = 152 \text{ inches} \times 0.906 \frac{\text{lb}}{\text{sf}} \div 12 \text{ (convert in to ft)} = 11.5 \text{ lb/ft}$$

A factor for 30% fittings, elevated installation (10 to 15 feet), and medium pressure duct installation was included in the labor cost. The total cost including overhead and profit was then multiplied by the location factor to give a total of $10.89 per lb of rectangular duct. Cost data for circular galvanized ductwork was found directly in the RS Means. It was estimated that there was a cost of $1.00 per sf of insulation on the supply duct.

The circular ducts are shown as single line diagrams as to not clutter the drawings any more. The last 3 feet of the circular duct runs to each diffuser are flexible duct, as specified in the specs. Note that the duct work up to the FPIU's is correct; downstream it may be a bit off due to reevaluation of the cfm recirculated by the boxes. However, this should still give a good representation of the design layout.

Secondary Chilled Water Loop Piping

The piping for the secondary chilled water loop (to the FPIU's) had to be laid out too so it could be priced. Since the fin tube radiators in the rooms served by the FPIU's were being replaced by heating coils in the FPIU's, it was assumed that the piping for the FPIU's heating coils would be equal to the piping for the fin tube radiators. Because of this no new added cost would be needed for the heating pipe loop. The primary chilled water loop which runs from the new 225 ton chillers to the AHU's and DOAS units' cooling coils (this sizing will be explained more later) was not resized. If anything, the piping would be reduced and possibly the pump as well because there is less flow rate and the pressure drop across the evaporators are now 15.8 feet opposed to the original chillers' having a pressure drop of 23 feet. It was assumed the price for the primary chilled water loop would not change significantly to alter the cost analysis.

The secondary chilled water loop would have to be priced as well as size a pump for the system. To save time, the supply chilled water piping layout for floor 2 was calculated and multiplied by eleven (one supply and return for each level = 10 and 1 extra since it will be a reverse return system). Floors 3 and 4 have the most FPIU's and piping needs while 5 and 1 have the least. The 2nd floor is a good representation of the average piping needed on each floor. Since the air is being served to the space at 47°F, it was calculated only 178 gpm would need to be circulated to the cooling coils of the FPIU's to meet the further cooling needed (can be seen by adding up the values in Appendix P cooling coils for fpiu's).

In sizing the pipe, the velocity limit was 4 ft/sec for pipes 2 inches or smaller and for pipes over 2 inches a head loss of 4 ft per 100 ft run max was instituted. These limitations are used because the piping will run overhead of occupants and if as long as the layout follows these guidelines, then there should not be a noise problem. Schedule 40 steel piping was used and the friction loss chart for it can be seen on the next page in Figure 19. This chart assumes 60°F water which is very close to the 58°F in this design – so no adjustments were needed.

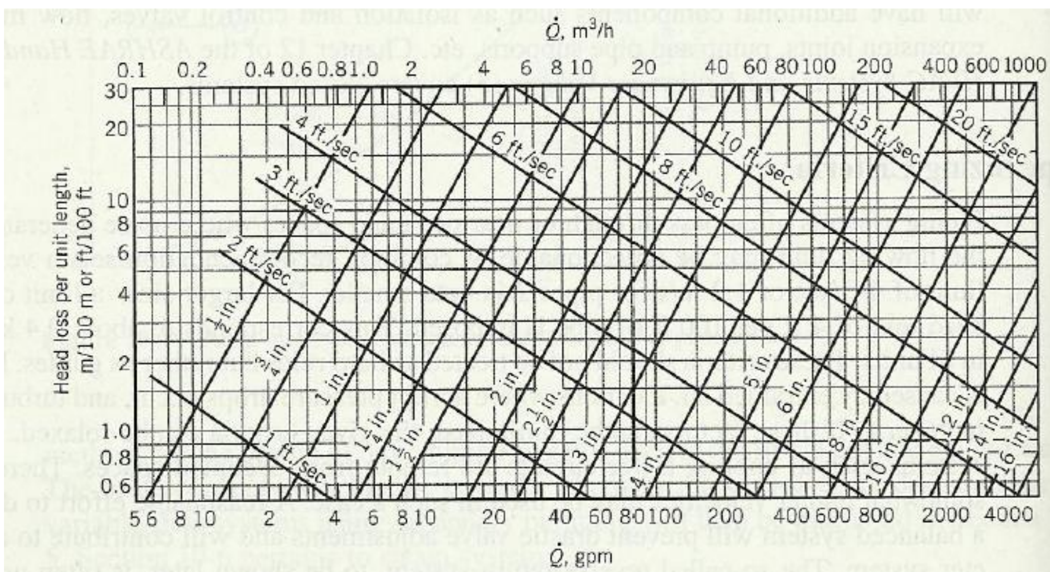


Figure 19 – Friction Loss Chart for Schedule 40 Steel

To further ease sizing the pipes, the chart in Figure x below was used. This is a simplification of Figure 20 above.

Water Pipe Sizing Table

Pipe Size	Maximum GPM			
	Schedule 40 Steel Open Systems	Schedule 40 Steel Closed Systems	Copper Type K, L Copper .8	Copper OD
⅜	---	---	.6	1/2
½	Note #1	Note #1	1.3	5/8
¾	2.75	4	4	7/8
1	6	7.5	8	1-1/8
1¼	11	15	14	1-3/8
1½	18	24	20	1-3/8
2	35	45	42	2-1/8
2½	62	70	80	2-5/8
3	100	130	140	2-1/8
4	200	270	280	9-1/8
5	350	475	360	5-1/8
6	600	800	500	6-1/8
8	1200	1600	--	--
10	2100	2400	--	--
12	3400	3500	--	--
14	4000	4200	--	--
16	5200	5500	--	--
18	6900	7000	--	--
20	8300	9000	--	--
24	12,500	12,500	--	--

Figure 20 – Pipe Sizing

The piping follows the duct layout of DOAS 2 through the shafts and follows both duct layouts for DOAS 1 and DOAS 2 on each floor. There is amble space since the duct sizes were greatly reduced so there is no trouble running the piping along the ducts. For best control, a reverse-return piping system should be used. Below is a picture of the piping on the second floor in Figure 21. It is shown just to show how little further piping is needed since the primary air does the majority of the cooling. Note how only a few FPIU's need cooling coils. The piping can be seen as a single yellow line. Just the supply piping is shown. For the actual system, return piping would be right next to the supply piping and it would be set up as a reverse-return system so there is a similar pressure drop up to and from each unit due to piping distance.

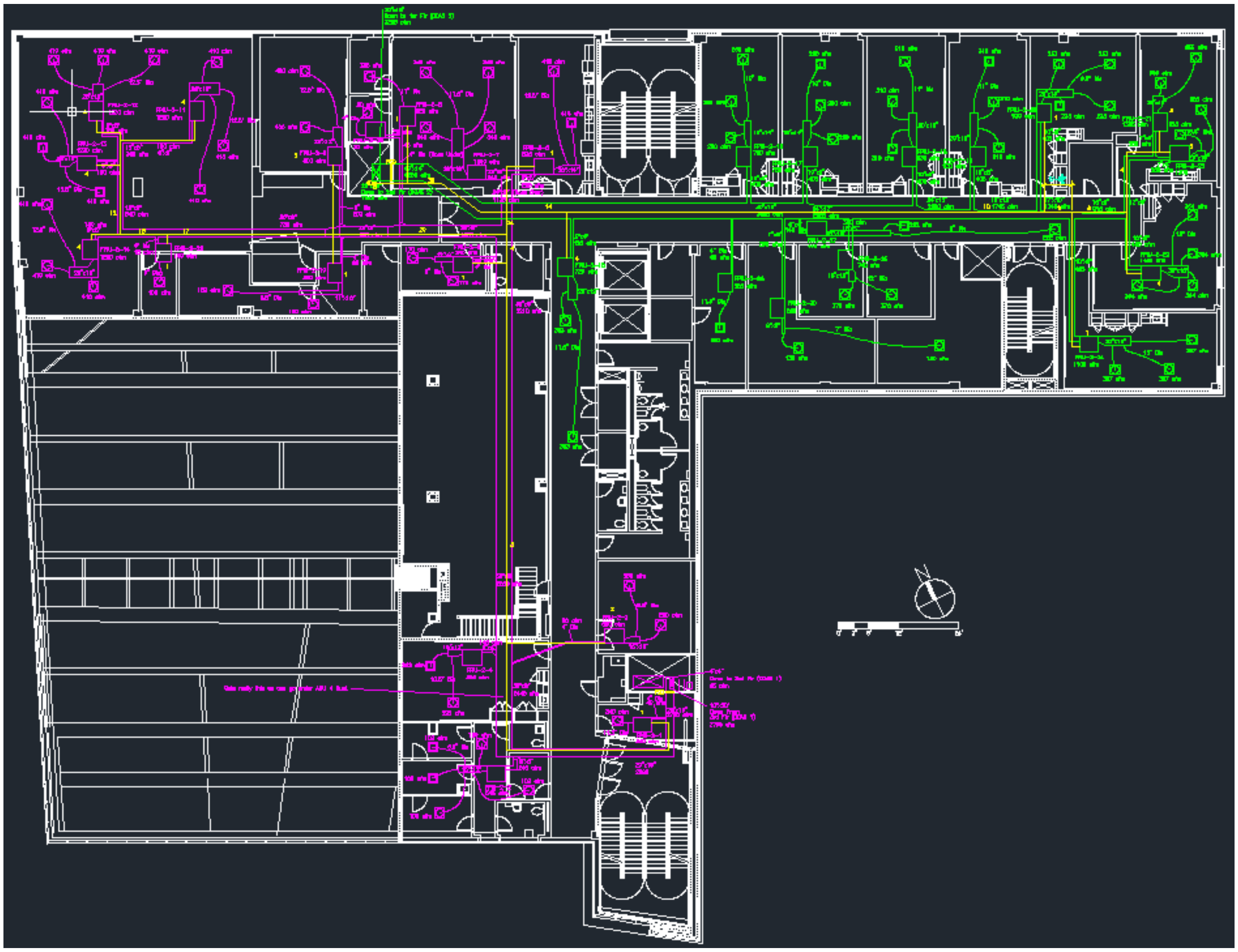


Figure 21 – 2nd Floor Piping

Using the RS Means Mechanical Data for schedule 40 steel and the take offs of the pipe layout on the 2nd floor it was calculated that the supply piping layout for this floor would be $13,288. Multiplying this number by 11 (since each floor will have a supply and return plus an extra 1 factor since reverse-return systems require more piping) and including the location factor (times 1.289) as well as a factor for fittings/insulation (11% of total) gives a total cost of $209,130 for the new secondary chilled water loop.

Lastly, a new pump had to be sized for the chilled water loop to the FPIU's cooling coils. The pump distributing hot water to the FPIU's heating coils is assumed to be sufficient because it was sized based on the runs to the fin tube radiators which are a similar distance if not further away than the heating coils in the FPIU's.

The total gpm for the new secondary chilled water loop pump was found by adding up the gpm of each cooling coil of the FPIU's. The total gpm for the secondary chilled water loop is 178 gpm. Similar to solving the external static pressure for the fans in the DOAS units, the total head of the piping run was solved for based upon the friction loss through valves/bends and friction loss along the runs. The following equations and charts were used in these calculations:

Resistance Coefficient: $K = f_t \times (value\ from\ Figure\ 22)$

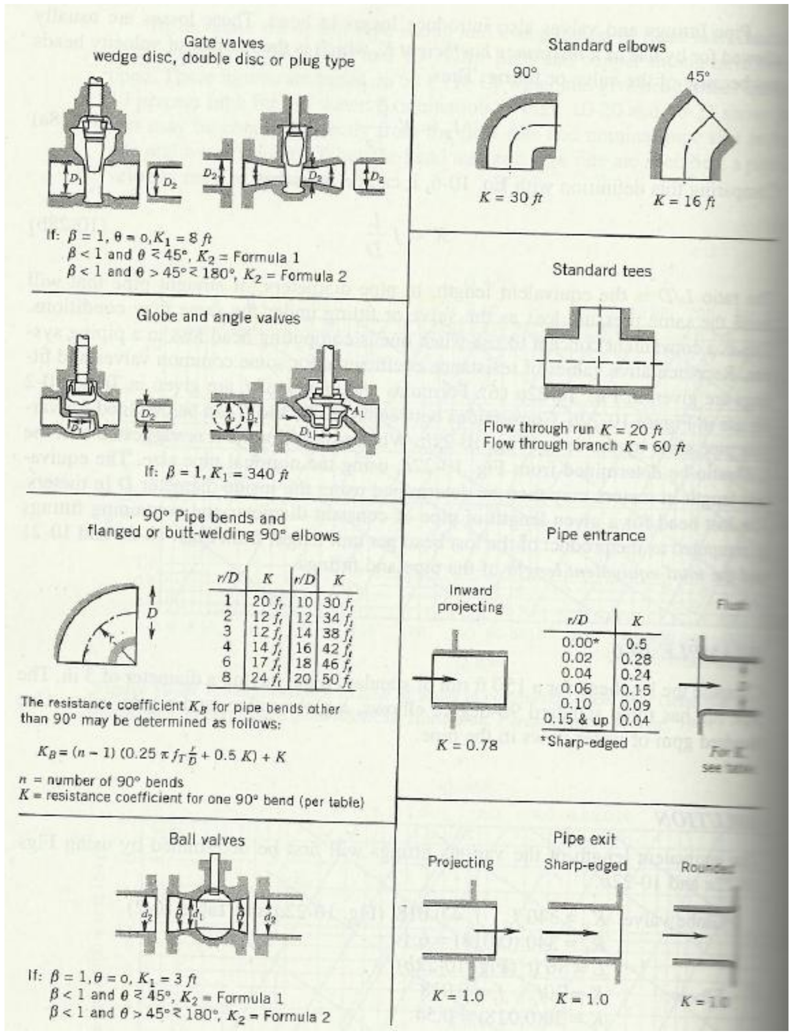


Figure 22 – Resistance Coefficient

Equivalent length of a fitting can then be found using the pipe's diameter, resistance coefficient and Figure 23 below.

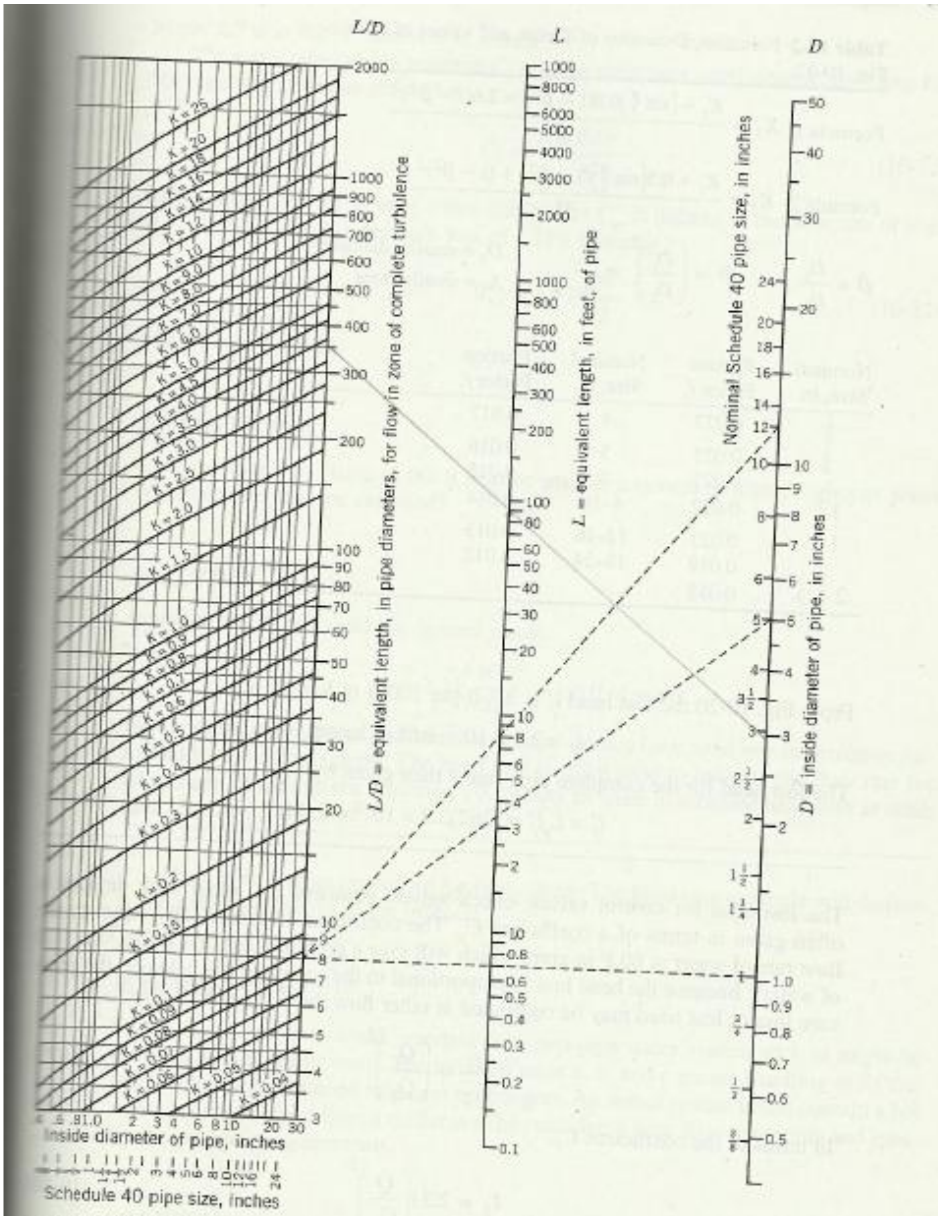


Figure 10-22b Equivalent lengths L and L/D and resistance coefficient K. (Courtesy of the Crane Company, Technical Paper No. 410.)

Figure 23 – Equivalent Lengths Fittings

Equivalent Length Total: $L_e = Pipe\ Length\ (ft) + Equive\ Length\ of\ Fitting\ (ft)$

Head Loss for a Run: $Loss\ (ft) = Equivalent\ Length\ Total\ \times Lost\ Head\ per\ 100\ ft\ (\frac{x\,ft}{100ft})$

f_t (friction factor) was found based on the size of the pipe. Figure 24 below shows the values of f_t for different pipe sizes.

Nominal Size, in.	Friction Factor f_t	Nominal Size, in.	Friction Factor f_t
$\frac{1}{2}$	0.027	4	0.017
$\frac{3}{4}$	0.025	5	0.016
1	0.023	6	0.015
$1\frac{1}{4}$	0.022	8–10	0.014
$1\frac{1}{2}$	0.021	12–16	0.013
2	0.019	18–24	0.012
$2\frac{1}{2}$, 3	0.018		

Figure 24 – Friction Factor

A few assumptions were made as well as the process is explained:

- The total head loss in feet from the pump in the roof mechanical penthouse to the FPIU's cooling coil in room 126C Vault W. Anteroom would be the biggest loss because this is the longest run.
- The total head loss for this run was calculated in Appendix V and found to be 5.52 feet. This value was then multiplied by two since it is a reverse-return system so there will be equal piping length and fittings in both directions. 5.52x 2 = 11.05 ft
- Since the pump is on the roof it will have to make up the elevation difference on the return from the FPIU's cooling coils. The pump is 62 feet above the lowest FPIU (in room 126 Vault W. Anteroom). This 62 feet was then added to the previous head loss. 11.05 + 62 = 73.05 ft
- Next the pressure drop through CH-3's (the chiller for the secondary chilled water loop) evaporator was added. This drop can be seen in the appendices:
  73.05 + 29.5 = 102.55 ft
- Lastly a factor of safety of 1.1 was applied. This factor of safety also includes the head loss from the valves and strainers near the pump – since these were neglected.
  1.1 x 102.55 = 113 ft
- The total head loss for the longest run was found to be 113 ft.

A schematic of the longest pipe run as well as the calculations can be seen in Appendix W.

A centrifugal pump was decided upon because it is the most common HVAC pump and it should suite this situation well. The total head loss of the system and gpm are known, 113 ft and 178 gpm. With these two pieces of information a pump could be chosen. The horsepower for this pump was found using a pump curve. This can be seen in Figure 25 below. The pump will have a motor that operates at 3500 rpm for this system.

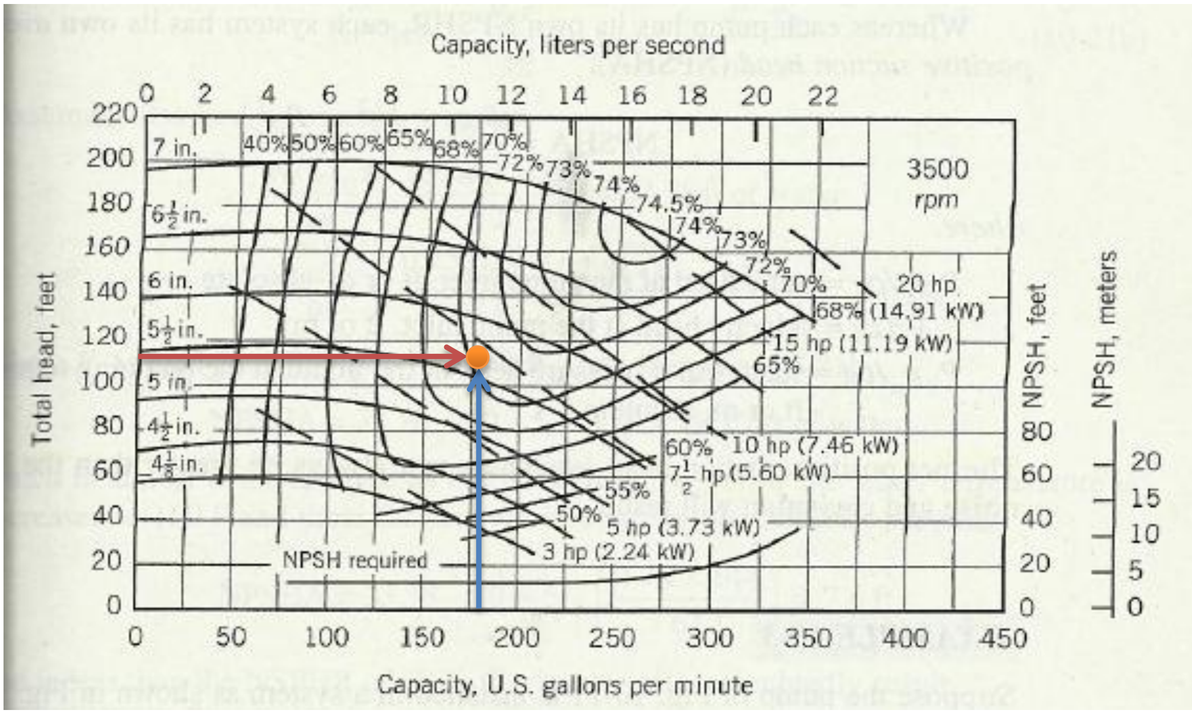


Figure 25 – Pump Curve

From plotting the points, it can be seen that a 7.5 horsepower motor would suffice. All of the characteristics of this pump can be seen in Table 34 below.

Pump Secondary Chilled Water Loop Characteristics							
Location	GPM	Total Design Head (ft)	Efficiency	HP	RPM	Electrical V/Phase/ Hertz	Impellar (inches)
Mechanical Penthouse	178	113	70.5%	7.5	3500	208/3/60	5.75

Table 34 – Pump Characteristics

The last step was to price the pump. The pricing for different pumps was found in the RS Means Mechanical Data book. Appendix X has the steps in choosing the correct price. It was estimated this pump would cost $5800.50 (including location factor). Two pumps should be bought and placed in parallel to create redundancy.

New Chillers

With the initiation of the FPIU's, the current chillers and chilled water loop must be rethought. The FPIU's have cooling coils that require a supply of chilled water at 58°F. Note that when chilled water is said it is referring to the 30% propylene-glycol water mixture. It would be unrealistic and extremely costly to use 58°F supply chilled water to the chillers. Because of this, two chilled water loops shall be utilized.

The current chilled water system has (2) 276 ton chillers that supply a chilled 30% propylene-glycol water mixture to the AHU's cooling coils. The chillers for the primary chilled water loop will be supplying chilled water to the cooling coils of the DOAS units and AHU's 4 through 6. Since the sensible load for cooling is also being accomplished at the rooms as well as there is less air to condition, the chillers can be downsized. The leaving water temperature from the chillers will remain the same at 44°F so the coils won't need to be changed in the AHU's. The tons of cooling needed for DOAS 1 and DOAS 2 were taken from the specifications, 81.48 and 144.8 tons respectively. These were added to the tons of cooling for AHU's 4 through 6:

$$223.38 + 81.48 + 144.8 = 450 \text{ tons}$$

The current chillers have a delta T of 9.6 degrees. Using this information it was calculated that the gpm flow would be 1125. The following information was specified to a manufacturer to size a chiller for this design:

type:		air cooled	
voltage:		3 phase, 208V, 60Hz	
EWT		54	deg F
LWT		44.4	deg F
GPM		1125	
Tons:		450	

The decision to use an air cooled chillers stems from there being insufficient space on the roof for a cooling tower. The current design of the building also follows this logic.

Two chillers were recommended by the manufacturer to accomplish these parameters. Two 225 ton York model no. YVAA0245CEV17 chillers were chosen. The main characteristics of these two chillers can be seen on the next page.

type:		air cooled
voltage:		3 phase, 208V, 60Hz
EWT		53
LWT		44
GPM		600
Tons:		225

The leaving water temperature dropped a bit as well as the return water temperature. The flow rate increased slightly. This could be bad because the AHU's cooling coils can only handle a certain flow rate. If you assume that the coils in the AHU's are slightly oversized, this minimal extra gpm served to them to meet the cooling load should be fine and won't be too much for the pipes. If the flow was too great for the pipes, than the flow would be restricted and the air wouldn't be able to be cooled to the correct temperature. For this analysis, it is assumed that a factor of safety was used in sizing the cooling coils in the AHU's so the coils can handle this extra flow (it is about a 8.5% increase and will only occur at max cooling which is in the summer when the building will not be occupied at full load). Since this max flow would occur in the summer but the building won't bet fully occupied, it is assumed that the coils will not see this full flow ever. The specifications for these two 225 ton chillers can be seen in Appendix Y.

The primary chilled water loop's piping and control scheme shall remain the same as it is now. The pipes may even be downsized a bit because the new loop needs 1200 gpm as opposed to the 1332 gpm. A schematic of the primary chilled water loop may be seen on the next page in Figure 26. This chilled water loop is a primary-only variable flow design. The flow thorough the chillers' evaporators shall vary with the load. The bypass valve is used to maintain the minimum flow through the chillers' evaporators (when they are on). The flow to the terminal loads vary depending upon the amount of gpm required.

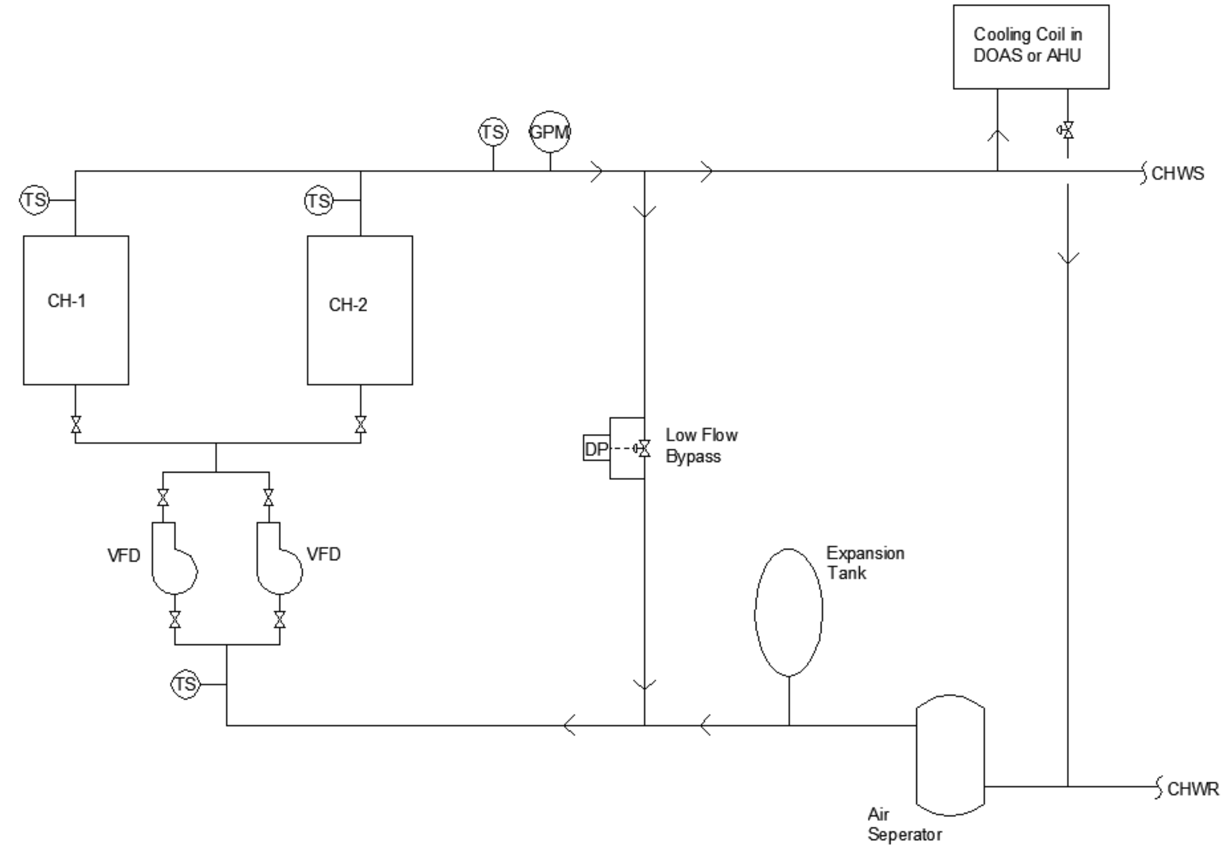


Figure 26 – Primary Chilled Water Loop

The secondary chilled water loop is for supplying the FPIU's cooling coils with 58°F chilled water. The following specifications were found for sizing a chiller for this loop.

type:	air cooled
voltage:	3 phase, 208V, 60Hz
EWT	62
LWT	58
GPM	178
Tons:	32

When these specifications were discussed with the manufacturer some issues arose. The manufacturer had no chillers that could produce a LWT of 58°F but the real problem was the very small delta T of 4°F. A small delta T produces a giant GPM requirement for the pump. Though the chiller may not have to do as much cooling, the extra pumping energy will override this savings. In practice, the ideal delta T for a chiller is 10 to 16 degrees F. This has been found to give the minimal cost between pumping and cooling.

To solve these problems, the secondary chilled water loop will mix water leaving the chiller with the return water of 62°F to get the supply of 58°F chilled water for the FPIU's cooling coils. This appears to be the best option. The tonnage of cooling for the chiller will remain the same and the supply GPM to FPIU's cooling coils will too. A schematic of the secondary chilled water loop can be seen below in Figure 27.

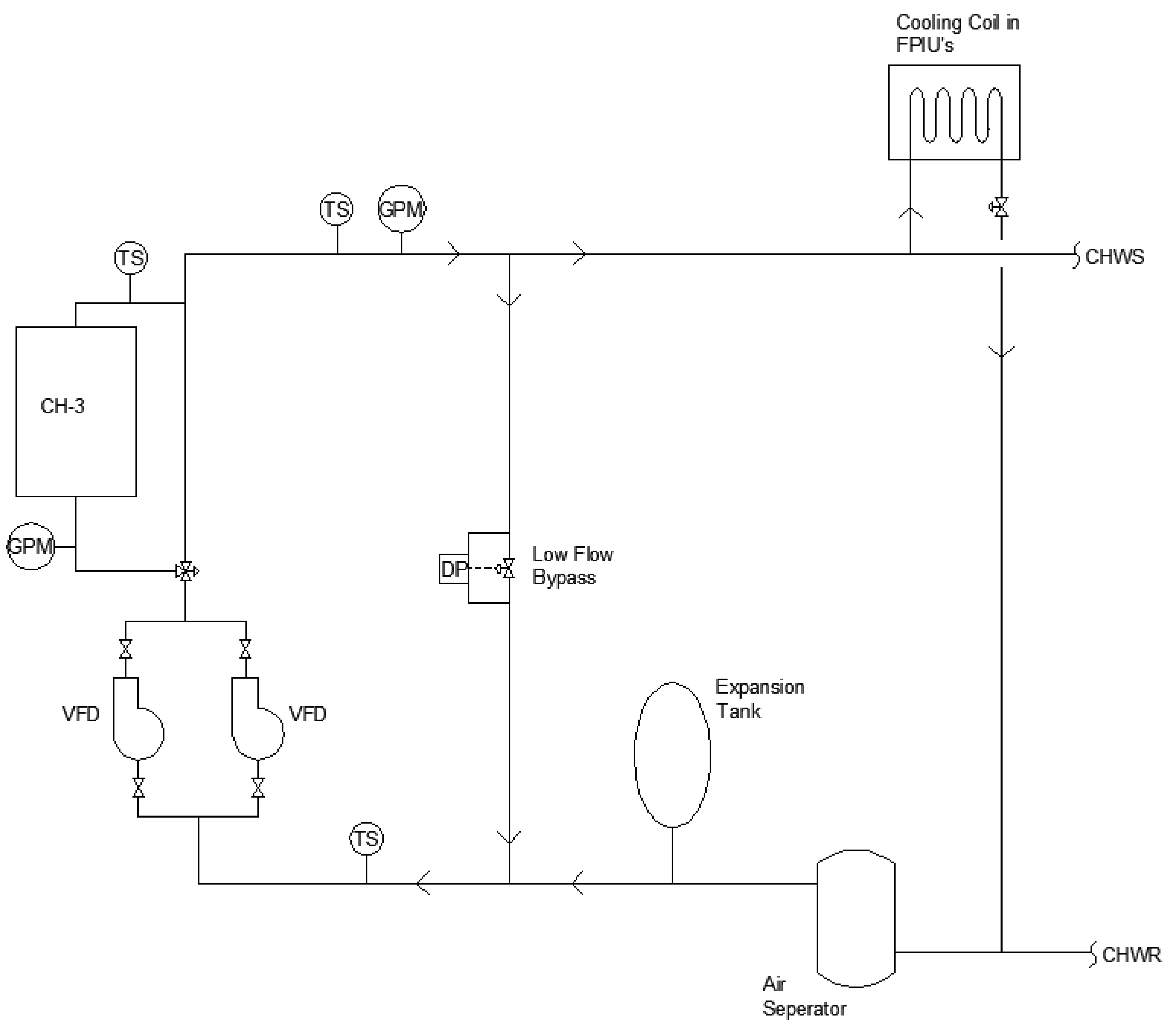
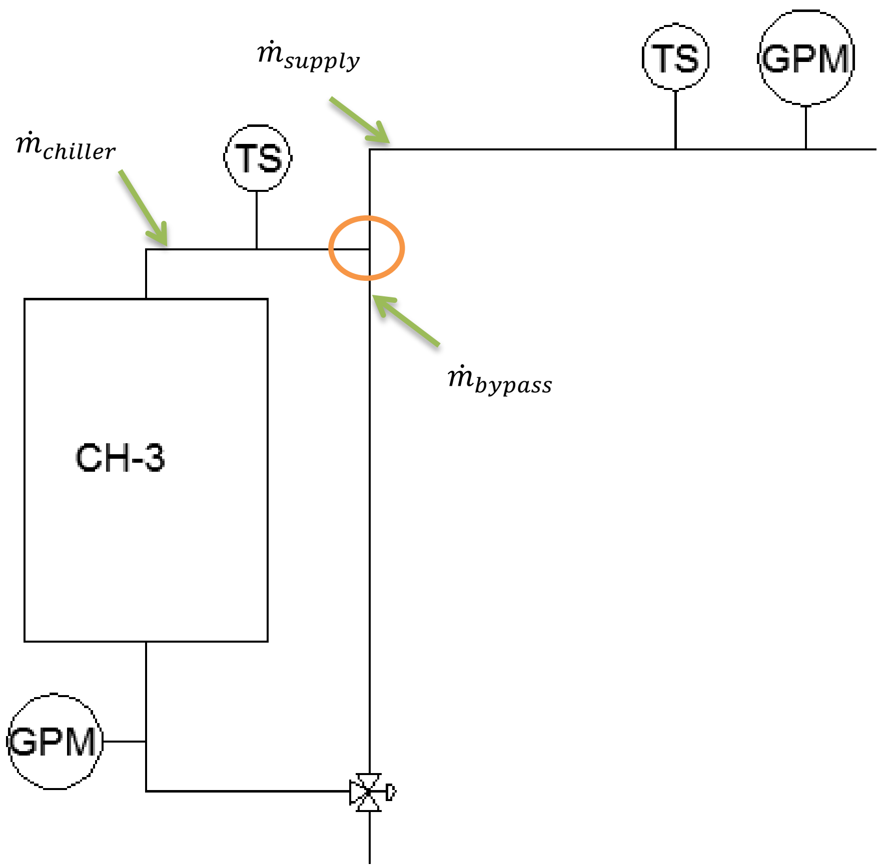


Figure 27 – Secondary Chilled Water Loop

To solve the for the amount of flow through CH-3, a mass and energy balance was done. This balance was done at the intersection point between the outlet of CH-3 with the intersection of the bypassed return water where it is mixed to make the supply chilled water. This point along with the equations can be seen below.



$$Energy\ Balance:\ \dot{m}_{chiller} \times LWT_{chiller} + \dot{m}_{bypass} \times 62°\text{F} = \dot{m}_{supply} \times 58°\text{F}$$

Considering the density is close to identical for these different chilled water temperatures (good assumption) gives the equation:

$$GPM_{chiller} \times LWT_{chiller} + GPM_{bypass} \times 62°\text{F} = 178\ GPM \times 58°\text{F}$$

The characteristics for a chiller were then determined using this equation and some background knowledge on the EWT and LWT restrictions. This gave a range for choosing a new chiller. The potential characteristics for CH-3 can be seen in Table 35 on the next page.

Chiller						
Tons	LWT (deg F)	EWT (deg F)	delta T	GPM thru Chiller	GPM to FPIU's	GPM Bypass
32	40	62	22	35	178	143
32	41	62	21	37	178	141
32	42	62	20	38	178	140
32	43	62	19	40	178	138
32	44	62	18	43	178	135
32	45	62	17	45	178	133
32	46	62	16	48	178	130
32	47	62	15	51	178	127
32	48	62	14	55	178	123
32	49	62	13	59	178	119
32	50	62	12	64	178	114
32	51	62	11	70	178	108
32	52	62	10	77	178	101
32	53	62	9	85	178	93
32	54	62	8	96	178	82

Table 35 – CH-3 Options

In submitting this information to the manufacturer, a YCAL0033EE17 York chiller was chosen as the best candidate. This chiller has the design criteria of the chiller on the last line above (highlighted in red). The specifications for this chiller can be seen in Appendix Z.

Another potential solution would be to put a heat exchanger between the primary loop's return water of 53°F and the secondary loop's return water of 62°F. The mixing of equal parts of these two streams would produce chilled water of 57.5°F, add in heating along the pipes would give you approximately a supply temperature of 58°F to the cooling coils of the FPIU's. This scenario could work but it would create a new delta T on the primary chillers. This would call for resizing of primary chillers. In the essence of time, this option was not investigated. It would be interesting to see how this scenario would work out.

Lastly, the mechanical penthouse is pretty full at the moment. The chilled water pumps may be able to be located outside with the chillers they serve. This would be ideal otherwise redesigning of the penthouse's layout would have to be done.

MAE – CFD Analysis

Objective: The objective of this CFD analysis is to determine the mixing patterns in a typical classroom for my thesis project. The existing system in the building is a VAV system with 12"x12" diffusers. The new air system in the building will use fan power induction units (FPIU) that feed 12"x12" diffusers. Since VAV systems can modulate the amount of flow, the VAV at full flow and at the minimum turndown of 30% will be investigated. The FPIU system delivers a constant air volume to the room. The main objective is to determine how well both systems distribute air to the space. This analysis will be judged upon air stratification in the room, temperature gradients, velocity, and if any drafty spaces occur. Phoenics was the software chosen to perform this CFD analysis. Three models, one for each of the scenarios, was created and run under non-isothermal conditions.

Classroom Layout: The first task was creating the classroom. A variety of classrooms exist in Hunter's Point South School so the most common that occurred was chosen. This was IS Classroom 357 which is also very close to the design of a few others as well. Below you can see the layout of the room in Figure 28.

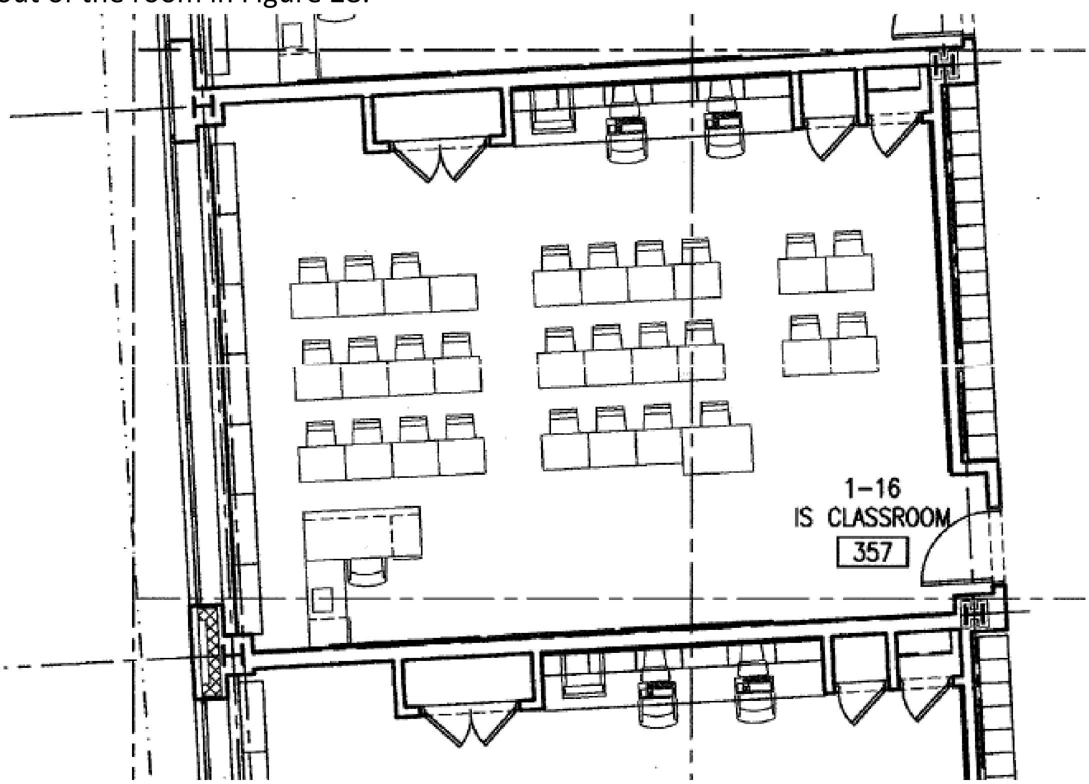


Figure 28 – IS Classroom 357 Layout

For a CFD analysis, you want to make the objects in the room as simple as possible. For this reason, only major objects in the room were considered. People, desks, cabinets, computers, the window, and the fin tube radiators were created in Phoenics. A list of a few of the objects' dimensions and locations in the room can be seen below in Table 36 and the created model can be seen in Figure 29.

	Size (meters)			Location (meters)		
	x	y	z	x	y	z
Room	9.449	7.137	3.048	0	0	0
Window	0	6.045	2.235	0	0.546	0.813
Large Cabinet	1.981	0.737	2.133	2.007	6.4	0
SmallCab	1.829	0.737	2.133	7.468	6.4	0
ComputerDesk	3.658	0.737	0.0254	3.962	6.4	0.671
Comp1	0.4	0.35	0.35	6.3	6.6	0.671
Comp2	0.4	0.35	0.35	5	6.6	0.671
FinTube	0.152	5.486	0.813	0	0.74	0
teacherdesk1	0.61	1.829	0.671	0.61	0	0
teacherdesk2	1.219	0.61	0.671	1.22	1.219	0
teacher	0.35	0.35	1.727	1.5	0.7	0
teacher computer	0.35	0.4	0.35	0.75	0.7	0.671
desk1	0.61	0.457	0.0254	0.914	4.699	0.671
stud1	0.35	0.35	1.219	1.05	5.2	0

Table 36 – Dimensions of Objects for CFD

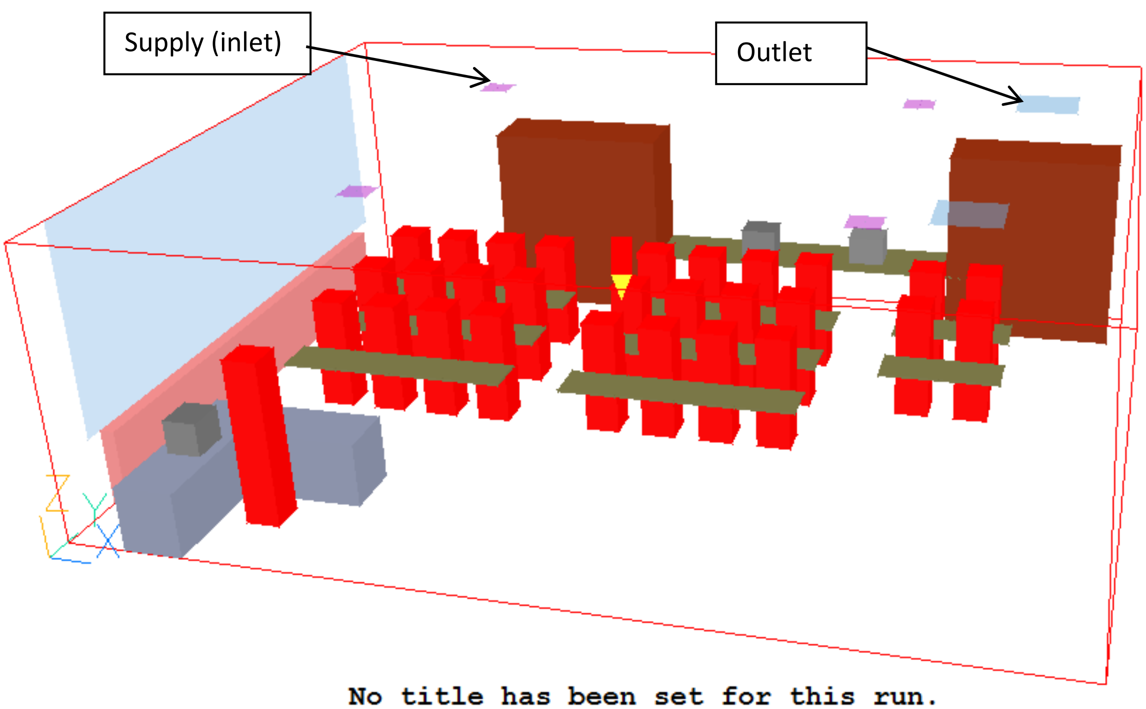


Figure 29 – CFD Room Model

For this investigation, three models were made:

1. VAV at full flow
2. VAV at 30% turndown
3. FPIU

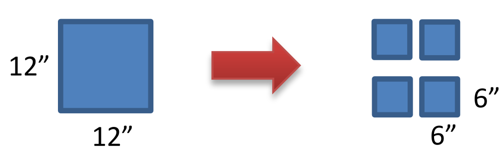
The only objects that differed from the models were the fin tube radiator and the diffuser locations/type. Both VAV models have the fin tube radiator in them. This is because heating is accomplished through the fin tube radiator and not by the overhead air supply. The FPIU model has no fin tube radiator because heating is done through a heating coil in the FPIU. This means the heating is done by the supply air overhead in the FPIU model.

Both VAV models have the same diffuser locations and types, just different flow rates (one at full and one at 30% turndown). The FPIU's have slightly different diffuser locations as well as a different flow rate.

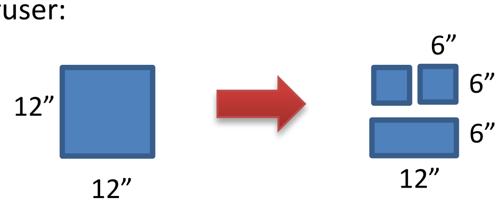
<u>Turbulent Models and Differencing Schemes</u>: The turbulent model and differencing scheme were chosen based on familiarity and acceptance. K-epsilon was used as the turbulent model because it is very widely accepted and I have used it the most. The hybrid scheme was used as the differencing scheme for the same reasons as above and because both diffusive and convective forces will occur in the room. 5000 iterations run time was allowed. All three models had these same qualities. This was done so if any differences occurred between the models then it couldn't be blamed on using a different model (like in a science experiment how you only want to change one variable at a time).

<u>Diffusers and the Momentum Method</u>: The diffusers used in the models were all 12"x12". Two types of diffusers existed however. One was a 4 way square diffuser and the other a 3 way square diffuser. For simplicity the 4 way square diffuser was broken up into 4 smaller 6"x6" boxes and the 3 way was broken into (2) 6"x6" boxes and (1) 6"x12" box. This can be seen more clearly in the images below.

4 way square diffuser:



3 way square diffuser:



The 4 way square diffusers distribute air perpendicular to all four of its sides. The specifications below show the air distribution for this diffuser.

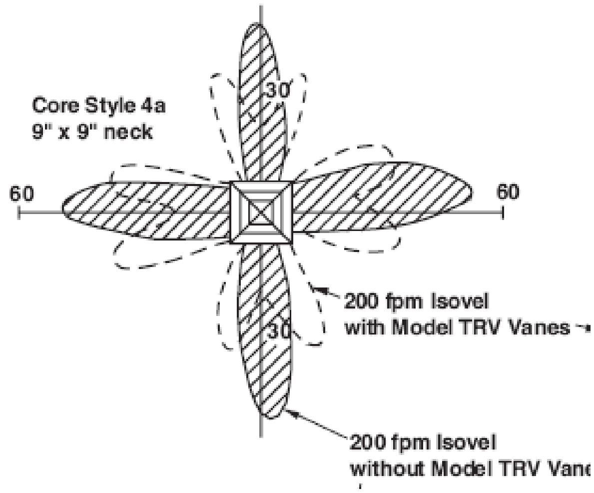
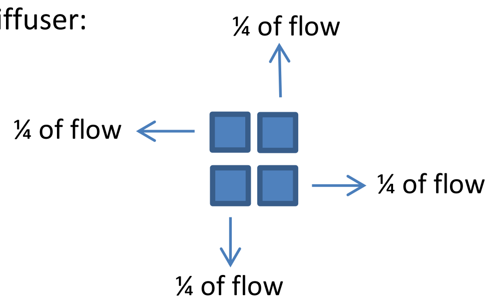


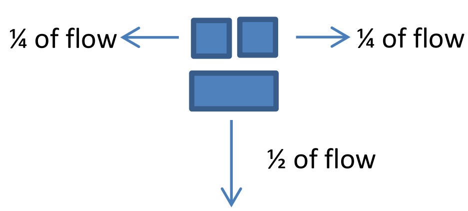
Figure 30 – Diffuser Air Dispersion

Since the air is distributed like this, it was determined that modeling the diffuser in 4 smaller segments each with one direction for its flow would be an accurate interpretation. The direction of the air flow can be seen below for both the 4 and 3 way diffusers.

4 way square diffuser:



3 way square diffuser:



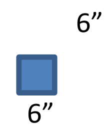
The momentum method was chosen because the box method is not recommended for square diffusers as well as the momentum method's ability to more accurately simulate momentum in the space. Simulating the momentum is crucial to this analysis because it will be looked at as one of the criteria to determine whether the VAV or FPIU better distributes/mixes air in the space.

For the momentum method to be used in Phoenics the mass flow rate for the mass continuity equation must be found as well as the ratio of effective area to diffuser area (net area ratio). Finally, the velocity of the x or y component for the momentum method must be determined. Knowing the cfm through the diffuser, the mass flow rate is easily calculated using:

m_dot = v_dot * rho = volume * rho * Area

Below is an example of these calculations for the FPIU’s diffusers (all are 4 way diffusers distributing 340 cfm each). The calculation is for one of the 6”x6” cells used to represent the diffuser.

Vz_mass = v_dot_in / Area_total = (340cfm/4) / (0.5 ft x 0.5 ft)



Vz_mass = 1.727 m/s

Vz_momentum = Vz_mass / net area ratio = 1.727 m/s / 0.7794 = 2.2158 m/s

Vx_momentum = Vz_momentum / tan(30 degrees) = 3.838 m/s

So enter into Phoenics:

- Net Area Ratio = 0.7794
- Vx = 2.2158 m/s
- Vy = -1.727

The calculations for the velocities (for mass and momentum) in all three of the models can be seen in Appendix AA.

An image of the diffuser with dimensions is shown in Figure 31 on the next page. It was used to help determine the net area ratio, which is equal to the effective area divided by the total area. This ratio is used to convert the velocities calculated above to keep conservation of momentum accurate. The total area was simply 144 inches squared (12” x 12”). The effective area is less because of the metal louvers. It was found to be roughly 112.2 inches squared resulting in a net area ratio of 0.7794. The full calculations for Net Area Ratio can be seen in Appendix AB. Note from the picture that the diffuser delivers air into a room at a 45 degree angle. This is a bad angle because it causes a lot of numerical diffusion (it is along the diagonal of a cell). To make up for this it was modeled that the air was brought into the room at a 30 degree angle with the ceiling.

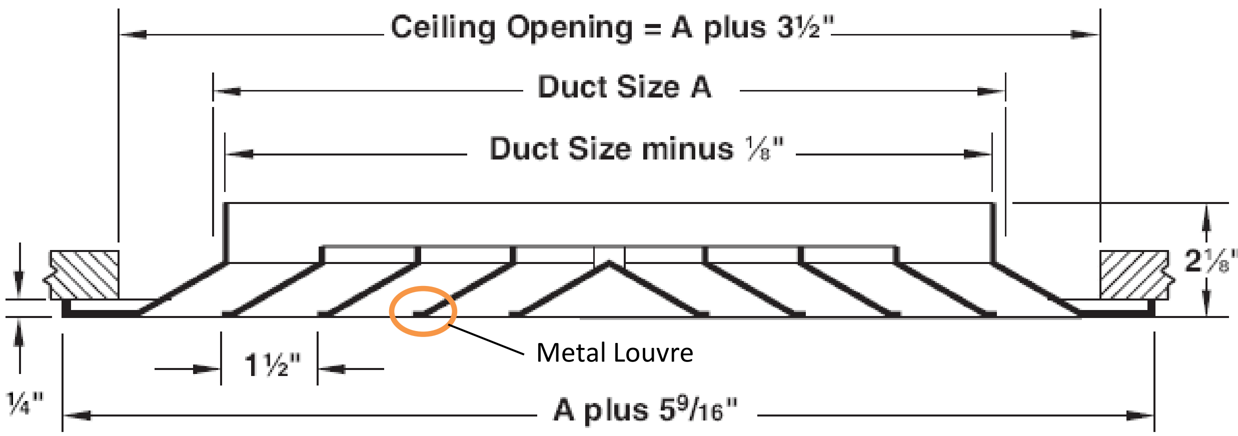


Figure 31 – Diffuser Cross Section

Final Model Layouts: Below are the final layouts for the inlets and outlets in each of the models along with their cfm. The inlets are red and the outlets are blue.

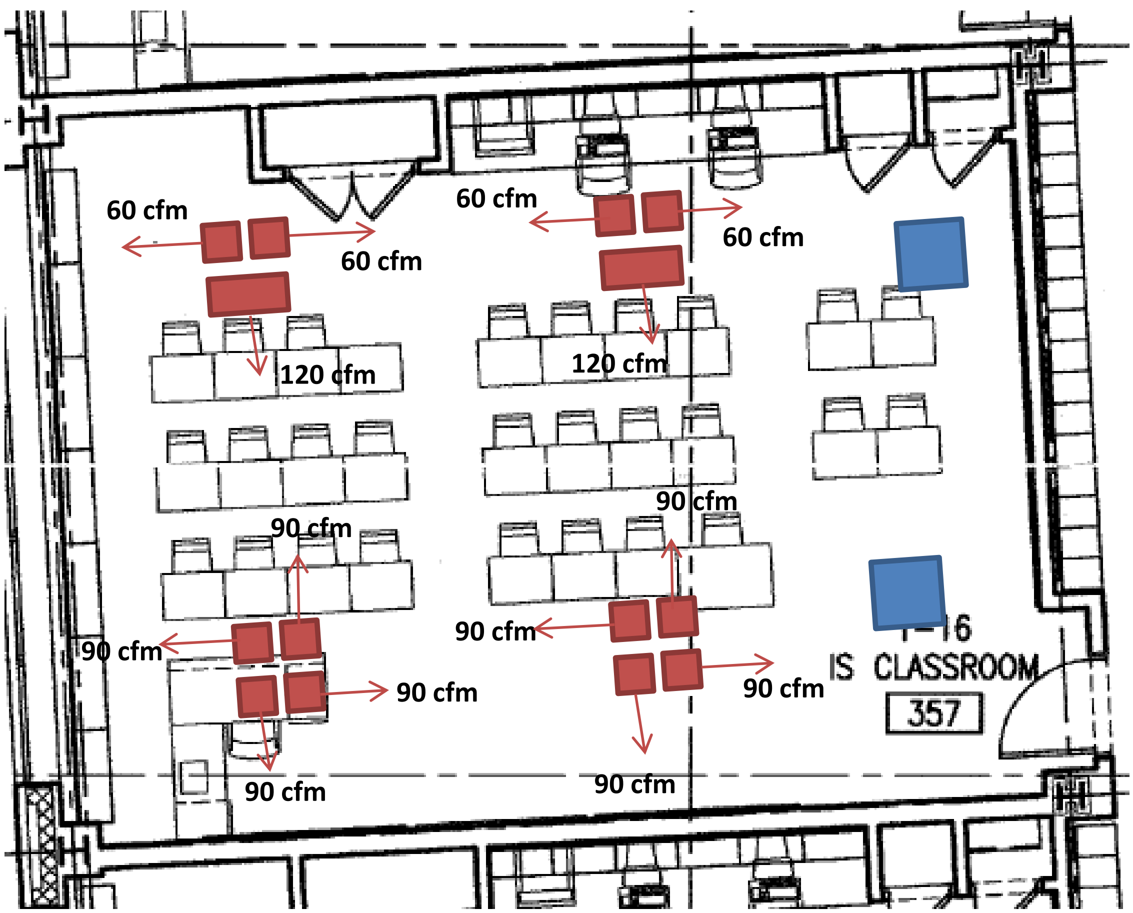


Figure 32 – VAV Full Flow Model

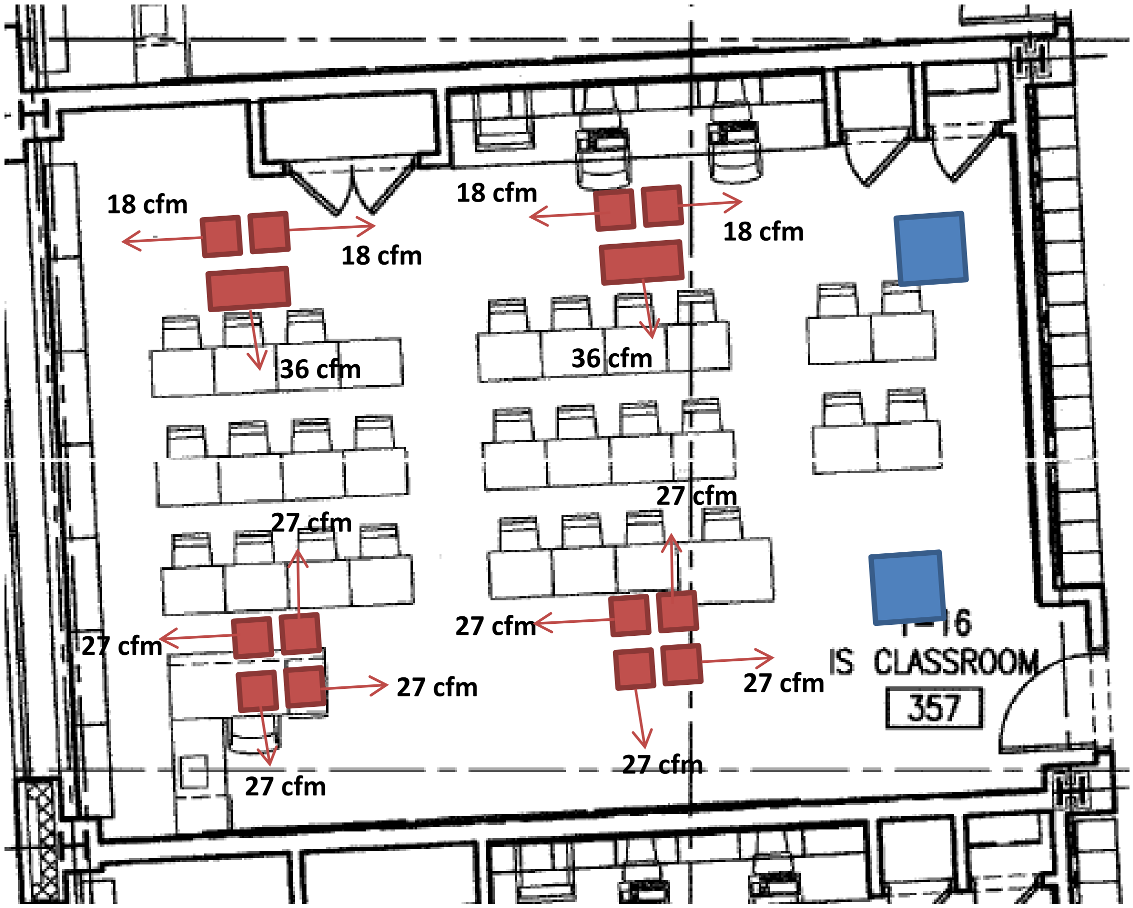


Figure 33 – VAV 30% Flow Model

Note that everything is in the same location as the VAV Full Flow Model. The difference is that the cfm through each diffuser has been reduced.

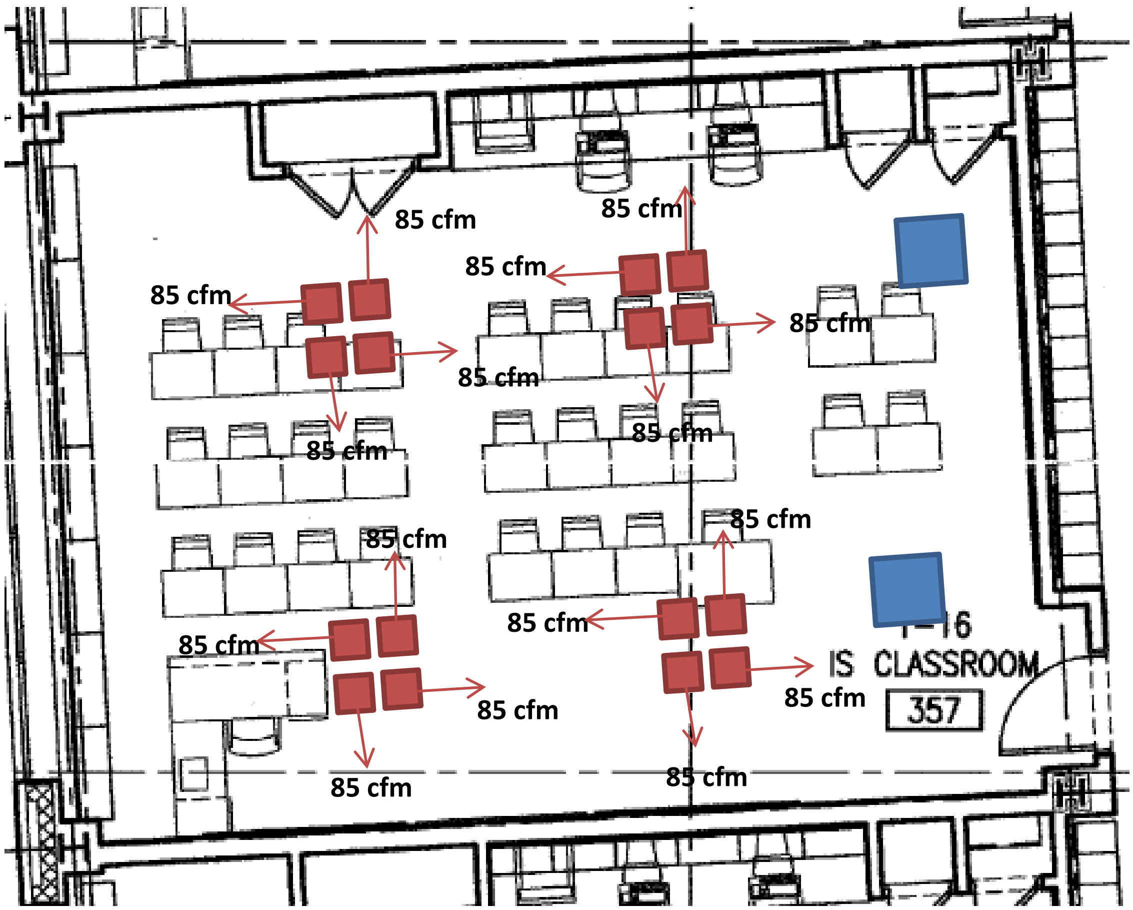


Figure 34 – FPIU Model

The outlet locations are the same as the two previous models. In the FPIU set up, the inlet locations changed slightly (more equally spaced) and the flow through the diffusers changed too.

Mesh/Grid: The mesh used for the VAV models was (71, 65, 42) cells in the (x,y,z) axis. The FPIU mesh was (97, 62, 42. The mesh near the inlets and returns was increased because this is a critical zone and using a smaller mesh would allow for more accurate results. Below are the images of the meshes near the inlets and outlets.

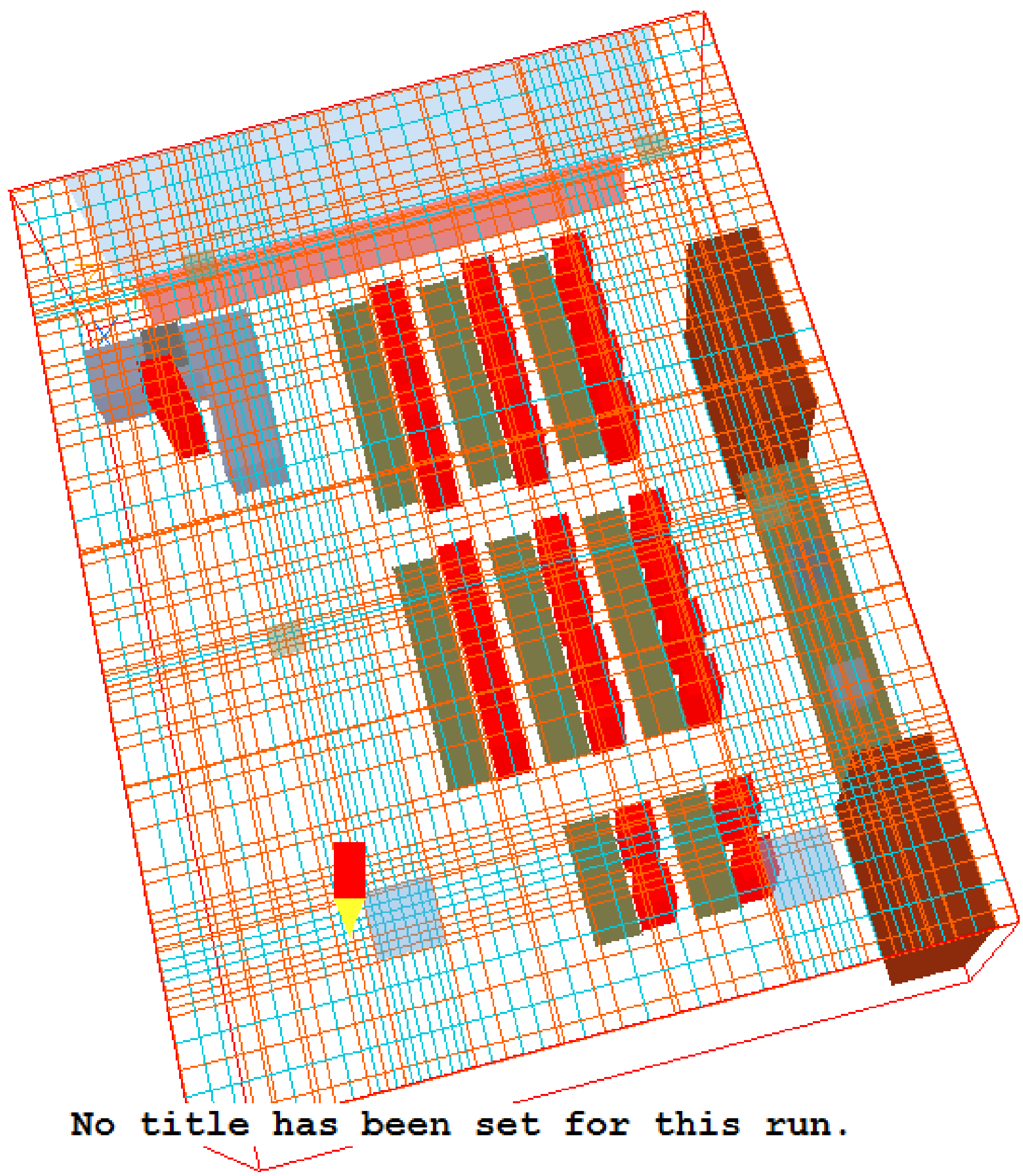


Figure 35 – Mesh for VAV Models (overhead view)

The mesh for both the VAV models is the same because they have the same locations for the inlets and outlets.

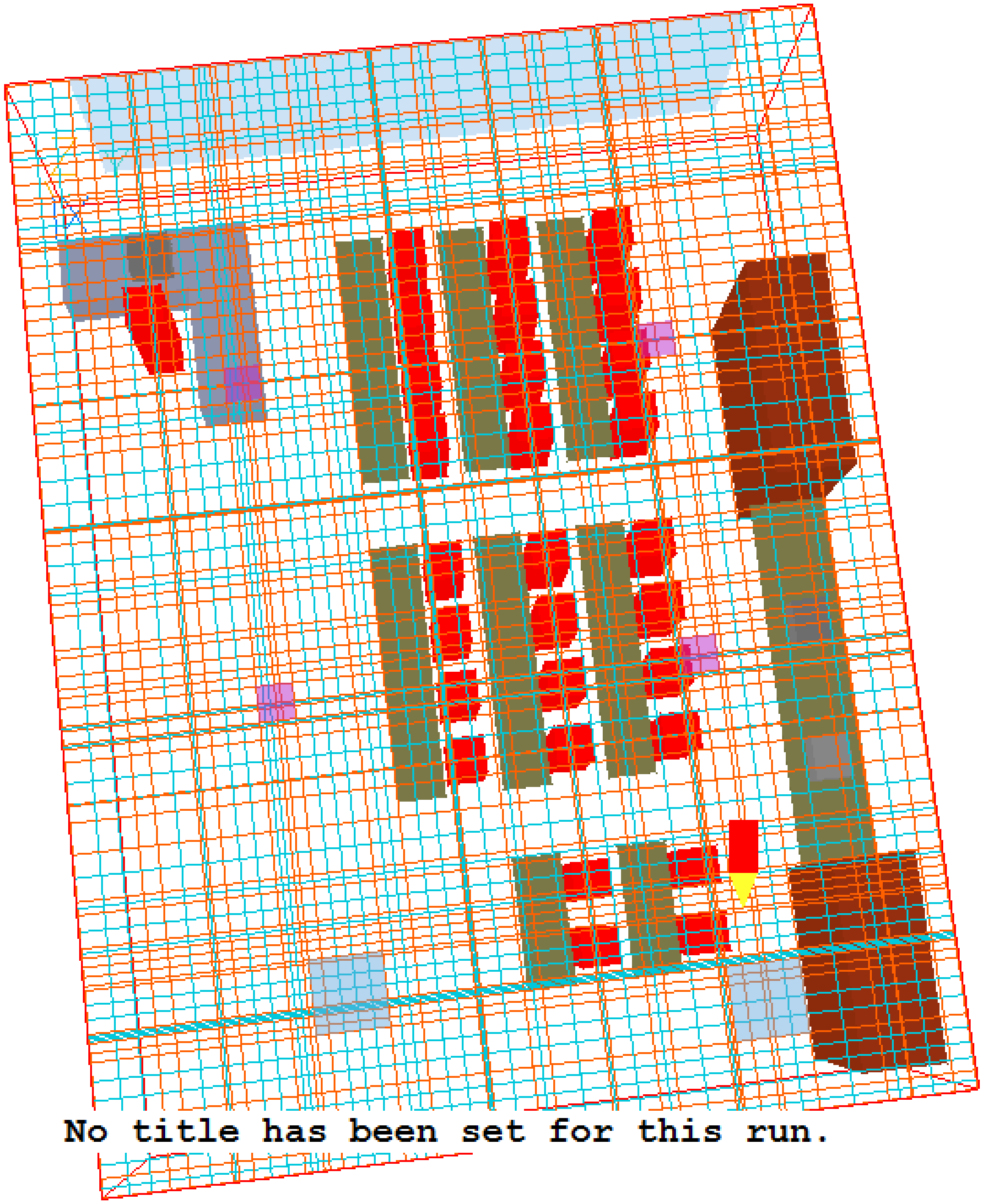


Figure 36 – Mesh for FPIU Model (overhead view)

VAV Full Flow Results: First the airflow and temperature fields were investigated under non-isothermal conditions for the VAV full flow model. The residuals found for mass and energy for the full VAV flow model were 1.66% and 0.39%, respectively. The percent can be as high as 7% for the energy residual and 3% for the mass residual. These two residuals are well within the recommended ranges. The residual figure can be seen below for the full VAV flow model.

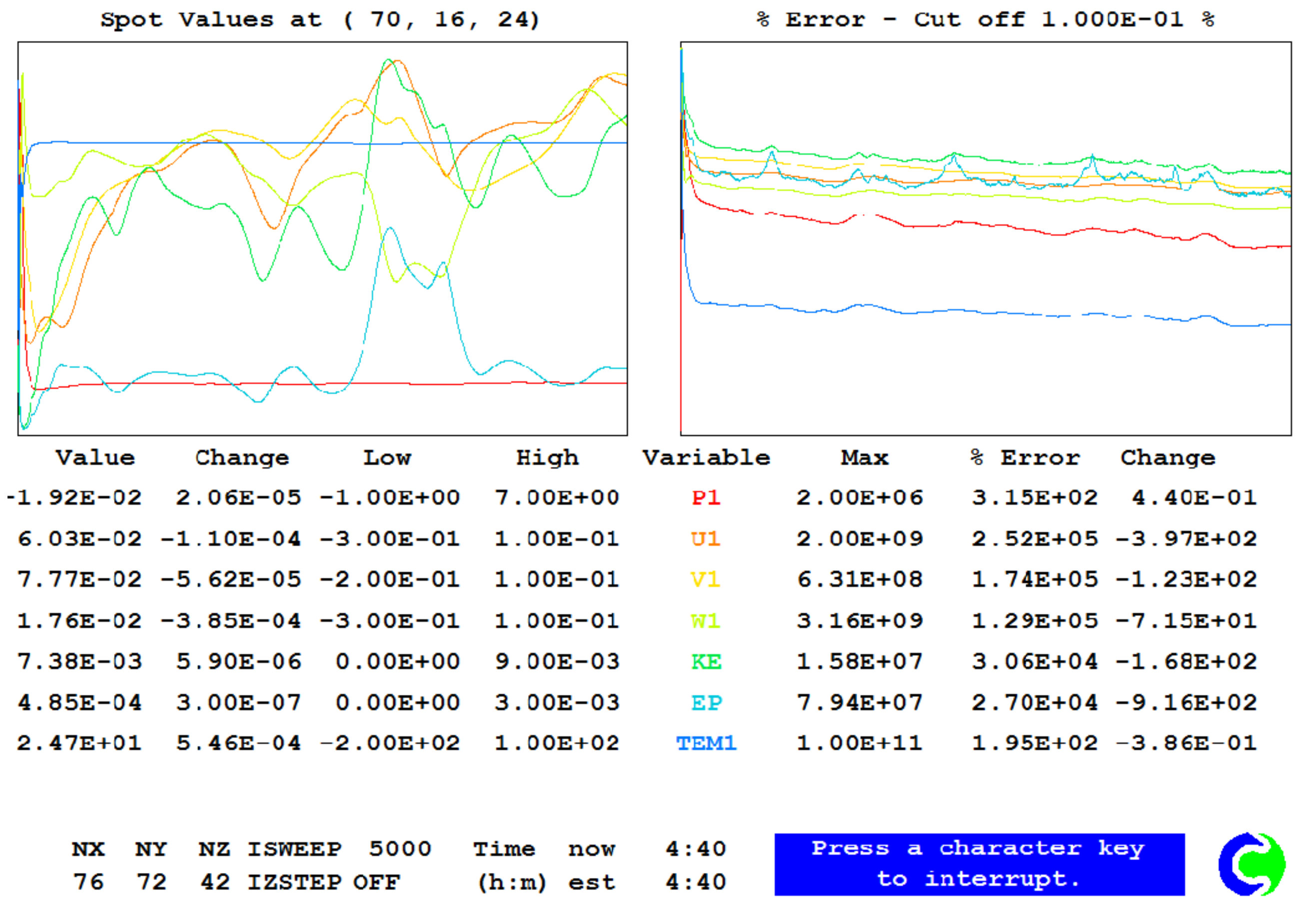


Figure 37 – Residual Figure VAV Full Flow

The full flow VAV model took 4 hours and 40 minutes to run. A linear relaxation factor of 0.7 was used for all the models (VAV full flow, 30% VAV flow, and the FPIU layout). The full VAV flow model assumed that the fin tube radiator was being run at full blast and that the supply air to the room was at 58°F. Infiltration as well as conduction loses through the exterior wall and window was modeled as negative heat fluxes. These same assumptions were made in the 30% VAV model except that the fin tube radiator was turned down as to not overheat the space (it was still needed to prevent drafts along the wall with the window). Table 37 on the next page shows the net Watts for each of the models well as the Watts given off by the sources in the room.

	VAV Full (Watts)	30 Percent VAV (Watts)	FPIU (Watts)
people	2175	2175	2175
lights	768	768	768
fin tube	3640	50	0
computer	405	405	405
exterior wall	-85	-85	-85
window	-1016	-1016	-1016
infilitration	-475	-475	-475
diffusers	-5416	-1625	-1754
total (W):	-4	197	18
air temp (deg F)	58	58	68
cfm	1200	360	1360

Table 37 – Watt Productions in Rooms

For the full VAV flow model, the net Watts in the room is negative meaning the space should be slightly overcooled. However when checking the results, the space was found to be well above the room setpoint. It can be seen that the heat given off by the people drove the fin tube radiators and diffuser airflow in the models. The velocity profiles can be seen below for the VAV full flow model.

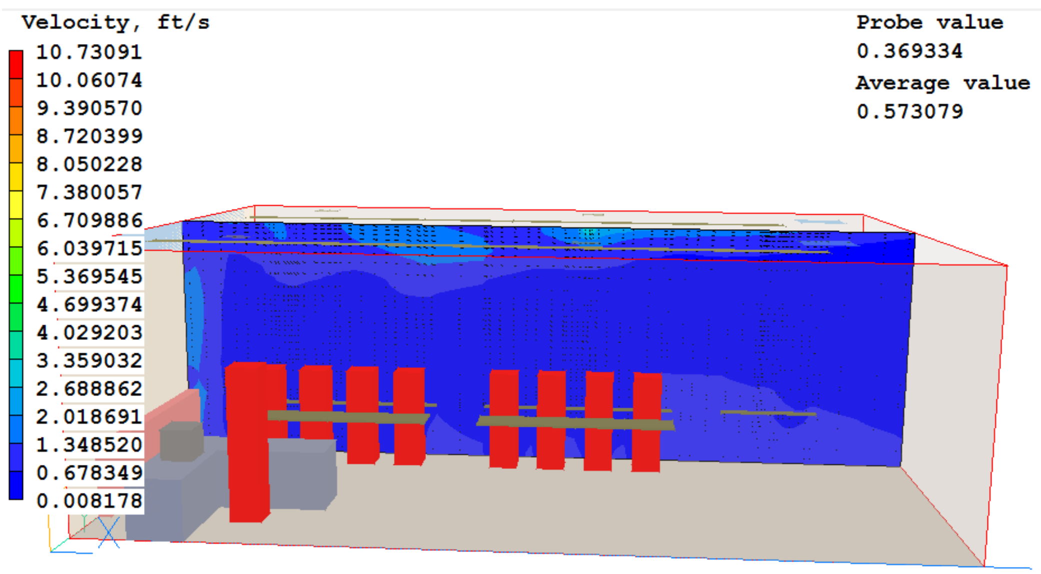


Figure 38 – VAV Full Flow, Velocity (along x-axis)

The probe in this snapshot is to the right of the students were the velocity is highest. The velocity is below 40 fpm so no drafts will occur here. To the right of the last students in this picture there is some areas were the air is above 40 fpm, around 54 fpm. This would cause drafts. Note that the air velocity near the cold window is higher than most room. A draft is induced across this cold surface but the fin tube radiator dissipates it before it reaches the occupants.

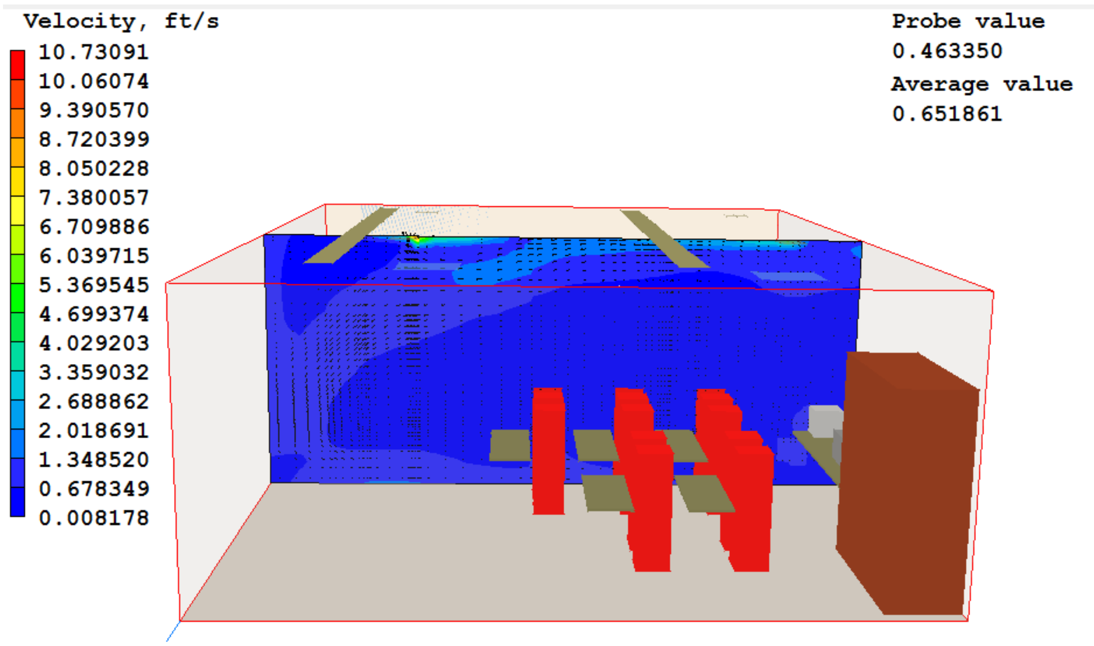


Figure 39 – VAV Full Flow, Velocity (along y-axis)

The probe for the above picture is located 4' off the ground in the center of the room. The results for the isothermal field show that the majority of the room has air traveling less than 40 fpm so no drafts will occur. A few spots are a tad above this. This could be bothersome because these spots are near the students. However, they do not go that far over 40 fpm. Overall the majority of the air in the students' area is draft free.

Next are the temperature profiles for the VAV full flow model.

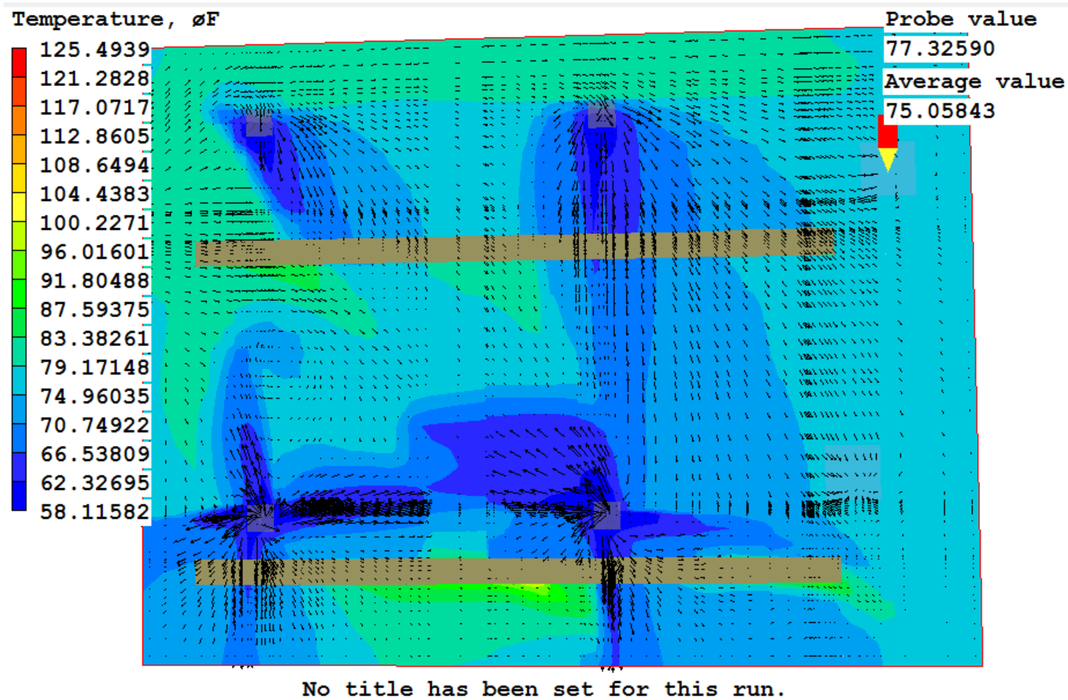


Figure 40 – VAV Full Flow, Temperature (along z-axis)

The probe is located in the return outlet. The above shot is overhead looking down at the room.

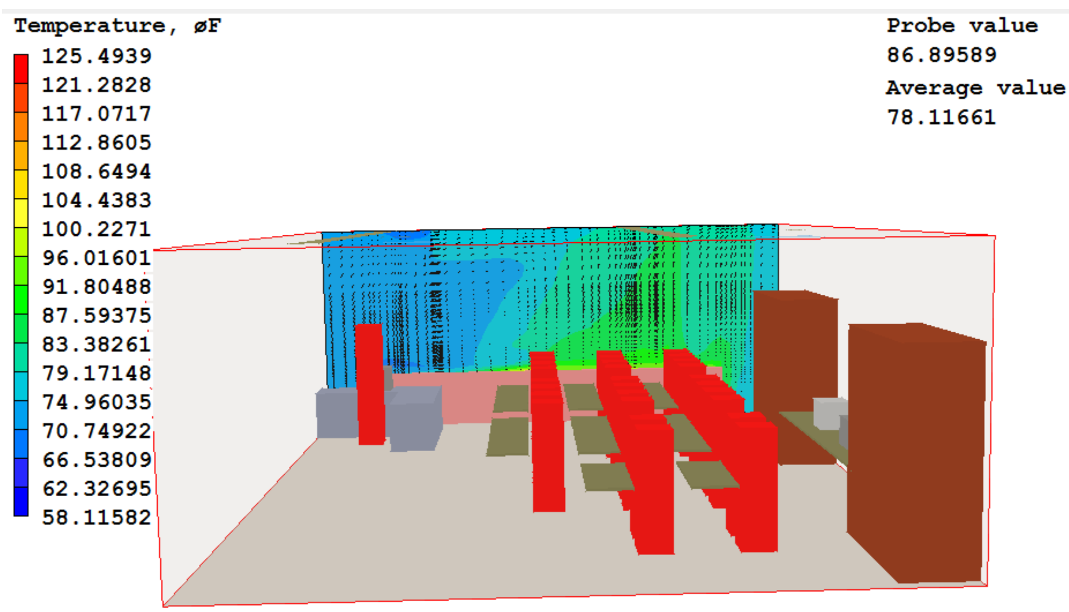


Figure 41 – VAV Full Flow, Temperature (along y-axis)

For this snapshot, it can be seen that the temperatures near the window are much higher than the room setpoint. This is because the fin tube radiator under the window is running at full blast. The temperature here is really high (probe located above the fin tube radiator), but as you move further away it becomes more uniform and closer to the room setpoint.

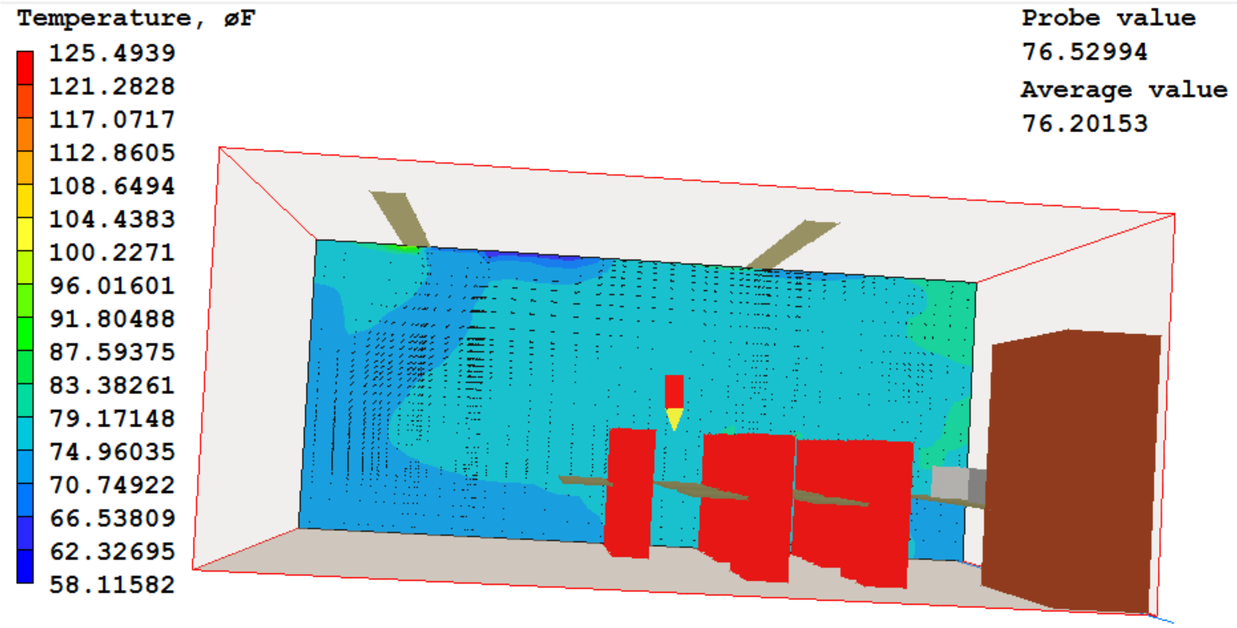


Figure 42 – VAV Full Flow, Temperature (along y-axis)

The temperature around the students is well above the setpoint of 72°F – high enough to cause discomfort.

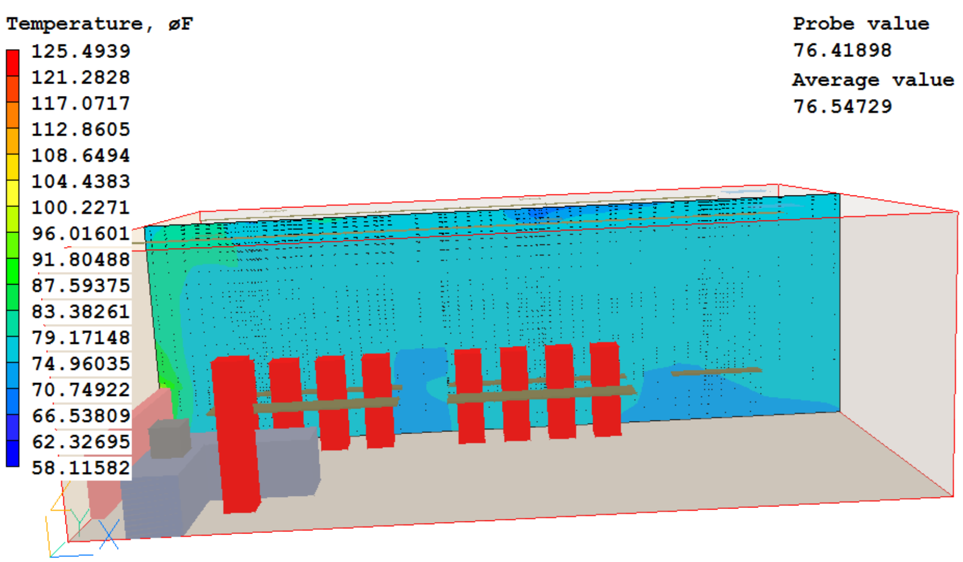
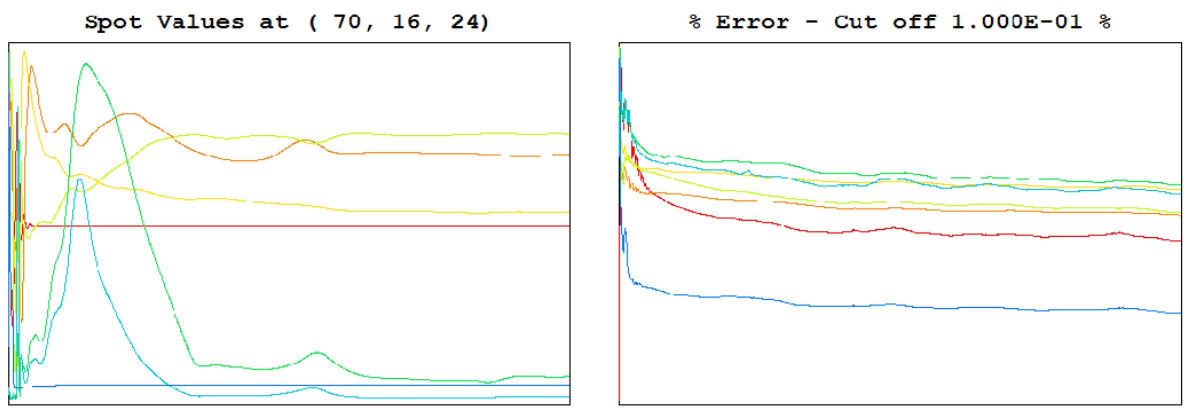


Figure 43 – VAV Full Flow, Temperature (along x-axis)

The probe is by the students next to the fin tube radiator. It can be seen that the air around the students here is also well over the room setpoint, it's about 76°F. This will cause discomfort to the students in this area. The temperature is a bit high throughout this cross section – averaging around 76.5°F. This can be fixed by dialing back the fin tube radiator. The fin tube radiator was on full blast at worst case scenario for this run. It's weird that the energy balance on the room showed that the space had a little excess cooling but yet the room appears to be overheated.

When the probe was placed at the return outlets in the VAV full flow, the temperature was found to be approximately 77°F. This is 5 degrees higher than the room setpoint. From the temperature distribution in the room it can be seen that the space would be too hot for the occupants.

<u>VAV 30% Flow Results</u>: The results for the 30% turndown VAV flow are shown now. For this scenario only a little heat would come out of the fin tube radiators because the loads in the room create enough heat to make up for the negative heat flux through the window and exterior wall. Also the fin tube radiator is needed to prevent drafts at the window. The mass residual is 2.178% and the energy residual is 0.49% - both falls within the acceptable range. Below is the mass residual figure.



Value	Change	Low	High	Variable	Max	% Error	Change
-3.35E-01	1.40E-06	-2.00E+01	2.00E+01	P1	2.00E+06	1.94E+02	-3.18E-01
8.88E-03	-7.19E-06	-2.00E-01	1.00E-01	U1	1.00E+11	1.95E+05	-1.81E+02
2.57E-02	-4.41E-06	-4.00E-01	4.00E-01	V1	6.31E+09	2.75E+05	-1.52E+02
2.55E-03	-1.39E-05	-6.00E-01	2.00E-01	W1	3.98E+09	4.31E+04	1.78E+01
6.05E-04	4.06E-07	0.00E+00	9.00E-03	KE	6.31E+07	2.33E+04	2.64E+01
1.61E-05	-1.02E-08	0.00E+00	2.00E-03	EP	1.58E+08	2.36E+04	-1.08E+01
2.52E+01	-2.33E-04	0.00E+00	6.00E+02	TEM1	1.00E+11	9.44E+01	-9.41E-02

NX NY NZ ISWEEP 5000 Time now 5:34
76 72 42 IZSTEP OFF (h:m) est 5:34
Press a character key to interrupt.

Figure 44 – Residual Figure VAV 30% Flow

The 30% vav flow model took 5 hours and 34 minutes to run. The velocity profiles for this scenario are shown starting on the next page.

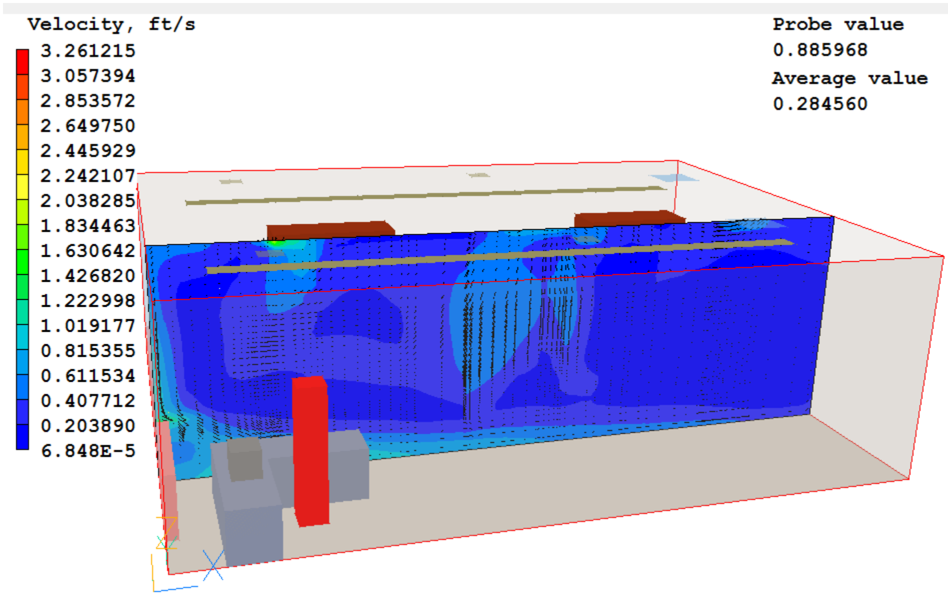


Figure 45 – VAV 30% Flow, Velocity (along x-axis)

It can be seen from this image that a lot of air movement occurs around the radiator. This is because the radiator is not putting out enough heat to negate the cold window and wall. The probe is located above the radiator and shows that the velocity is so high here that it will cause drafts.

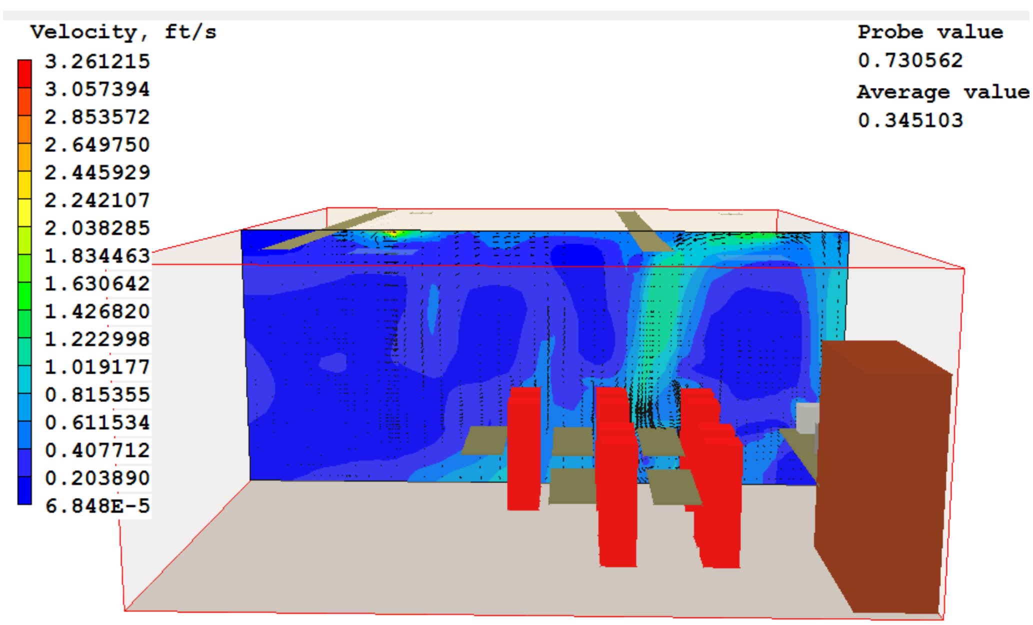


Figure 46 – VAV 30% Flow, Velocity (along y-axis)

The velocity in this slide is well above the recommended 40 fpm. As the probe travels higher into the green contours, the drafts become worse and worse. Near the front board the velocity is fine but in the 30% VAV flow model, many locations were found to have high velocities which would cause drafts. This is an example of one of them. Drafts occur overhead due to the low momentum and low temperature of the air. The air leaving the diffuser is very cold compared to the room (58°F supply, room setpoint 72°F). Since the air has such a low momentum and it is very cold, not all of the air sticks to the ceiling (Coanda effect) but instead sinks into the space causing drafts (cold air falls). This is a common problem in reduced flow for VAV systems.

Next are the temperature distributions in the rooms for the 30% VAV flow.

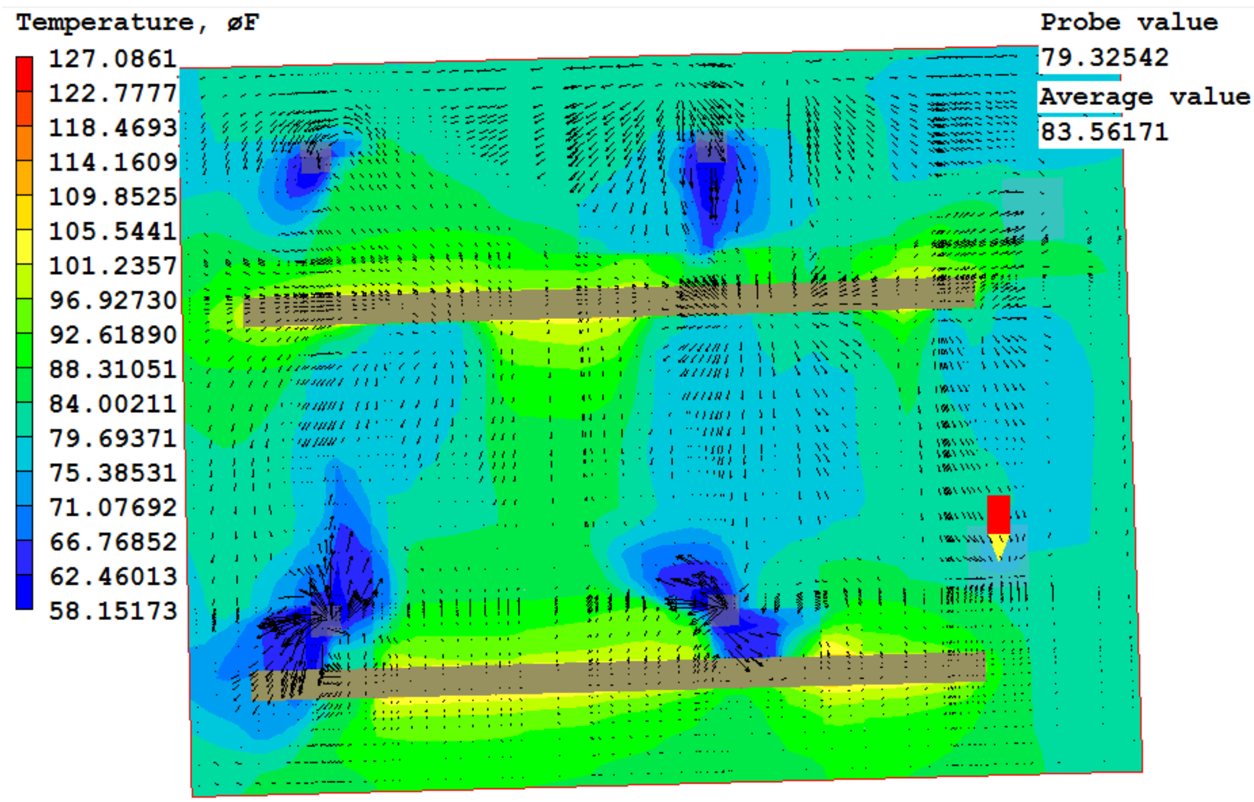


Figure 47 – VAV 30% Flow, Temperature (along z-axis)

The probe is located in the return outlet. The above shot is overhead looking down at the room.

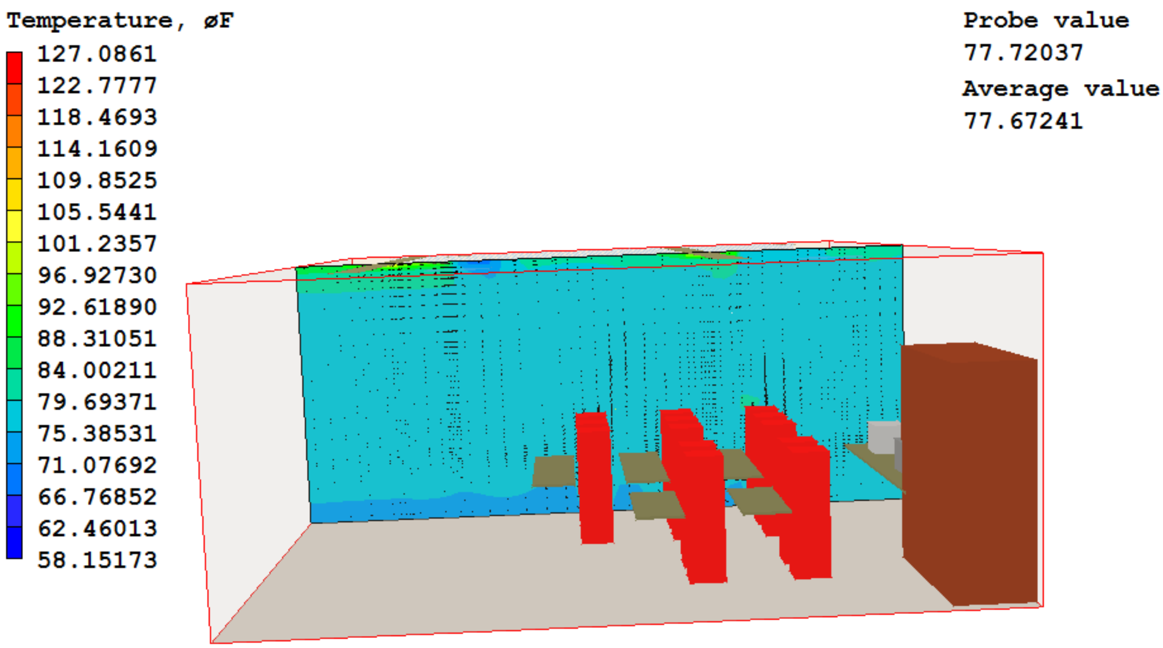


Figure 48 – VAV 30% Flow, Temperature (along y-axis)

The temperature in this cross section is 5 degrees above the setpoint. The room is too hot in the student area. This temperature was taken in the middle of the room where the cooling done by the supply air is not enough to match the heat given off by the students and far enough away from the window so the loses through the façade can't be felt.

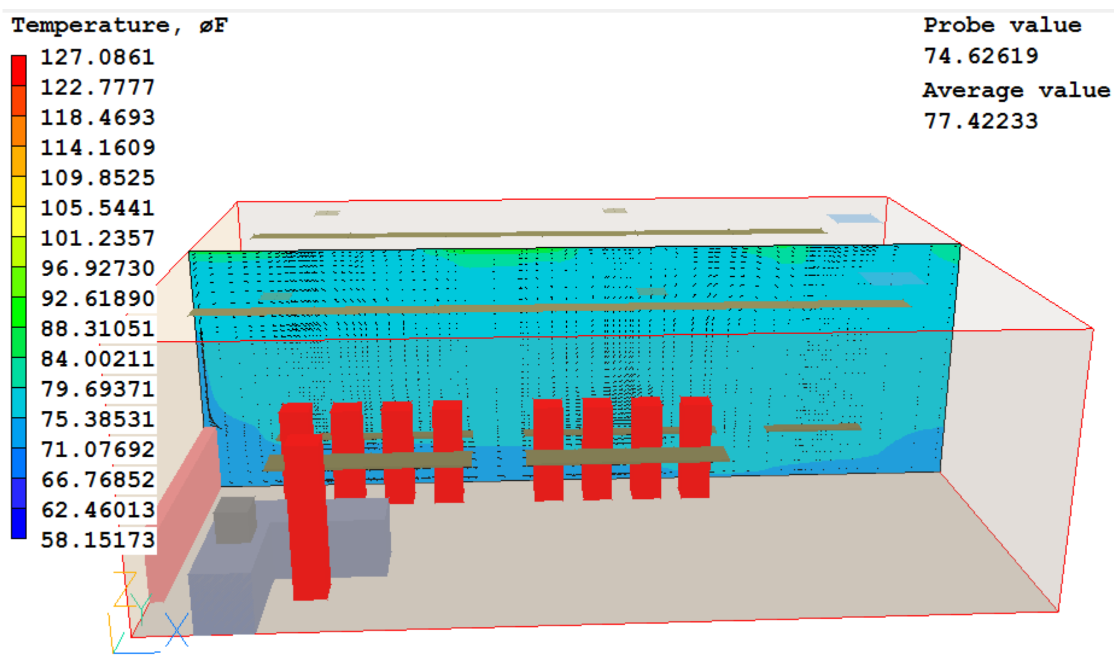


Figure 49 – VAV 30% Flow, Temperature (along x-axis)

Once again the temperatures in the cross section are much too high and will cause discomfort to the occupants in the room. For this picture, the probe was located next to the students near the window. The effects of the cold window can be seen on the temperature of the air in the space. The hot air is cooled over the window and falls to the ground by the fin tube radiator. The fin tube radiator is on to help negate the cooling done by the window but it ends up putting extra Watts in the room past the equilibrium point. This means the room should be a bit above the setpoint temperature but on average it is well above.

The 30% flow VAV results show a lot of drafts created in the room under the diffusers along with too high of temperatures in the space. The drafts are a bit confusing considering the velocity of the air supplied to the room is much slower that the full VAV flow model which didn't seem to have any draft problems. The conclusions for both the VAV models show that the spaces will be overheated and that there is a problem with high temperatures for the students near the fin tube radiators as well as draft problems for the 30% VAV flow model.

<u>FPIU Model</u>: The airflow and temperature fields were investigated under non-isothermal conditions for the FPIU model during the heating season (coldest winter day). The residuals found for mass and energy were 1.3% and 0.174%, respectively. Both residuals fall within the recommended ranges. The residual figure for this run can be seen below.

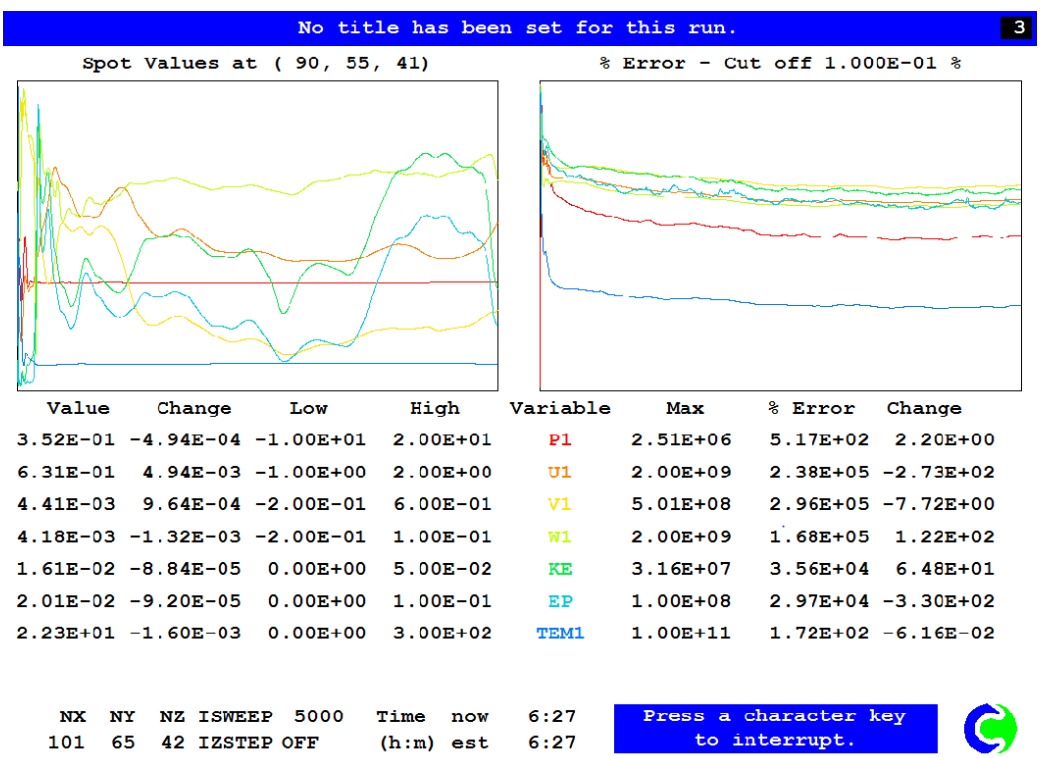


Figure 50 – Residual Figure FPIU Model

The model took 6 hours and 27 minutes to run. The velocity profiles found can be seen below.

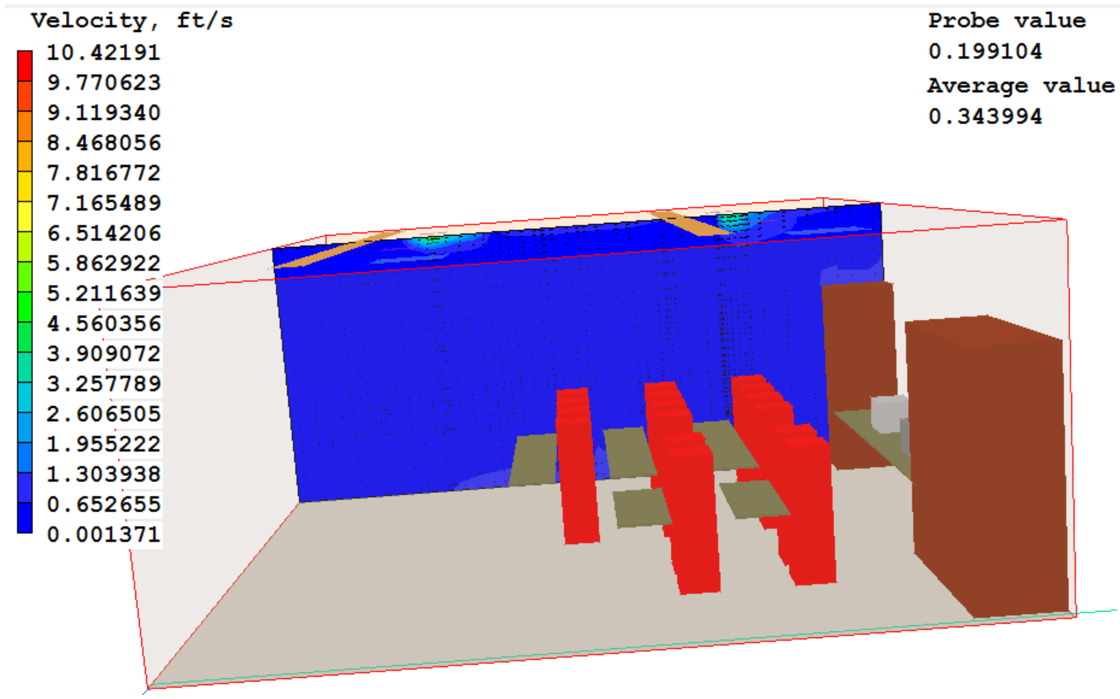


Figure 51 – FPIU Flow, Velocity (along y-axis)

The probe is located 4' off the ground around the students.

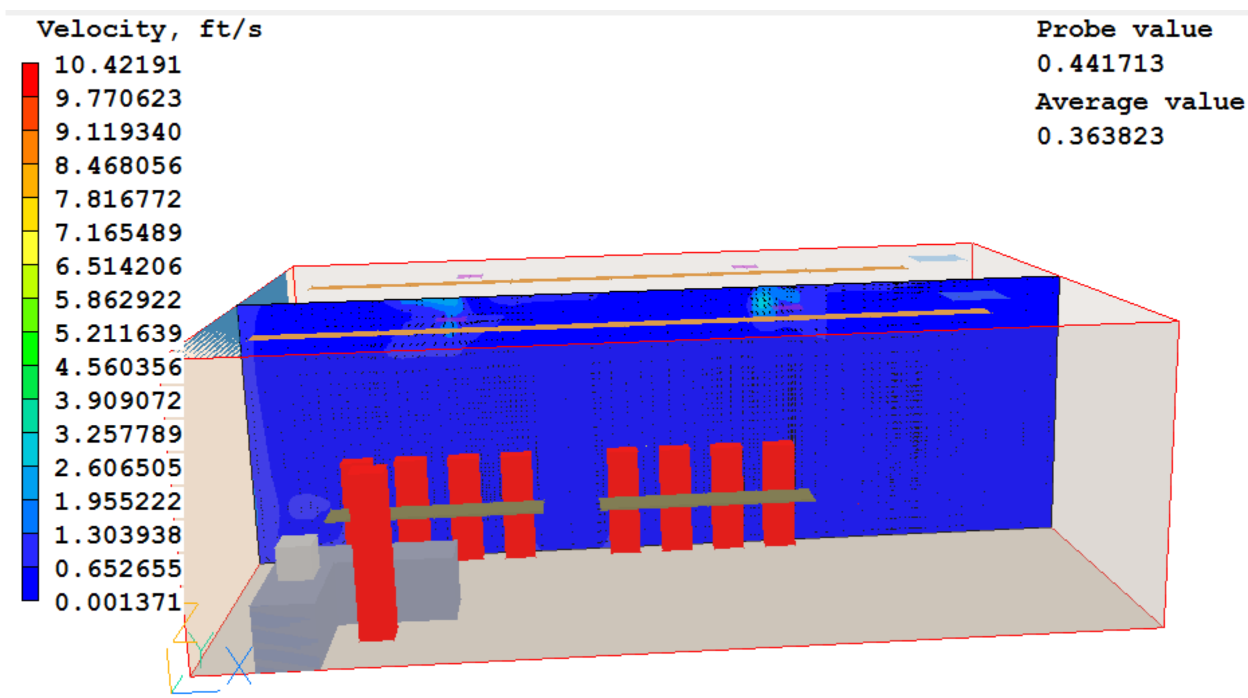


Figure 52 – FPIU Flow, Velocity (along x-axis)

Around the students, the air has a velocity less than 40 fpm meaning that there should be no drafts. The velocity of the air by the window is a bit higher (around 60 fpm). This is due to the drafts caused by the air being cooled when it goes over the window. These drafts however do not cross over into the student area. There may be a little draft along the side of the students closest to the window.

The temperature profiles for the FPIU model are shown below.

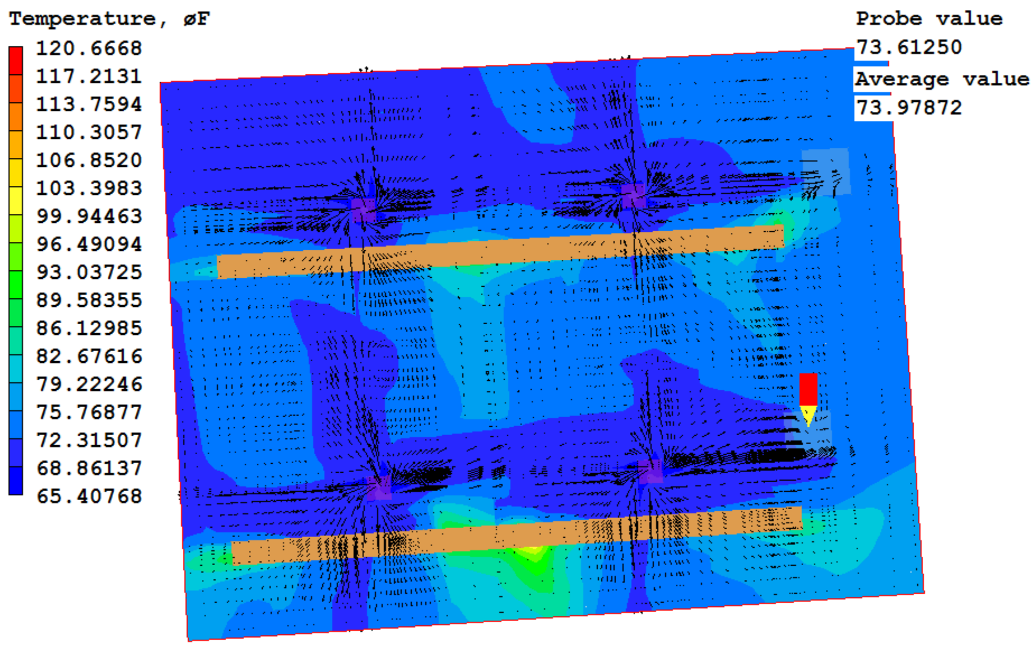


Figure 53 – FPIU Flow, Temperature (along z-axis)

The probe is located in the return outlet. This snapshot is an overhead view of the room.

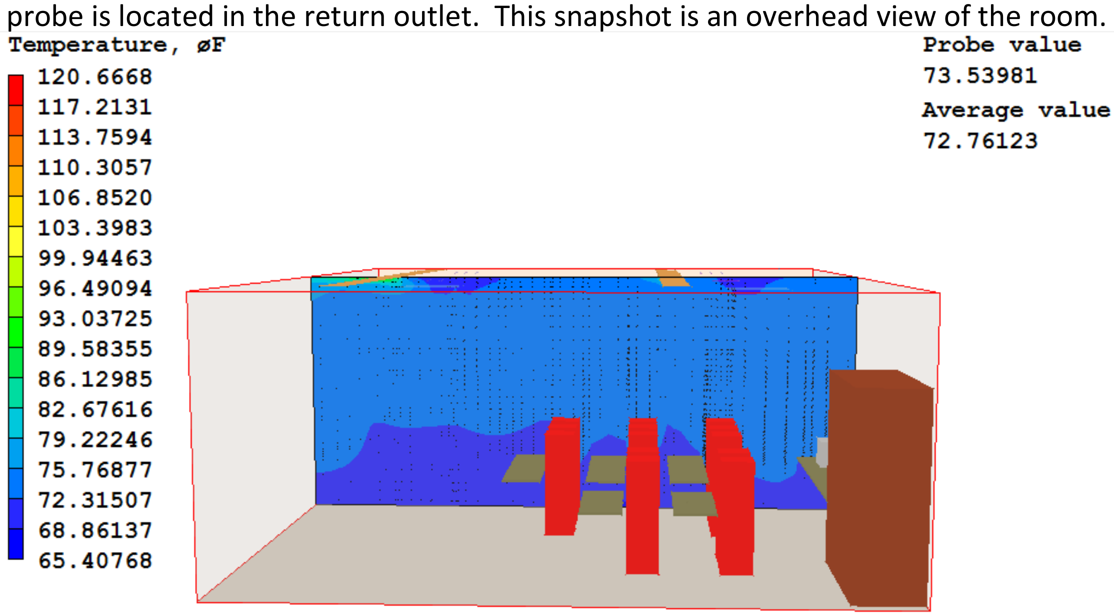


Figure 54 – FPIU Flow, Temperature (along y-axis)

It can be seen that the temperature around the students is on average slightly above the setpoint by only 1 degree. This is very promising. No big temperature differences exist and the room appears to have a uniform temperature.

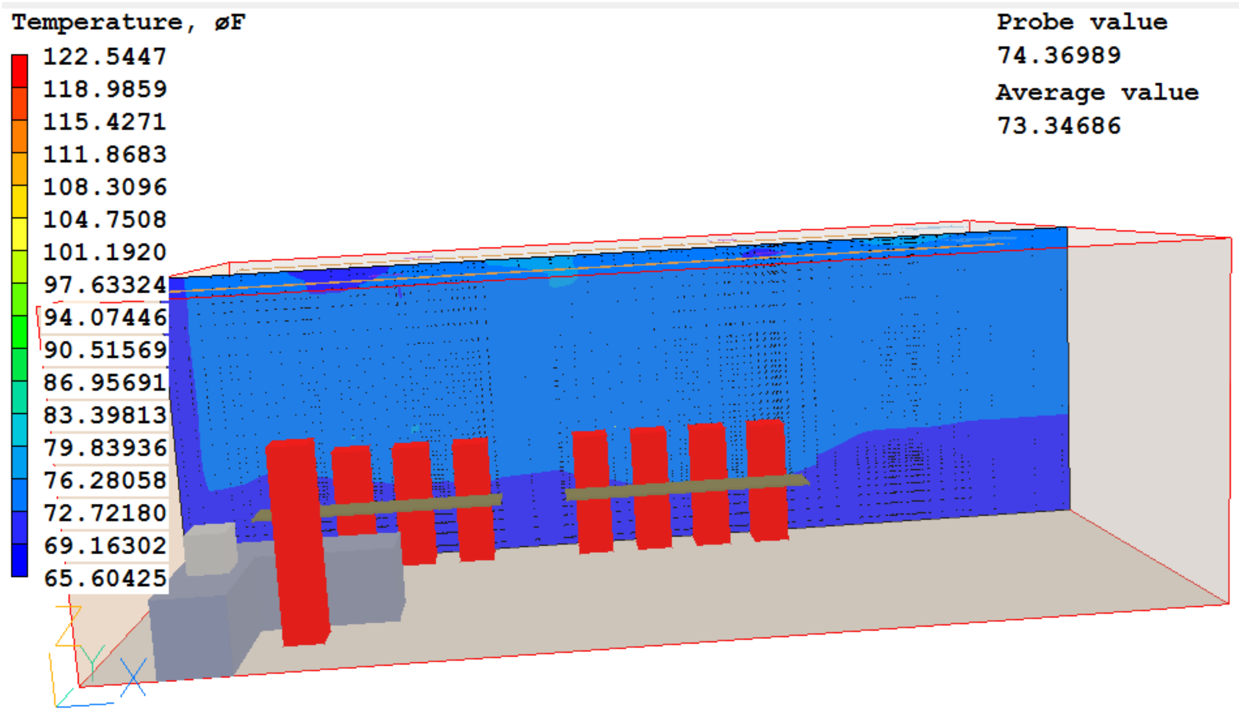


Figure 55 – FPIU Flow, Temperature (along x-axis)

Though a few different contour colors appear in the student area, the temperatures in this area only range from 68°F to 73°F where the 68°F is at the feet of the occupants and the 73°F is well above the students' heads. It can be seen that the heat loses through the window have an effect on the temperature in this area. Surprisingly though, the temperature is not lowered enough near the students to create thermal discomfort. The temperature is about 69°F at the wall but this is not within the occupied area so it is fine.

The temperature around the students is typically 72°F to 73°F. The return temperature was found to be 73.5°F in the return outlet. The set point temperature of the room is 72°F so the average temperature is directly on target. From these results it appears there should be no thermal discomfort in the FPIU room's layout.

<u>Comparing Results:</u> The results from the FPIU scenario show the best air mixing and distribution in the space. Air velocity is kept below the recommended value of 40 fpm in the occupants' space to prevent drafts. The temperature in the room is right around the setpoint of 72°F (pretty much everywhere in the occupied zone). The best part about the FPIU results is it created a very uniform temperature and velocity profile in the room. This is great considering

the space layout can be rearranged without worrying about whether there will be draft problems or great temperature fluctuations in different parts of the room.

The VAV models gave mixed results. A major draft problem occurred in the 30% VAV flow scenario. Both suffered from areas with temperatures well above the room setpoint. The air velocity around the students in the full flow VAV model was mostly below 40 fpm but random drafty areas did appear. In real life, the best option for the VAV system would be to turn it down somewhere between full and 30% flow and modulate the fin tube radiator's output accordingly. The results do not lead me to believe that the VAV system cannot create a thermal comfortable room free of drafts. The results for these two scenarios just show that with the current set up of the diffusers' supply cfm and temperature along with the fin tube radiator will not produce a thermally comfortable room.

Electrical Breadth

With the downsizing of the air handling units and splitting the original one chilled water loop with two chillers into a two chilled water loop with 3 smaller chillers, allowed for sufficient roof space to be cleared. Along with moving the chillers and new DOAS units around (as well as a few exhaust fans), the northeast roof area was freed up to allow photovoltaic solar panels to be installed. Though New York as a state does not have the most ideal features for solar panel installation in terms of sun, the solar array on the top of Hunter's Point South School would have direct sunlight with very minimal shading. No taller buildings or structures exist near Hunter's Point South School and all of the exhaust vents and fans have been moved behind the solar array (north of it). The adjourning roof parapet in the corner will have to be reduced to the same size as the rest of the extended exterior wall (4 feet above the roof) to allow for better solar gains. This can be seen in Figure 56 below.

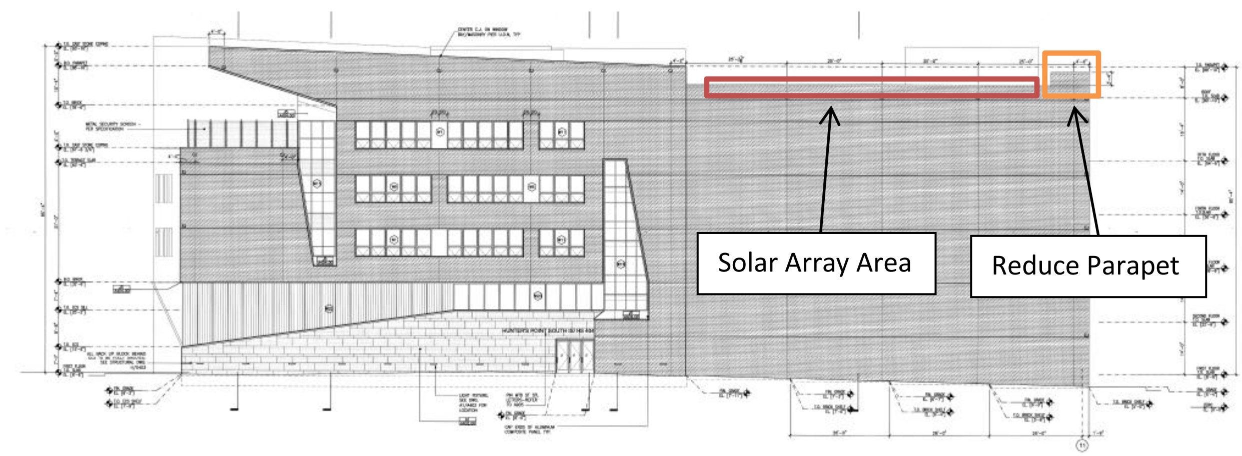


Figure 56 – Southern Elevation Drawing (from A202)

The most beneficial reason for photovoltaic solar panels is that New York has the third highest electricity cost of states in the U.S. at 19 cents per kWh. This means that the solar array will payback quicker and produce a bigger payout in its life cycle.

The first step was determining which solar panel to choose and what mounting system would work with the panels. The SunPower 308 Watt solar panel was chosen for its optimum electrical performance. This panel has an 18% efficiency rating as compared to the 14% conventional panels have and since it is a larger panel it produces more electricity. This panel was also largely chosen because it would work with the SunPower PowerGuard mounting system. For buildings over 60 feet tall, typical solar panels cannot be used because of the great upwind forces on the panels. Since the roof of Hunter's Point South School is approximately 72 feet in the air, the SunPower 308 Watt solar panel in conjunction with the SunPower PowerGuard mounting system would work for this installation.

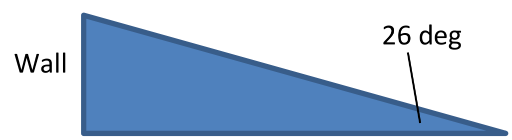
The SunPower PowerGuard allows for the solar panels to lie flush on the roof. The optimal tilt for a fixed solar array operating year round is 33.5 degrees in Queens, New York. However, since the panels will be flat less electrical production will occur. Though this is not desirable, there are some advantages to the SunPower PowerGuard. No roof penetrations will need to be made to anchor the system to the roof (instead cement pavers are used along the perimeter to hold the array down) so no leaking in the roof will occur. PowerGuard can be used for roofs that are over 60 feet in the air and work well with SunPower 308 Watt panels.

The next step was laying the panels out on the roof. SunPower 308 Watt panels must be strung out in multiples of 8 (meaning the total number of solar panels must be a multiple of 8). A minimum of nine feet is required for a step back from the edge of the roof to allow for maintenance and to reduce upwind effects. This 9 foot setback is checked below to make sure no shading would occur on the panels from the wall that extends four feet up along the perimeter of the roof during the winter solstice. In the winter solstice the sun will have an altitude of 26 degrees at its low point. Using the Pythagorean Theorem it can be seen that the setback of 9 feet is sufficient enough so that the 4 foot wall extension will not shade the panels.

SohCahToa:

$$Tan(26°) = 4' \div x$$

$$x = 8.2'$$



The shadow will only reach 8.2 feet in from the wall so the solar panels are safe (9 feet back from the wall).

A 10 foot wall is directly to the left of the solar panel system. In the winter this wall will cast a 20 foot shadow. Since there is a setback of 9 feet form this wall, then 11' into the installation will be shaded. This is approximately 2 panels in. This is bad but as long as the sun is above a 42 degree angle, no shading will occur on the panels. For this shading to occur, the sun must be on its way down in the west. The wall is directly northwest of the solar array meaning that it will only cast a shadow once a day when the sun is setting. This means that the shading will not occur during peak energy generation during the day. In the end this wall will not have too great of an effect on the solar generation – thus it has been neglected for this analysis.

The final solar panel array along with its setbacks can be seen in Figure x below. Note that a 1.5 foot border surrounds the solar panels. This is part of the PowerGuard where the cement pavers weigh down the installation. The final shape is a complete rectangle that consists of 224 photovoltaic solar panels. Many customers are very picky that their solar arrays be complete rectangles for the aesthetic purpose.

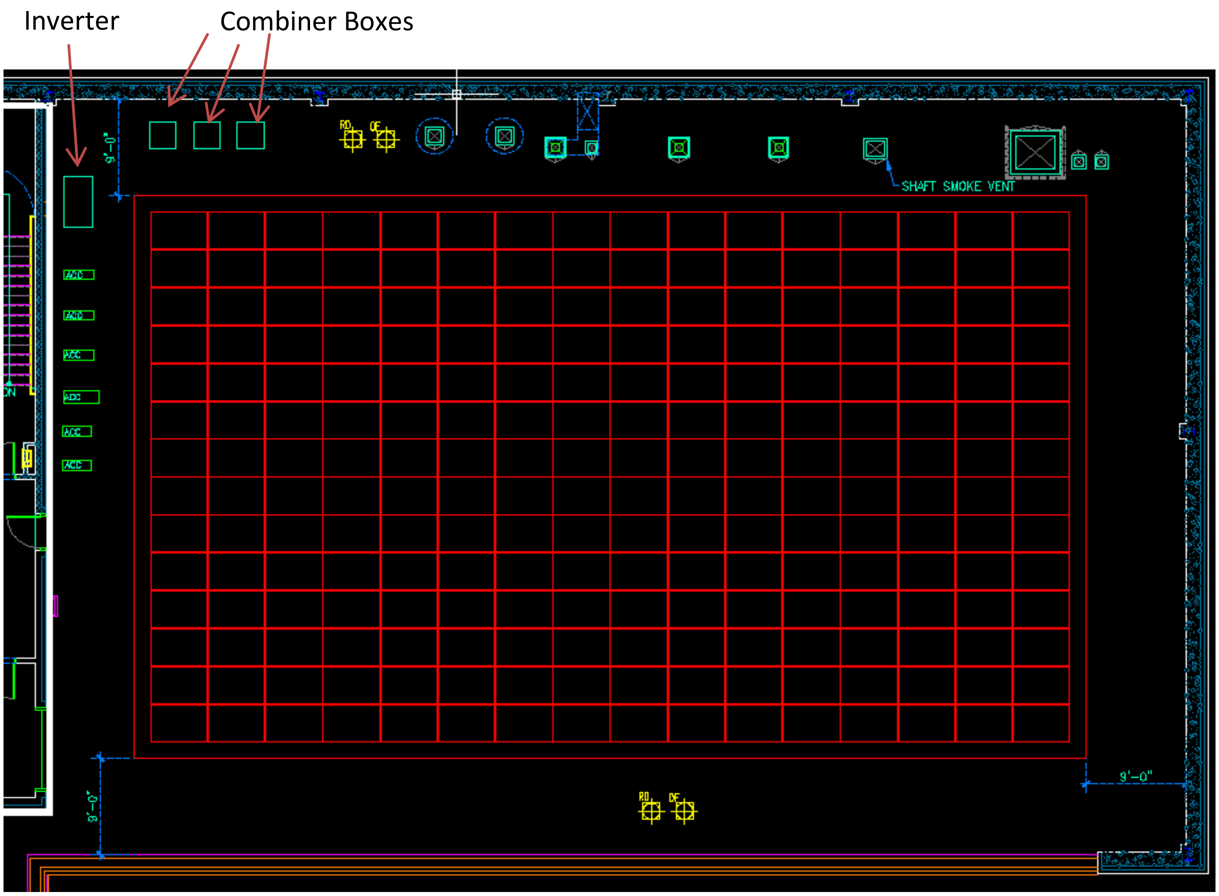


Figure 57 – Solar Panel Array

Once the array was laid out, the electrical production and life cycle analysis could be performed. The total system size for the solar array is 68.99 kW (224 panels times 308 Watts). It was chosen to use a 75 kW Satcon Inverter for this array. The system produces approximately 78,884 kWh per year which equates to 5% of Hunter's Point South School's new electrical bill (for the new changes proposed). Though this may not be a large percent, it will still save the school money and produce emission free electricity – making the building more sustainable. Electrical production on a month to month basis can be seen below in Figure 58 along with how much money the production will save the school a year in Table 38 (this is assuming the current rate of $0.19 per kWh).

Appendices AC through AE have the specifications for the solar equipment used. The appendices show the SunPower 308 Panel, SunPower PowerGuard, and Satcon 75 kW Inverter, respectively. This information is shown to give a better understanding of the equipment. The short circuit current found on the SunPower 308 Panel specifications was used in the calculations that follow to size the wire. Also note the inverter is NEMA 3R meaning that it can be installed outside (on the roof). This saves space in the mechanical penthouse.

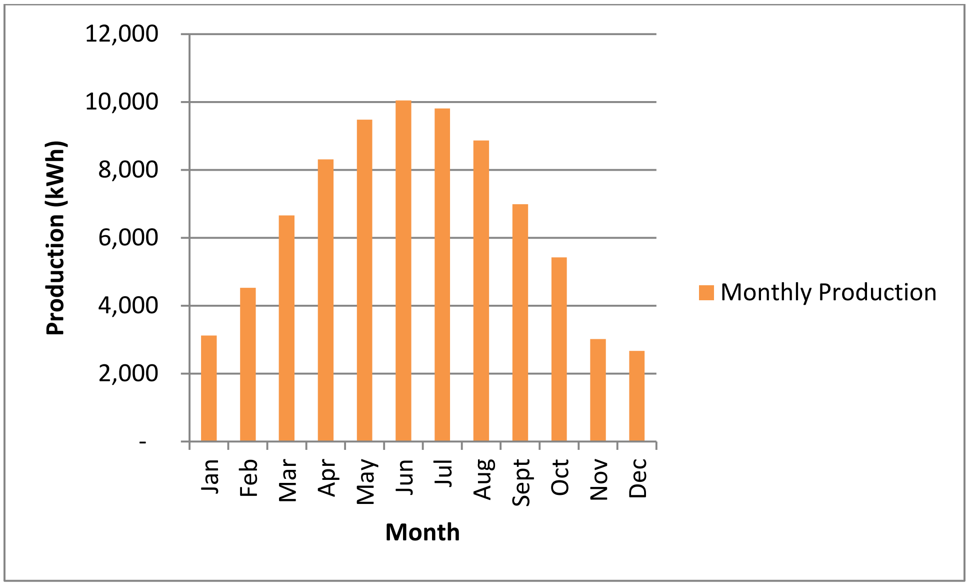


Figure 58 – Monthly Electrical Production

Month	Production (kWh)	Electrical Savings
Jan	3,117	$ 592.23
Feb	4,526	$ 859.94
Mar	6,654	$ 1,264.26
Apr	8,308	$ 1,578.52
May	9,477	$ 1,800.63
Jun	10,045	$ 1,908.55
Jul	9,803	$ 1,862.57
Aug	8,860	$ 1,683.40
Sept	6,984	$ 1,326.96
Oct	5,423	$ 1,030.37
Nov	3,018	$ 573.42
Dec	2,669	$ 507.11
Totals:	78,884	$14,987.96

Table 38 – Monthly Electrical Savings

The total cost of the solar array (including installation/labor as well as all the wiring, combiner boxes, inverter, etc.) is $296,666. Though this may seem like a large amount at first, there are many federal and state incentives that will help lower this price. The first incentive is the

Renewable Energy Grant given by the U.S. Department of Treasury. For solar electric, this grant is equal to 30% of the total solar array cost (meaning $89,000 in this case). The next incentive is the New York City Property Tax Abatement. This is a state incentive that allows for a property tax deduction equal to 5% of the total photovoltaic array cost annually for 4 years (meaning 20% of the total cost in the end). This equates to a savings of $59,333. The last incentive is the Modified Accelerated Cost-Recovery System (MACRS) Depreciation. This is a federal incentive that allows for renewable energy technologies (such as solar) to be classified as a five-year property for depreciation deductions. This will result in a savings of $88,258 over five years. After all the incentives it can be seen that the solar array which originally cost $296,666 will be reduced to a cost of $60,075 (20.3% of the original price).

It is important to mention that there are also other New York State incentives for solar photovoltaic installations. However, Hunter’s Point South School is not eligible for this because they purchase their power from the New York Power Authority (NYPA). The other incentives require that the buildings that install solar buy their electric from companies that pay to the System Benefits Charge (SBC) or Renewable Portfolio Standard (RPS). Since the NYPA does not pay to either of these causes, Hunter’s Point South School is not eligible for additional solar incentives in New York. Lastly, New York does not have an SREC market (solar renewable energy credit). SREC credits may be sold from the solar array owner to power companies in SREC markets. This accounts for a good chunk of money for solar producers. It is estimated that Hunter’s Point South School could sell their SREC credits for approximately $20,000 per year if New York were to have a similar SREC market to Pennsylvania’s. Unfortunately, it does not have an SREC market at all.

Solar arrays of this magnitude are usually paid for using a loan and can be available through SunPower for SunPower products. Since significant upfront savings were made in the mechanical alterations, no loan was needed to pay for this solar array. A cash flow diagram year to year for the 25 year life cycle can be seen below in Table 39. The red represents negative cash flow. Also note that an inverter replacement is assumed in year 15 which accounts for the much higher maintenance cost. Electric savings each year are not symmetric because price escalation was assumed for electricity costs over time, as well as for maintenance.

Year:	0	1	2	3	4	5	6	7	8	9	10	11	12
Maintenance	$ -	$ 300	$ 300	$ 300	$ 300	$ 300	$ 300	$ 300	$ 300	$ 300	$ 300	$ 300	$ 300
Renewable Energy Grant (Treasury)	$ -	$ 89,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
NY City Property Tax Abatement	$ -	$ 14,833	$ 14,833	$ 14,833	$ 14,833	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
MACRS Depreciation	$ -	$ 52,955	$ 14,121	$ 8,826	$ 5,295	$ 7,061	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Electric Savings	$ -	$ 13,939	$ 13,639	$ 13,639	$ 13,489	$ 13,489	$ 13,489	$ 13,639	$ 13,789	$ 13,939	$ 14,089	$ 14,089	$ 14,089
Payments	$ 296,666	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Annual Cash Flow	$(296,666)	$ 170,427	$ 42,293	$ 36,998	$ 33,317	$ 20,250	$ 13,189	$ 13,339	$ 13,489	$ 13,639	$ 13,789	$ 13,789	$ 13,789
Cumulative Cash Flow	$(296,666)	$(126,239)	$ (83,946)	$(46,948)	$(13,631)	$ 6,619	$ 19,809	$ 33,148	$ 46,637	$ 60,275	$ 74,064	$ 87,853	$101,642

13	14	15	16	17	18	19	20	21	22	23	24	25
$ 300	$ 300	$ 20,600	$ 300	$ 300	$ 300	$ 300	$ 300	$ 300	$ 300	$ 300	$ 300	$ 300
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 14,089	$ 14,089	$ 14,089	$ 14,089	$ 13,939	$ 13,939	$ 13,939	$ 14,089	$ 14,089	$ 14,239	$ 14,239	$ 14,239	$ 14,239
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 13,789	$ 13,789	$ (6,511)	$ 13,789	$ 13,639	$ 13,639	$ 13,639	$ 13,789	$ 13,789	$ 13,939	$ 13,939	$ 13,939	$ 13,939
$115,430	$129,219	$122,708	$136,497	$150,135	$163,774	$177,413	$191,202	$204,990	$218,929	$232,868	$246,806	$260,745

Table 39 – Life Cycle Cost

After computing all the incentives in the life cycle analysis, the photovoltaic solar array had a five year payback (red box in Table x above shows this). Over the course of its 25 year life, the system produces 1,972,100 kWh. This equates to reducing greenhouse gas emissions by 1,351 tons of CO_2. With electric price escalation, the system had a cumulative cash flow of $260,745 which is a total life-cycle payback of 188%.

Lastly, the system had to have its parts sized and be tied into Hunter’s Point South School. Below in Figure 59 is a schematic of a string of solar panels (8 solar panels tied together). Notice how the panels are combined negative to positive. After the panels are put in strings, they are then fed to combiner boxes. It was calculated 3 combiner boxes were needed – 10 strings of panels each to 2 of boxes and 8 strings to another (10 x 8 x 2 + 8 x 8 = 224 panels).

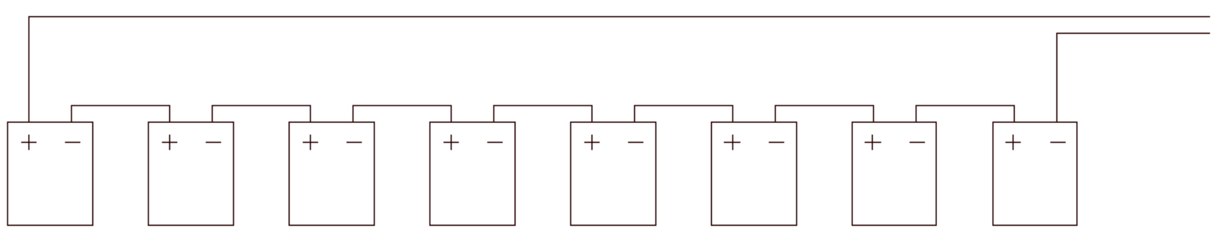


Figure 59 – String of Panels

On the next page is a diagram of the whole solar photovoltaic system in Figure 60, the wire sizes are called out as well. The panels are strung and then fed into 3 combiner boxes. From there the combiner boxes feed into the DC Disconnect and then the DC current is converted to useful AC current for the building in the inverter. From the inverter the current travels through the AC Disconnect and is back fed into Switchboard 2. Switchboard 2 was chosen because it has 3 open poles on it.

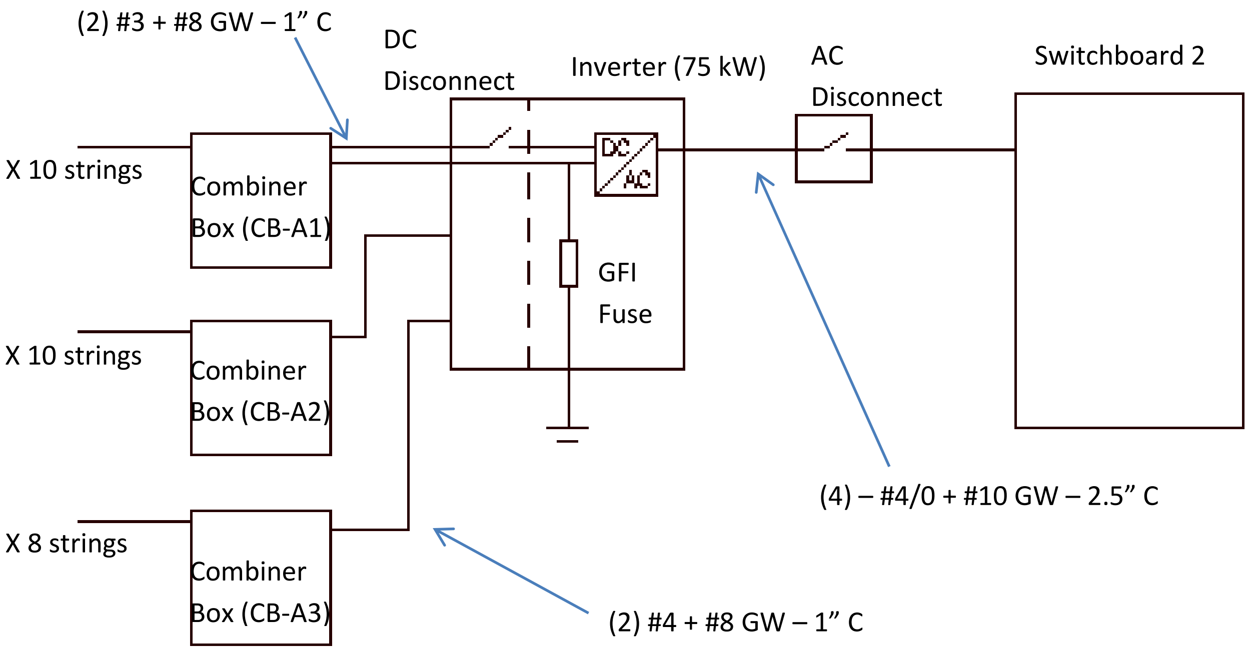


Figure 60 – Schematic of Solar Photovoltaic System

The calculations for the wire sizing can be seen in Appendix AF. Appendix AG has the NEC Tables referred to in the wire sizing calculations. Below is a summary in Table 40 of the combiner box sizing.

Name	# of Circuits	Maximum Current (Amps)	Output Wire Size (2)	Fuse Rating (Amps)	Ground Wire Size	EMT Size
CB-A1	10	75.3	3 AWG	80	8 AWG	1"
CB-A2	10	75.3	3 AWG	80	8 AWG	1"
CB-A3	8	60.2	4 AWG	75	8 AWG	1"

Table 40 – Combiner Box Information

Switchboard 2 had to be tied into from the inverter. An image of the balancing on the current Switchboard 2 can be seen below in Figure 61.

JOB NUMBER					
DISTRIBUTION PANEL	SWBD-2 (SERVICE)	3PH, 4W+G,			
VOLTAGE	208				
BUS SIZE	2000	10		LOCATION	1st Fl Elec Service Rm
PROTECTIVE DEVICE	1	(Fuse=1 Bkr=2)		MOUNTING	FLOOR
MAIN OVERCURRENT DEVICE		2000		AIC	200000

CKT No	NAME	HP	KVA	AMP	POLE	PROTECTIVE DEVICE SW/BKR FRAME	FUSE/ TRIP	WIRE PER/SET	FEEDER SETS	WIRE SIZE	COND SIZE	NEUTR SIZE	GND SIZE
1	1EDP-LS/ATS-LS		231	640	3	800	800	4	2	500	3 1/2	500	2/0
2	Panel 5DP-K1		107	297	3	400	400	4	1	500	3 1/2	500	2
3	Panel 3LP-DIM-1		57	159	3	200	200	4	1	3/0	2	3/0	4
4	Panels (1-2)AP-B		42	116	3	200	150	4	1	1/0	2	1/0	6
5	Panels (3-4)AP-B		70	194	3	400	250	4	1	250	2 1/2	250	4
6	Panels (3-5)AP-A		53	146	3	200	200	4	1	3/0	2	3/0	4
7	Panels (1-2)AP-A		63	175	3	400	225	4	1	4/0	2 1/2	4/0	4
8	Panels (1-3)LP-A		66	183	3	400	250	4	1	250	2 1/2	250	4
9	Panel (4-5)LP-A		45	126	3	200	175	4	1	2/0	2	2/0	6
10	Panel 3LP-DIM-2		57	158	3	200	200	4	1	3/0	2	3/0	4
11	Spare			0	0	400	0	0	#N/A	#N/A	#N/A	#N/A	#N/A
12	Spare			0	0	400	0	0	#N/A	#N/A	#N/A	#N/A	#N/A
13	Spare			0	0	200	0	0	#N/A	#N/A	#N/A	#N/A	#N/A
TOTAL KVA				790									
TOTAL AMP				2194									
SPARE (DECIMAL)				0.1									
DEM. (DECIMAL)				0.7									
FEEDER DEMAND AMP				1755									

Figure 61 – Switchboard 2 Initial

The original breaker on the switchboard was 2000 Amps. Adding in the inverter will add 208 Amps. The breaker is sized based on the feeder demand amperage. The old panel had a demand amperage of 1755. A demand factor was not included for the inverter. This gives a total new demand amperage of 1755 + 208 = 1963 Amps. This is still below the 2000 Amps breaker so there is no need for an upsize. The balanced new switchboard 2 can be seen in Appendix AH.

Structural Breadth

When solar panels are added to a roof a structural analysis must always be performed. The non-composite deck, beams, girders, and columns were checked to see if the extra weight would be managed. The structural calculations, assumptions, and drawing layout can be seen in Appendix AI for all of the above listed as well as the pages used in the steel manual and Vulcraft catalog after the calculations in Appendices AJ through AL. The results showed that the beams and columns were sufficient with the added load. However, the non-composite deck and girder had to be upsized. The non-composite deck failed due to deflection under live and total load. The deck was originally designed as a 3.25" lightweight concrete over a 3" deep-18 gage metal deck. It has been changed to a Vulcraft 2C16 non-composite deck, which is 5" lightweight concrete with a 3" deep-16 gage deck. The girders also failed under total load deflection. The girders were upsized from a W21x50 to a W24x55.

The new DOAS units sit atop the old AHU's positions and the new chillers sit on the existing chillers' locations. Since the new DOAS units weigh less than the existing AHU's and the new chillers weigh less than the old ones, a structural analysis will not be needed to prove that the roof will support these new loads. A reduction in weight on the roof will not cause it to fail. The old roof layout can be seen below in Figure 62 (the mechanical equipment being changed is bold labeled).

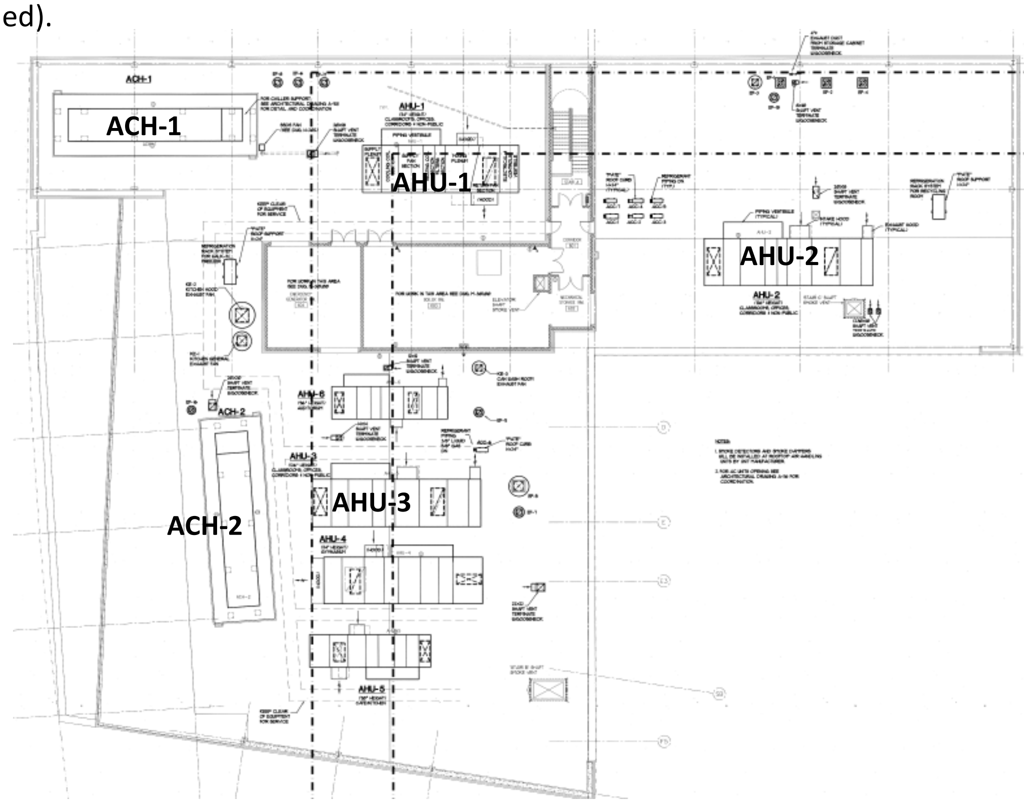


Figure 62 – Old Roof Layout

The locations of the three new chillers, 2 DOAS units, and the photovoltaic solar panels can be seen below in Figure 63 in red.

Figure 63 – New Roof Layout

Lastly, the upgrades to the current roof were priced. The prices for the structural roof upgrades can be seen below in Table 41 and the calculations in Appendix AM. The total cost for the upgrades was $18,501.79. This is a onetime cost and requires no maintenance. This cost is easily paid off by the solar panels.

Structural Upgrade Costs			
Lightweight Conrete	Steel Deck	Girders	Total Cost
$ 8,392.23	$9,398.36	$711.20	$18,501.79

Table 41 – Structural Upgrade Costs

Results

Energy Reduction and Costs

After all of the design changes, it was found that there would be both an electricity savings each year as well as a savings in natural gas. The savings can be seen below in Table 42 as well as the cost savings per year. The numbers from the original Design Engineer's calculations are added as reference.

	Electricty (kWh per year)	Natural Gas (BTU x 10^6 per year)	Electricity Cost per year	Natural Gas Cost per year	Total Cost per year	Cost per Square Foot of Building
Design Engineer	1,720,210	6,740	$ 290,640	$ 104,066	$ 394,706	$ 2.58
Existing Building (TRACE)	1,614,418	4,228	$ 306,739	$ 65,202	$ 371,941	$ 2.43
Design Changes (TRACE)	1,508,917	2,504	$ 286,694	$ 38,604	$ 325,298	$ 2.13
Differnce (TRACE)	105,501	1,725	$ 20,045	$ 26,598	$ 46,643	$ 0.31
Reduction in % (between TRACE models)	7%	41%	7%	41%	13%	13%

Table 42 – Energy Comparison

The electricity demand each year was mainly reduced due to the photovoltaic solar array. There was a small reduction in electricity also due to the mechanical changes. The biggest savings was in the reduction in natural gas – so much so that the boiler system could be reduced. This huge reduction in natural gas usage is due to the total energy recovery wheels in the DOAS units. The wheels can accomplish the majority of heating of the outside air needed for ventilation by using the energy from the exhaust air. This means that the preheat coil was not needed anymore (it would be good practice to keep it though incase the wheel failed).

On the next page Figures 64 and 65 show two graphs comparing the usage of electricity and therms of natural gas throughout the year for the existing building and the building with the proposed design changes. During just about every month the electricity and natural gas usage is reduced for both cases.

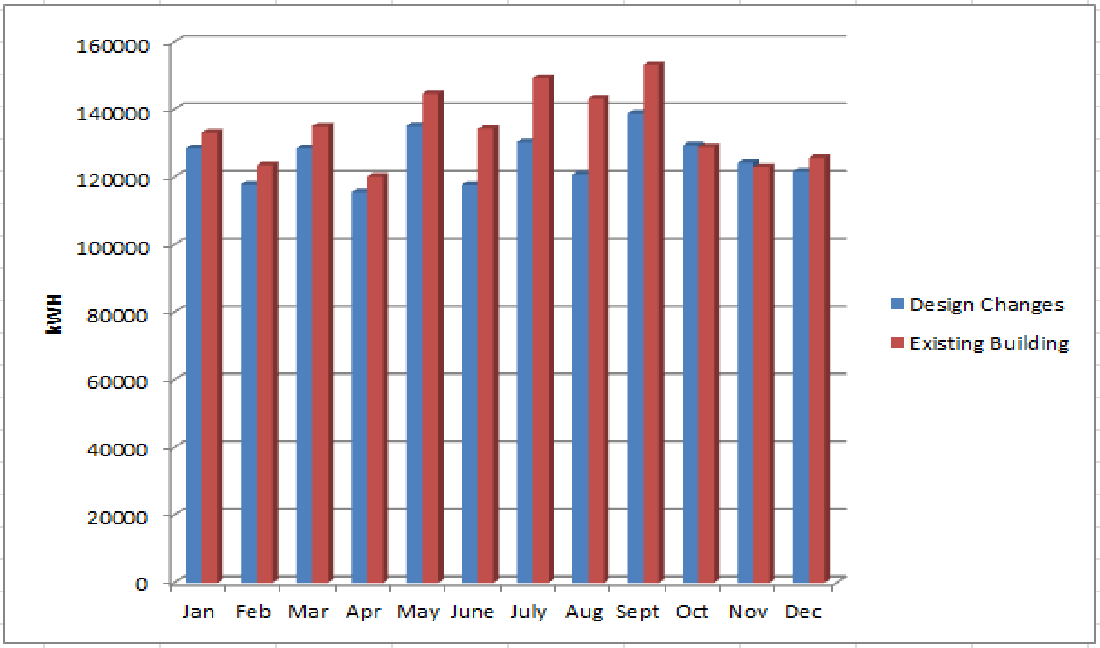


Figure 64 – Comparison of Electricity Usage

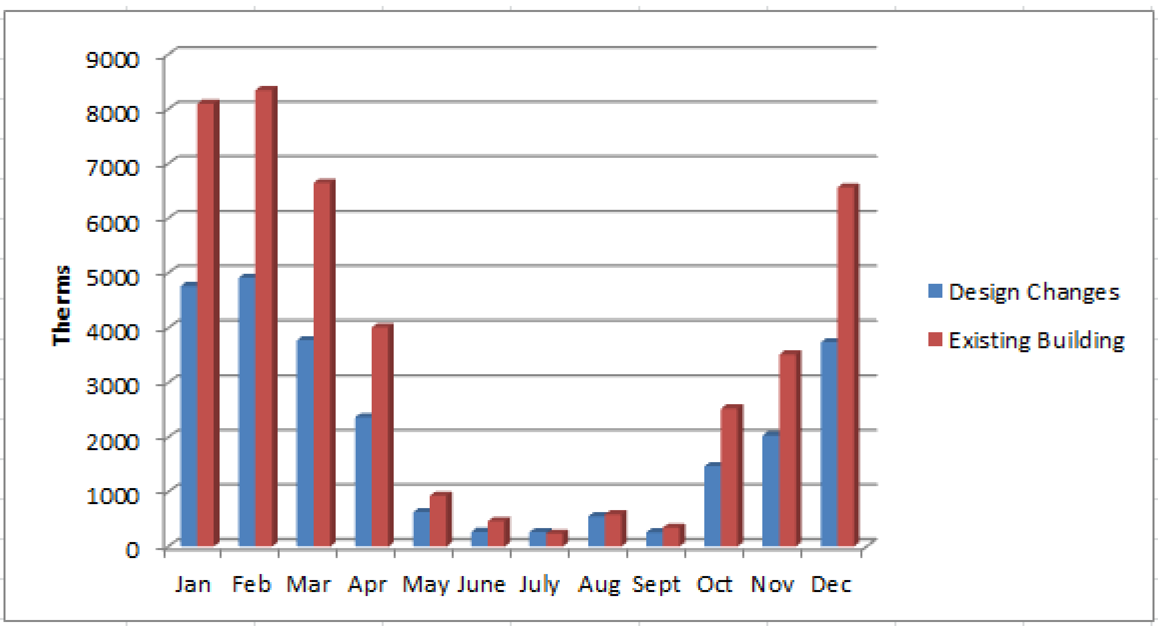


Figure 65 – Comparison of Natural Gas Usage

A breakdown of where the energy was used in the building with the proposed designs can be seen below in Table 43 and for the existing building in Table 44. As it can be seen from the two tables, pump energy in the new redesign increased. This is expected because chilled water must now be pumped to the FPIU's cooling coils throughout the building. Fan energy decreased only slightly in the new design because the DOAS units supply so much less air to the spaces than AHU's 1 through 3 but there is additional fan energy needed at the rooms for the recirculated air to the FPIU's. Lastly, as discussed before, the natural gas usage greatly reduced in the new design due to the usage of the total energy recovery wheels. This can be seen under the heating tab. It is interesting to see that the electricity for heating in the new design increased as compared to the existing building. This is due to the electricity needed to be put into to spinning the wheels.

	% of Building Consumption	kWh	Gas (kbtu)
Heating	31.8	4,022	2,503,480
Cooling	7.4	171,388	-
Fans	22.3	516,984	-
Pumps	8.1	187,196	-
Lighting	17.4	404,413	-
Receptacles	13.1	303,799	-

Table 43 – Energy Usage Breakdown Proposed Designs

	% of Building Consumption	kWh	Gas (kbtu)
Heating	43.5	3,243	4,228,437
Cooling	7.3	208,595	-
Fans	19.4	553,218	-
Pumps	5.2	148,158	-
Lighting	14.2	404,413	-
Receptacles	10.4	296,791	-

Table 44 – Energy Usage Breakdown Existing Building

A pie chart was created to better see the energy consumption breakdown for the new design. This can be seen below in Figure 66.

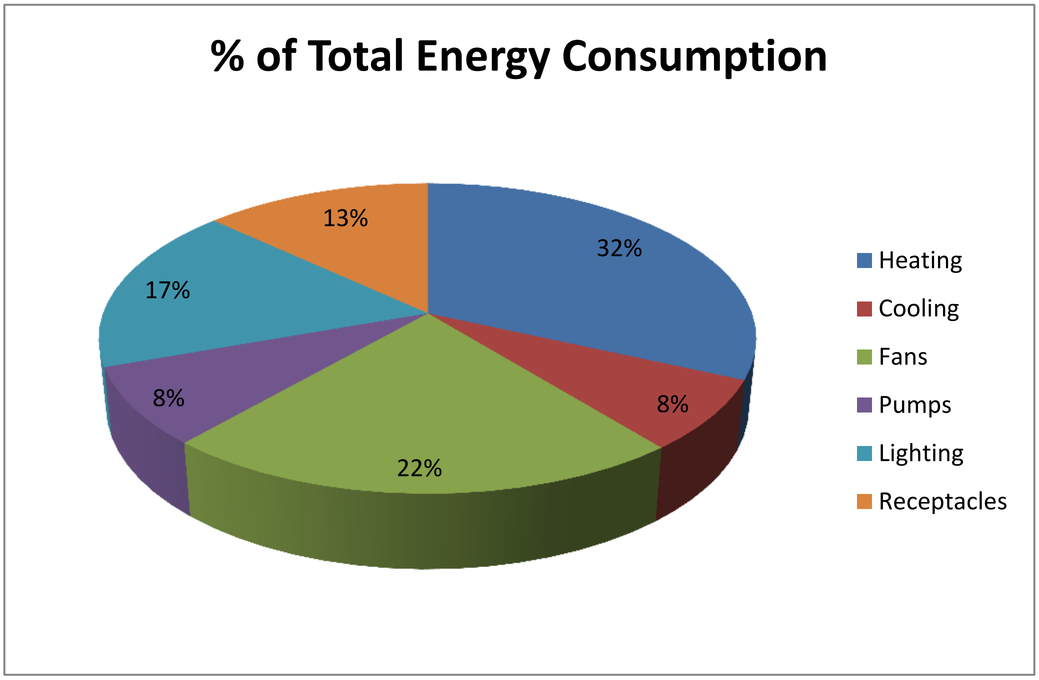


Figure 66 – Energy Usage Breakdown Proposed Design

Savings were also created in the changes of the mechanical system. Below in Table 45 is a comparison of the initial cost savings between the old rooftop AHU's 1 through 3 and the original 2 chillers compared to the new 2DOAS (including total energy recovery wheels) and 3 chillers.

New Design			Base Building	
DOAS 1	$ 75,000		AHU's 1-3	$ 765,650
DOAS 2	$ 122,000		Old Chillers	$ 820,000
CH-1	$ 155,000			
CH-2	$ 155,000			
CH-3	$ 26,900			
Total=	$ 533,900			
Cost with installation/labor/location factor				
Total=	$ 963,476		Total =	$ 1,585,650

Table 45 – Initial Savings of AHU's and Chillers

The changes in the AHU's and chillers amounted to a savings of $622,174 in initial costs. Adding the FPIU's and creating a secondary chilled water loop also caused a big change in costs. Below in Table 46 is the cost associated with the FPIU's. This table shows the cost of the FPIU's, the price of ductwork due to the reduction in duct sizes, the additional piping costs for the secondary chilled water loop, the additional cost of pumps due to the secondary chilled water loop, and an estimate for an increase in the HVAC controls cost associated with the FPIU's and secondary chilled water loop.

FPIU's Cost	New Duct Cost Total	Additional Piping	2 New Pumps Cost	Extra HVAC Controls	Total New Cost
$241,809.18	$227,498.00	$209,130.00	$ 11,601.00	$136,500.00	$826,538.18

Table 46 – Cost Associated with the FPIU's New Design

The next table, Table 47, shows the cost relating to the original building for the changes to a FPIU system. The original building uses VAV boxes with fin tube radiators for heating. In the new design, the VAV boxes and fin tube radiators were removed and replaced with the FPIU's which had heating coils in them. The ductwork is also larger in the original design because more air is supplied to the rooms by the VAV AHU's compared to the DOAS units.

VAV Box Cost	Old Duct Cost	Fin Tube Radiators	Old Total Cost
$216,000.00	$961,675.00	$300,000.00	$1,477,675.00

Table 47 – Base Building Costs Associated with FPIU's

The new FPIU system saves $651,137 from the above cost comparison. Overall the new mechanical changes to Hunter's Point South School save $1,273,311. This is more than enough to pay for the photovoltaic solar array ($296,666) and the upgrade needed in structural costs ($18,502). The initial upfront cost savings with all the design changes is $958,143. This is quite a lot. However, to get a better picture of the true savings – including energy reduction, the cost of the solar array's maintenance, and solar incentives – a 25 year life cycle comparison was done between the original design of Hunter's Point South School and the proposed changes.

Life Cycle Cost Analysis

Once all the changes to Hunter's Point South School were designed and priced, a life cycle cost analysis could be performed to see the true savings of the new design. The life cycle cost (LCC) analysis was performed over a 25 year period. This was done because that is the system life of the solar array. Price escalations for electricity and gas as well as discount rates were found in the Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2011. For annual costs, a discount rate of 2.3% was used. Below in Table 48 is the 25 year LCC analysis for the existing building (base building). It shows the price of electricity and natural gas brought back to a net present value so it can easily be compared to the proposed designs. No maintenance for HVAC equipment/systems was used for either the base or proposed design building. This is because maintenance information is very hard to determine and is usually dictated by what contract is signed between the building owner and manufacturer. It was assumed the difference in mechanical maintenance costs between the base and proposed design building would be very minimal.

Year	25 Year LCC	Escalation		Cost Each Year	
		Electricity	Natural Gas	Electricity	Natural Gas
1	2013	0.93	0.95	$ 285,267	$ 61,942
2	2014	0.91	0.91	$ 279,132	$ 59,334
3	2015	0.91	0.90	$ 279,132	$ 58,682
4	2016	0.90	0.90	$ 276,065	$ 58,682
5	2017	0.90	0.91	$ 276,065	$ 59,334
6	2018	0.90	0.92	$ 276,065	$ 59,986
7	2019	0.91	0.93	$ 279,132	$ 60,638
8	2020	0.92	0.94	$ 282,200	$ 61,290
9	2021	0.93	0.95	$ 285,267	$ 61,942
10	2022	0.94	0.97	$ 288,335	$ 63,246
11	2023	0.94	0.98	$ 288,335	$ 63,898
12	2024	0.94	0.99	$ 288,335	$ 64,550
13	2025	0.94	1.00	$ 288,335	$ 65,202
14	2026	0.94	1.01	$ 288,335	$ 65,854
15	2027	0.94	1.02	$ 288,335	$ 66,506
16	2028	0.94	1.03	$ 288,335	$ 67,158
17	2029	0.93	1.04	$ 285,267	$ 67,810
18	2030	0.93	1.05	$ 285,267	$ 68,462
19	2031	0.93	1.06	$ 285,267	$ 69,114
20	2032	0.94	1.07	$ 288,335	$ 69,766
21	2033	0.94	1.08	$ 288,335	$ 70,418
22	2034	0.95	1.09	$ 291,402	$ 71,070
23	2035	0.95	1.09	$ 291,402	$ 71,070
24	2036	0.95	1.11	$ 291,402	$ 72,374
25	2037	0.95	1.12	$ 291,402	$ 73,026
			NPV:	$5,368,339	$1,216,738
			Total NPV:	$6,585,077	

Table 48 – LCC Base Building

The LCC of the proposed design building was then computed. The values in red signify savings that were made in the new design. Savings were made in the mechanical systems and through incentives for the solar array. In this analysis, all cost increases and decreases of the new design were considered. Table 49 below shows the LCC analysis of the proposed design building.

		Escalation		Cost Each Year		Initial Costs			Maintenance		Solar Incentives		
Year	25 Year LCC	Electricity	Natural Gas	Electricity	Natural Gas	Mechanical	Solar	Structural	Solar	Inverter	Renewable Energy Grant (Treasury)	NYC Property Tax Abatement	MARCS Depreciation
1	2013	0.93	0.95	$ 266,625	$ 36,674	$ 1,273,311	$296,666	$ 18,502	$ 300		$ 89,000	$ 14,833	$ 52,955
2	2014	0.91	0.91	$ 260,892	$ 35,130				$ 300			$ 14,833	$ 14,121
3	2015	0.91	0.90	$ 260,892	$ 34,744				$ 300			$ 14,833	$ 8,826
4	2016	0.90	0.90	$ 258,025	$ 34,744				$ 300			$ 14,833	$ 5,295
5	2017	0.90	0.91	$ 258,025	$ 35,130				$ 300				$ 7,061
6	2018	0.90	0.92	$ 258,025	$ 35,516				$ 300				
7	2019	0.91	0.93	$ 260,892	$ 35,902				$ 300				
8	2020	0.92	0.94	$ 263,758	$ 36,288				$ 300				
9	2021	0.93	0.95	$ 266,625	$ 36,674				$ 300				
10	2022	0.94	0.97	$ 269,492	$ 37,446				$ 300				
11	2023	0.94	0.98	$ 269,492	$ 37,832				$ 300				
12	2024	0.94	0.99	$ 269,492	$ 38,218				$ 300				
13	2025	0.94	1.00	$ 269,492	$ 38,604				$ 300				
14	2026	0.94	1.01	$ 269,492	$ 38,990				$ 300				
15	2027	0.94	1.02	$ 269,492	$ 39,376				$ 300	$ 20,300			
16	2028	0.94	1.03	$ 269,492	$ 39,762				$ 300				
17	2029	0.93	1.04	$ 266,625	$ 40,148				$ 300				
18	2030	0.93	1.05	$ 266,625	$ 40,534				$ 300				
19	2031	0.93	1.06	$ 266,625	$ 40,920				$ 300				
20	2032	0.94	1.07	$ 269,492	$ 41,306				$ 300				
21	2033	0.94	1.08	$ 269,492	$ 41,692				$ 300				
22	2034	0.95	1.09	$ 272,359	$ 42,078				$ 300				
23	2035	0.95	1.09	$ 272,359	$ 42,078				$ 300				
24	2036	0.95	1.11	$ 272,359	$ 42,850				$ 300				
25	2037	0.95	1.12	$ 272,359	$ 43,236				$ 300				
			NPV:	$5,017,524	$720,391	$ 1,273,311	$296,666	$ 18,502	$5,656	$ 14,433	$ 89,000	$ 57,374	$ 86,595
			Total NPV:	$4,566,893									

Table 49 – LCC Proposed Designs

The base building had a NPV of $6,585,077 while the proposed design building had a NPV of $4,566,893. This gives a NPV savings of $2,018,185 (for the initial 25 years). A breakdown of where costs were saved can be seen in Table 50 below. Note the red value is extra costs that the proposed design had to pay and that the values are all in NPV.

LCC Savings over 25 Years (NPV)	
Initial Cost:	$ 958,143
Electricity:	$ 350,815
Natural Gas:	$ 496,347
Solar Maintenance and Inverter:	$ 20,089
Solar Incentives:	$ 232,969
Total:	$ 2,018,185

Table 50– LCC Comparison

Emissions

As part of the objectives of the proposed designs, emissions reduction was strived for. This will further help Hunter's Point South School in its efforts to become a more green and sustainable school. It will also serve as a teaching mechanism for the students. The emissions created by electricity, on site combustion, and transportation for fuel to the building can be seen below in Tables 51 through 53 for Hunter's Point South School with the proposed redesigns.

Pollutant	lb of pollutant per kWh of electricity	lb of pollutant per year due to electricity
CO_{2e}	1.03E+00	1,554,184.51
CO_2	9.61E-01	1,450,069.24
CH_4	2.59E-01	390,809.50
N_2O	1.68E-05	25.35
NO_x	1.72E-03	2,595.34
SO_x	6.23E-03	9,400.55
CO	1.75E-03	2,640.60
TNMOC	6.38E-05	96.27
Lead	5.59E-08	0.08
Mercury	3.99E-08	0.06
PM10	6.87E-05	103.66
Solid Waste	6.18E-02	93,251.07
kWh/year =	1,508,917	

Table 51 – Proposed Design Electricity Emissions

Pollutant	lb of pollutant per 1000 cubic ft of natural gas	lb of pollutant per year due to on-site combustion
CO_{2e}	1.23E+02	307,930.50
CO_2	1.22E+02	305,427.00
CH_4	2.50E-03	6.26
N_2O	2.50E-03	6.26
NO_x	1.11E-01	277.89
SO_x	6.32E-04	1.58
CO	9.33E-02	233.58
VOC	6.13E-03	15.35
Lead	5.00E-07	0.00
Mercury	2.60E-07	0.00
PM10	8.40E-03	21.03
cubic feet of natural gas =		2503500

Table 52 – Proposed Design Emissions On-Site Combustion

Pollutant	lb of pollutant per 1000 cubic ft of natural gas	lb of pollutant per year due transportation to site
CO_{2e}	2.78E+01	69,597.30
CO_2	1.16E+01	29,040.60
CH_4	7.04E-01	1,762.46
N_2O	2.35E-04	0.59
NO_x	1.64E-02	41.06
SO_x	1.22E+00	3,054.27
CO	1.36E-02	34.05
TNMOC	4.56E-05	0.11
Lead	2.41E-07	0.00
Mercury	5.51E-08	0.00
PM10	8.17E-04	2.05
PM-unspecified	1.42E-03	3.55
Solid Waste	1.60E+00	4,005.60
cubic feet of natural gas =		2503500

Table 53 – Proposed Design Emissions Transportation

The total emissions of the new design can be seen and compared with the original building's emissions below in Table 54.

Pollutant	Existing Building (lb of pollutant)	Redesign (lb of pollutant)	Reduction in Emissions (lb of pollutant)	Reduction %
CO_{2e}	2,300,493.26	1,931,712.31	368,780.95	16.0%
CO_2	2,116,369.94	1,784,536.84	331,833.10	15.7%
CH_4	421,121.63	392,578.23	28,543.40	6.8%
N_2O	38.69	32.20	6.49	16.8%
NO_x	3,315.50	2,914.28	401.21	12.1%
SO_x	15,219.14	12,456.41	2,762.74	18.2%
CO	3,277.25	2,908.23	369.02	11.3%
TNMOC	103.19	96.38	6.81	6.6%
VOC	25.92	15.35	10.57	40.8%
Lead	0.093	0.086	0.007	7.7%
Mercury	0.066	0.061	0.005	7.2%
PM10	149.88	126.74	23.15	15.4%
PM-unspecified	6.00	3.55	2.45	40.8%
Solid Waste	106,536.47	97,256.67	9,279.80	8.7%

Table 54 – Emissions Comparison

The emissions of each pollutant were decreased by atleast 6.8%. Overall great reductions were made in emissions. The total carbon dioxide equivalent emission reduced by 16%.

Conclusion

The proposed changes to Hunter's Point South School not only made the school more sustainable but also more energy efficient. Electric and natural gas usage both decreased. The downsizing of AHU's 1, 2, and 3 to two DOAS units as well as the chillers downsizing helped produce a big upfront cost. This along with the savings from smaller ducts, allowed for full financing of the photovoltaic solar panel array. This solar array gave a green, sustainable function to Hunter's Point South School that can be used as both a learning tool for the students as well as free electricity generation. Emissions output were also lowered.

The objectives of creating a more sustainable school and supplying the correct amount of ventilation air to each room were both accomplished in the new design. In the end, the proposed design changes had a huge impact on Hunter's Point South School for the better.

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Appendix A – List of Tables

Appendix B – List of Figures

Appendix C – Minimum Ventilation Calculation

AHU-1

Room No.	Room Name	Occupancy Type	Area (sf)	Rp (cfm/person)	Ra (cfm/sf)	Pz	Vbz (cfm)	Ez	Voz (cfm)	Vpz (cfm)	Zp	Evz
141	CustodianStorage	Storage Rooms	401	0	0.12	0	49	0.8	62	135	0.46	1.10
101/103	Is Project Room	Classrooms (age 9 plus)	1412	5	0.12	70	520	0.8	650	1240	0.52	1.04
105	Is Art	Art Classroom	1088	10	0.018	54	560	0.8	700	960	0.73	0.83
109A	Supervisor	Office Space	270	5	0.06	2	27	0.8	34	100	0.34	1.22
	Corridor 1st Floor West	Corridors	2800	0	0.06	0	168	0.8	210	230	0.91	0.65
246	Medical Suite	Daycare sickroom	702	10	0.18	6	187	0.8	234	230	1.02	0.55
241	Custodian Shop	Break Rooms	364	5	0.06	3	37	0.8	47	125	0.38	1.19
207B	Storage	Storage Rooms	104	0	0.12	0	13	0.8	17	34	0.50	1.06
205A	Office Work Room	Office Space	331	5	0.06	3	35	1	35	59	0.59	0.97
207	Staff Development/Literacy Coach	Conference/meeting	954	5	0.06	47	293	0.8	367	620	0.59	0.97
207A	Office	Office Space	77	5	0.06	1	10	0.8	13	45	0.29	1.27
205B	A/V Storage	Storage Rooms	89	0	0.12	0	11	1	11	12	0.92	0.65
205C	Tech Center	Computer lab	412	10	0.12	10	150	0.8	188	200	0.94	0.62
205	Library	Libraries	3883	5	0.06	48	473	0.8	592	1170	0.51	1.06
242	Physical Therapy	Health club/aerobics	477	20	0.06	4	109	1	109	105	1.04	0.52
206	Office	Office Space	203	5	0.06	2	23	0.8	29	35	0.83	0.73
209	Cw - Activities for Daily Living	Classrooms (age 9 plus)	500	10	0.12	12	180	0.8	225	235	0.96	0.61
	Corridor 2nd Floor South	Corridors	1230	0	0.06	0	74	0.8	93	125	0.74	0.82
308A	Meeting Room	Conference/meeting	133	5	0.06	6	38	1	38	160	0.24	1.33
301	Is Classroom	Classrooms (age 9 plus)	684	10	0.12	34	423	0.8	529	550	0.96	0.60
303	Is Classroom	Classrooms (age 9 plus)	684	10	0.12	34	423	0.8	529	550	0.96	0.60
305	Is Classroom	Classrooms (age 9 plus)	688	10	0.12	34	423	0.8	529	550	0.96	0.60
307	Records	Storage Rooms	208	0	0.12	0	25	1	25	100	0.25	1.31
311	Gen Office	Office Space	494	5	0.06	5	55	0.8	69	190	0.36	1.20
315	Principal	Office Space	394	5	0.06	3	39	0.8	49	100	0.49	1.07
309A	Waiting	Reception areas	144	5	0.06	6	39	1	39	67	0.58	0.98
309	Mail	Office Space	288	5	0.06	2	28	1	28	35	0.80	0.76
	Corridor 3rd Floor West	Corridors	1350	0	0.06	0	81	0.8	102	135	0.76	0.81
401	Hs Classroom	Classrooms (age 9 plus)	680	10	0.12	34	422	0.8	528	550	0.96	0.60
403/405	Hs Classroom	Classrooms (age 9 plus)	1400	10	0.12	68	848	0.8	1060	1100	0.96	0.60
407	Records	Storage Rooms	208	0	0.12	0	25	1	25	100	0.25	1.31
411	Gen Office	Office Space	494	5	0.06	5	55	0.8	69	99	0.70	0.87
415	Principal	Office Space	394	5	0.06	2	34	0.8	43	100	0.43	1.13
311A	Copy	Office Space	144	5	0.06	1	14	0.8	18	41	0.44	1.12
411A	Copy	Office Space	144	5	0.06	1	14	0.8	18	21	0.86	0.71
409	Mail	Office Space	288	5	0.06	2	28	1	28	35	0.80	0.76
409A	Waiting	Reception areas	144	5	0.06	6	39	1	39	67	0.58	0.98
	Corridor 4th Floor West	Corridors	1350	0	0.06	0	81	0.8	102	135	0.76	0.81
524	Hs Receiving	Office Space	428	5	0.06	1	31	0.8	39	83	0.47	1.09
522	Hs Receiving Vestibule	Reception areas	386	5	0.06	2	34	0.8	43	103	0.42	1.15
518/518A/518B	Hs Guidance College	Office Space	372	5	0.06	3	38	0.8	48	100	0.48	1.08
516/516A/516B	Hs Guidance Office	Office Space	489	5	0.06	5	55	0.8	69	200	0.35	1.22
	Corridor 5th Floor East	Corridors	1800	0	0.06	0	108	0.8	135	200	0.68	0.89
508	Hs Supervisory	Office Space	224	5	0.06	2	24	1	24	60	0.40	1.16
506	Mediation	Conference/meeting	99	5	0.06	4	26	1	26	40	0.65	0.91
245	Office	Office Space	164	5	0.06	2	20	0.8	25	100	0.25	1.31
308B	Guidance Room	Office Space	250	5	0.06	2	25	1	25	160	0.16	1.41
						526	6414			11391		
			AHU-1				Vou ^			Vps ^		
		actual	min oa intake (cfm):		14945							
		actual	max supply (cfm):		30000					Xs =	0.56308	
			minimum oa fraction AHU can		0.50							
				Ev=	0.52	System Ventilation Efficiency						
				Vot=	12218							
				30%above	15883							

AHU-2													
Room No.	Room Name	Occupancy Type	Area (sf)	Rp (cfm/person)	Ra (cfm/sf)	Pz	Vbz (cfm)	Ez	Voz (cfm)	Vpz (cfm)	Zp	Evz	
113/115	Is & Hs Parents Meeting Room	Conference/meeting	802	5	0.06	10	99	0.8	124	270	0.46	1.18	
126A, 126C, L1C	Furniture Storage, Vault W. Anteroom, Vestibu	Storage Room	474	0	0.12	0	57	0.8	72	150	0.48	1.16	
119	Custodial Office	Office Space	314	5	0.06	3	34	1	34	100	0.34	1.30	
116	School Safety Office/Locker Rooms	Office Space	479	5	0.06	3	44	0.8	55	100	0.55	1.09	
118, 120	Is Receiving/General Supply Room	Office Space	519	5	0.06	5	57	0.8	72	100	0.72	0.92	
	Corridor 1st Floor East	Corridors	1060	0	0.06	0	64	1	64	100	0.64	1.00	
213/215/219/221	Special Education Classroom	Classrooms (age 9 plus)	1888	10	0.12	100	1227	0.8	1534	1600	0.96	0.68	
217	Special Education Clasroom	Classrooms (age 9 plus)	500	10	0.12	25	310	0.8	388	400	0.97	0.67	
225	Special Education Clasroom	Classrooms (age 9 plus)	659	10	0.12	31	390	0.8	488	510	0.96	0.69	
226	Special Education Clasroom	Classrooms (age 9 plus)	505	10	0.12	25	311	0.8	389	375	1.04	0.61	
224	Special Education Clasroom	Classrooms (age 9 plus)	530	10	0.12	26	324	0.8	405	425	0.95	0.69	
222	Hs Book Storage	Storage Room	489	0	0.12	0	59	0.8	74	113	0.65	0.99	
220	Classroom Speech	Classrooms (age 9 plus)	190	10	0.12	9	113	1	113	148	0.76	0.88	
218	Classroom Speech	Classrooms (age 9 plus)	190	10	0.12	9	113	1	113	148	0.76	0.88	
216	Is Book Storage	Storage Room	489	0	0.12	0	59	0.8	74	113	0.65	0.99	
214	Is Audio/Video Security Storage Room	Storage Room	361	0	0.12	0	44	0.8	55	65	0.85	0.80	
	Corridor 2nd Floor East	Corridors	1450	0	0.06	0	87	1	87	145	0.60	1.04	
318	Is Music	Classrooms (age 9 plus)	536	10	0.12	27	335	0.8	419	405	1.03	0.61	
320	Is Resource	Classrooms (age 9 plus)	323	10	0.12	16	199	0.8	249	260	0.96	0.68	
322	Is Resource	Classrooms (age 9 plus)	311	10	0.12	15	188	0.8	235	245	0.96	0.68	
	Corridor 3rd Floor East	Corridors	830	0	0.06	0	50	1	50	100	0.50	1.14	
324	Is Classroom	Classrooms (age 9 plus)	726	10	0.12	34	428	0.8	535	555	0.96	0.68	
325	Is Special Education	Classrooms (age 9 plus)	467	10	0.12	23	287	0.8	359	375	0.96	0.69	
323	Is Science Lab	Science Laboratories	903	10	0.18	30	463	0.8	579	600	0.97	0.68	
321	Is Science Prep	Science Laboratories	374	10	0.18	1	78	0.8	98	1200	0.08	1.56	
319	Is Science Lab	Science Laboratories	900	10	0.18	30	462	0.8	578	600	0.96	0.68	
317	Is Classroom	Classrooms (age 9 plus)	726	10	0.12	36	448	0.8	560	580	0.97	0.68	
	Corridor 4th Floor East	Corridors	830	0	0.06	0	50	1	50	100	0.50	1.14	
417/419/421	Hs Classroom	Classrooms (age 9 plus)	2022	10	0.12	102	1263	0.8	1579	1650	0.96	0.69	
423/425	Hs Classroom	Classrooms (age 9 plus)	1415	10	0.12	70	870	0.8	1088	1130	0.96	0.68	
424	Hs Classroom	Classrooms (age 9 plus)	685	10	0.12	34	423	0.8	529	550	0.96	0.68	
422	Hs Resource	Classrooms (age 9 plus)	356	10	0.12	17	213	0.8	267	280	0.95	0.69	
420	Hs Music Storage	Storage Room	383	0	0.12	0	46	0.8	58	69	0.84	0.80	
418	Hs Music	Classrooms (age 9 plus)	465	10	0.12	23	286	0.8	358	367	0.98	0.67	
517	Hs Special Education	Classrooms (age 9 plus)	468	10	0.12	23	287	0.8	359	185	1.94	-0.30	not used
519	Hs Science Lab	Science Laboratories	1261	10	0.18	38	607	0.8	759	1300	0.58	1.06	
521	Science Prep	Science Laboratories	501	10	0.18	5	141	0.8	177	1200	0.15	1.49	
523	Science Lab Demo	Science Laboratories	996	10	0.18	30	480	0.8	600	625	0.96	0.68	
525	Science Lab Demo	Science Laboratories	1010	10	0.18	30	482	0.8	603	630	0.96	0.69	
						830	11478			17868			
			AHU-2				Vou ^			Vps ^			
		actual	min oa intake (cfm):		19445								
		actual	max supply (cfm):		31700					Xs =	0.64238		

minimum oa fraction AHU can		0.61	
	Ev=	0.61	System Ventilation Efficiency
	Vot=	18971	
	30% above	24662	

AHU-3

Room No.	Room Name	Occupancy Type	Area (sf)	Rp (cfm/person)	Ra (cfm/sf)	Pz	Vbz (cfm)	Ez	Voz (cfm)	Vpz (cfm)	Zp	Evz
361/359/357/355	Is Classroom	Classroom (age 9 plus)	2892	10	0.12	144	1788	0.8	2235	2320	0.96	0.74
353	Is Classroom	Classroom (age 9 plus)	780	10	0.12	39	484	0.8	605	630	0.96	0.74
351/349	Is Classroom	Classroom (age 9 plus)	1358	10	0.12	66	823	0.8	1029	1070	0.96	0.74
347	Is Special Education	Classroom (age 9 plus)	438	10	0.12	21	263	0.8	329	340	0.97	0.73
341	Is Staff Locker	Storage Room	280	0	0.12	0	34	0.8	43	180	0.24	1.46
	Corridor 3rd Floor South	Corridors	3125	0	0.06	0	188	0.8	235	325	0.72	0.98
461/459/457/455	Hs Classroom	Classroom (age 9 plus)	2944	10	0.12	144	1794	0.8	2243	2400	0.93	0.77
453	Hs Classroom	Classroom (age 9 plus)	780	10	0.12	39	484	0.8	605	630	0.96	0.74
451/449	Hs Classroom	Classroom (age 9 plus)	1360	10	0.12	66	824	0.8	1030	1070	0.96	0.74
447	Hs Special Education	Classroom (age 9 plus)	389	10	0.12	12	167	0.8	209	220	0.95	0.75
441	Hs Staff Locker	Storage Room	280	0	0.12	0	34	0.8	43	185	0.23	1.47
	Corridor 4th Floor South	Corridors	3125	0	0.06	0	188	0.8	235	325	0.72	0.98
	Corridor 5th Floor South	Corridors	1540	0	0.06	0	93	1	93	230	0.40	1.30
539/541	Men's & Women's Locker Rooms	Storage Room	170	0	0.12	0	21	0.8	27	110	0.25	1.45
545	Guidance Records	Office Space	165	5	0.06	1	15	0.8	19	45	0.42	1.28
547	Program Office	Office Space	235	5	0.06	2	25	0.8	32	155	0.21	1.49
549	Hs Store	Storage Room	260	0	0.12	2	32	0.8	40	100	0.40	1.30
551	Government & Club House	Office Space	474	5	0.06	6	59	0.8	74	200	0.37	1.33
552	Hs Art Room	Art Classroom	1051	10	0.18	52	710	0.8	888	925	0.96	0.74
						594	8026			11460		
			AHU-3				Vou ^			Vps ^		
		actual	min oa intake (cfm):		13210							
		actual	max supply (cfm):		27000					Xs =	0.70035	
			minimum oa fraction AHU can supply		0.49							
				Ev=	0.73	System Ventilation Efficiency						
				Vot=	10954							
				30% above	14240							

AHU-4											
Room No.	Room Name	Occupancy Type	Area (sf)	Rp (cfm/person)	Ra (cfm/sf)	Pz (people)	Vbz (cfm)	Ez	Voz (cfm)	Vpz (cfm)	Zp
130/146	Competition Gymnasium	Multipurpose Assembly	8052	5	0.06	660	3784	1	3784	15040	0.25
130A	Gym Storage	Storage Rooms	366	0	0.12	0	44	1	44	180	0.24
106	Is Girls' Locker Room	Storage Rooms	345	0	0.12	0	42	1	42	350	0.12
108	Health Instructor's Office	Office Space	349	5	0.06	2	31	1	31	180	0.17
102	Is Boys' Locker Room	Storage Rooms	345	0	0.12	0	42	1	42	350	0.12
134	Hs Girls' Locker Room	Storage Rooms	470	0	0.12	0	57	1	57	420	0.14
144	Hs Boys' Locker Room	Storage Rooms	430	0	0.12	0	52	1	52	380	0.14
145	Visitor Team's Locker Room	Storage Rooms	270	0	0.12	0	33	1	33	180	0.18
230/240	Auxiliary Exercise Room	Health Club/Aerobics Room	1900	20	0.06	38	874	1	874	2000	0.44
						Vou	4959				

AHU-4		
actual	min oa intake (cfm):	13360
actual	max supply (cfm):	20860
	minimum oa fraction	0.64
	Vot=	7085
	30% above	9211

Max Zp =	0.44
Ev =	0.7

AHU-4						
Room Number	Room Name	Design Ventillation	Minimum Ventilation	% Above Standard 62.1	Compliant With Standard	Above 30% (LEED)
130/146	Competition Gymnasium	9633	3784	255	Yes	Yes
130A	Gym Storage	115	44	262	Yes	Yes
106	Is Girls' Locker Room	224	42	534	Yes	Yes
108	Health Instructor's Office	115	31	372	Yes	Yes
102	Is Boys' Locker Room	224	42	534	Yes	Yes
134	Hs Girls' Locker Room	269	57	472	Yes	Yes
144	Hs Boys' Locker Room	243	52	468	Yes	Yes
145	Visitor Team's Locker Room	115	33	349	Yes	Yes
230/240	Auxiliary Exercise Room	1281	874	147	Yes	Yes

AHU-5												
Room No.	Room Name	Occupancy Type	Area (sf)	Rp (cfm/person)	Ra (cfm/sf)	Pz	Vbz (cfm)	Ez	Voz (cfm)	Vpz (cfm)	Zp	Evz
338/356	Is Café	Cafeteria/fast food-dining	2530	7.5	0.18	172	1746	1	1746	4920	0.35	0.96
534	Kitchen Complex	Cafeteria/fast food-dining	2174	7.5	0.18	16	512	1	512	3038	0.17	1.15
534C	Office 3	Office	125	5	0.06	1	13	1	13	75	0.17	1.14
534H	Food Storage	Storage	480	0	0.12	0	58	1	58	100	0.58	0.74
505/511	Hs Café	Cafeteria/fast food-dining	3150	7.5	0.18	210	2142	1	2142	5990	0.36	0.96
513, 515	Staff Dining & Servery	Cafeteria/fast food-dining	1027	7.5	0.18	8	245	1	245	600	0.41	0.91
536, 538	Men/Women Locker Room	Storage	320	0	0.12	0	39	1	39	250	0.16	1.16
534A	Can Wash	Storage	480	0	0.12	0	58	1	58	200	0.29	1.03
						Vou	4813			15173		
			AHU-5							Vpz ^		
		actual	min oa intake (cfm):		11840							
		actual	max supply (cfm):		18700					Xs =	0.317208	
			minimum oa fraction AHU can supply		0.63							
				Ev=	0.74	System Ventilation Efficiency						
				Vot=	6529							
				30% above	8488							

AHU-5						
Room Number	Room Name	Design Ventillation	Minimum Ventilation	% Above Standard 62.1	Compliant With Standard	Above 30% (LEED)
338/356	Is Café	3116	1746	178	Yes	Yes
534	Kitchen Complex	1924	512	376	Yes	Yes
534C	Office 3	48	13	369	Yes	Yes
534H	Food Storage	64	58	110	Yes	No
505/511	Hs Café	3793	2142	177	Yes	Yes
513	Staff Dining & Servery	380	245	155	Yes	Yes
536, 538	Men/Women Locker Room	159	39	408	Yes	Yes
534A	Can Wash	127	58	219	Yes	Yes

AHU-6

Room No.	Room Name	Occupancy Type	Area (sf)	Rp (cfm/person)	Ra (cfm/sf)	Pz	Vbz (cfm)	Ez	Voz (cfm)	Vpz (cfm)	Zp
338/356	Auditorium	Auditorium Seating Area	3844	5	0.06	366	2061	1	2061	7488	0.28
360	Dress Room	Storage Room	190	0	0.12	0	23	1	23	150	0.15
362	Dress Room	Storage Room	190	0	0.12	0	23	1	23	150	0.15
406	Projection Room	Telephone/Data Entry	117	5	0.06	2	18	1	18	140	0.13
						Vou	2125				

	AHU-6	
actual	min oa intake (cfm):	6325
actual	max supply (cfm):	9600
	minimum oa fraction AHU can supply	0.66
	Vot=	2657
	30% above	3454

Max Zp =	0.28
Ev =	0.8

AHU-6

Room Number	Room Name	Design Ventillation	Minimum Ventilation	% Above Standard 62.1	Compliant With Standard	Above 30% (LEED)
338/356	Auditorium	4934	2061	239	Yes	Yes
360	Dress Room	99	23	430	Yes	Yes
362	Dress Room	99	23	430	Yes	Yes
406	Projection Room	93	18	517	Yes	Yes

Appendix D – Latent Load Calculation

Room No.	Room Name	# of People in Space	Latent Load of an Occupant (Btu/hr)	Total Latent Load on Space (Btu/hr)	CFM Required to Meet Latent Load
141	Custodian Storage	3	250	750	54
101	Is Project Room	35	200	7000	507
103	Is Project Room	35	200	7000	507
105	Is Art	54	250	13500	978
109A	Supervisor	2	200	400	29
107	Is Art Storage	1	250	250	18
	Corridor 1st Floor West	0	250	0	0
246	Medical Suite	6	250	1500	109
241	Custodian Shop	3	200	600	43
207B	Storage	0	200	0	0
205A	Office Work Room	3	200	600	43
207	Staff Development/Literacy Coaches	47	200	9400	681
207A	Office	1	200	200	14
205B	A/V Storage	0	200	0	0
205C	Tech Center	10	200	2000	145
205	Library	48	200	9600	696
242	Physical Therapy	4	250	1000	72
206	Office	2	200	400	29
209	Cw - Activities for Daily Living	12	200	2400	174
	Corridor 2nd Floor South	0	250	0	0
308	Guidance Suite	0	200	0	0
308A	Office	1	200	200	14
308B	Office	1	200	200	14
308D	Meeting	6	200	1200	87
301	Is Classroom	34	200	6800	493
303	Is Classroom	34	200	6800	493
305	Is Classroom	34	200	6800	493
307	Records	1	200	200	14
311	Gen Office	5	200	1000	72
315	Principal	3	200	600	43
309A	Waiting	6	200	1200	87
309	Mail	2	200	400	29
	Corridor 3rd Floor West	0	250	0	0
401	Hs Classroom	34	200	6800	493
403	Hs Classroom	31	200	6200	449
405	Hs Classroom	31	200	6200	449
407	Records	1	200	200	14
411	Gen Office	5	200	1000	72
415	Principal	2	200	400	29
311A	Copy	1	200	200	14
411A	Copy	1	200	200	14
409	Mail	2	200	400	29
409A	Waiting	6	200	1200	87
	Corridor 4th Floor West	0	250	0	0
524	Hs Receiving	2	200	400	29

522	Hs Receiving Vestibule	2	200	400	29
518	Hs College Suite	2	200	400	29
518A	Hs College Office	2	200	400	29
518B	Hs College Conference	5	200	1000	72
516	Hs Guidance Suite	3	200	600	43
516A	Hs Guidance Conf	6	200	1200	87
516B	Hs Guidance Office	2	200	400	29
516C	Hs Guidance Office	2	200	400	29
	Corridor 5th Floor East	0	250	0	0
508	Hs Supervisory	2	200	400	29
506	Mediation	4	200	800	58
245	Office	2	200	400	29
308B	Guidance Room	2	200	400	29
113	Hs Parents/Community Office	5	200	1000	72
115	Is Parents Coordinator Room	5	200	1000	72
L1C	Vestibule	0	200	0	0
126A	Furniture Storage	0	200	0	0
126B	Storage	0	200	0	0
126C	Vault W. Anteroom	0	200	0	0
119	Custodial Office	3	250	750	54
116	School Safety Office/Locker Rooms	3	200	600	43
118	Is Receiving Room	2	200	400	29
120	Is General Supply Room	0	200	0	0
	Corridor 1st Floor East	0	250	0	0
213	Special Education Classroom	25	200	5000	362
215	Special Education Classroom	25	200	5000	362
219	Special Education Classroom	25	200	5000	362
221	Special Education Classroom	25	200	5000	362
217	Special Education Clasroom	25	200	5000	362
225	Special Education Clasroom	31	200	6200	449
226	Special Education Clasroom	25	200	5000	362
224	Special Education Clasroom	26	200	5200	377
222	Hs Book Store	4	200	800	58
220	Classroom Speech	9	200	1800	130
218	Classroom Speech	9	200	1800	130
216	Is Book Store	4	200	800	58
214	Is Audio/Video Security Storage Room	0	200	0	0
	Corridor 2nd Floor East	0	250	0	0
318	Is Music	27	250	6750	489
318A	Is Music Storage	0	200	0	0
318B	Is Music Storage	0	200	0	0
318C	Is Music Storage	0	200	0	0
320	Is Resource	16	200	3200	232
322	Is Resource	15	200	3000	217
	Corridor 3rd Floor East	0	250	0	0
324	Is Classroom	34	200	6800	493
325	Is Special Education	23	200	4600	333

323	Is Science Lab	30	200	6000	435
321	Is Science Prep	1	200	200	14
319	Is Science Lab	30	200	6000	435
317	Is Classroom	36	200	7200	522
	Corridor 4th Floor East	0	250	0	0
417	Hs Project Room	34	200	6800	493
419	Hs Project Room	34	200	6800	493
421	Hs Classroom	31	200	6200	449
423	Hs Classroom	35	200	7000	507
425	Hs Classroom	35	200	7000	507
424	Hs Classroom	34	200	6800	493
422	Hs Resource	17	200	3400	246
420	Hs Music Storage	0	200	0	0
418	Hs Music	23	200	4600	333
418A	Hs Music Storage	0	200	0	0
418B	Hs Music Storage	0	200	0	0
418C	Hs Music Storage	0	200	0	0
517	Hs Special Education	23	200	4600	333
519	Hs Science Lab	38	200	7600	551
521	Science Prep	5	200	1000	72
523	Science Lab Demo	30	200	6000	435
525	Science Lab Demo	30	200	6000	435
361	Is Classroom	30	200	6000	435
359	Is Classroom	30	200	6000	435
357	Is Classroom	30	200	6000	435
355	Is Classroom	30	200	6000	435
353	Is Classroom	39	200	7800	565
351	Is Classroom	30	200	6000	435
349	Is Classroom	30	200	6000	435
347	Is Special Education	21	200	4200	304
341	Is Staff Locker	0	250	0	0
	Corridor 3rd Floor South	0	250	0	0
461	Hs Classroom	30	200	6000	435
459	Hs Classroom	30	200	6000	435
457	Hs Classroom	30	200	6000	435
455	Hs Classroom	30	200	6000	435
453	Hs Classroom	39	200	7800	565
451	Hs Classroom	31	200	6200	449
449	Hs Classroom	31	200	6200	449
447	Hs Special Education	12	200	2400	174
441	Hs Staff Locker	0	250	0	0
	Corridor 4th Floor South	0	250	0	0
	Corridor 5th Floor South	0	250	0	0
539	Men's Kitchen Locker Rooms	0	250	0	0
541	Women's Kitchen Locker Rooms	0	250	0	0
545	Guidance Records	1	200	200	14
547	Program Office	1	200	200	14

547A	Program Office	1	200	200	14
549	Hs Store	1	200	200	14
549A	Hs Store	1	200	200	14
551	Government & Club House	6	200	1200	87
551A	Government & Club Office	1	200	200	14
551B	Government & Club Office	1	200	200	14
552	Hs Art Room	52	250	13000	942

Appendix E – NYC Mechanical Code Ventilation

DOAS CFM - NYC Mechanical Code 2008

Room No.	Room Name	Occupancy Type	Area (sf)	Rp (cfm/person)	Ra (cfm/sf)	Pz	CFM
141	Custodian Storage	Classrooms	401	15	0	3	45
101	Is Project Room	Classrooms (age 9 plus)	800	15	0	35	525
103	Is Project Room	Classrooms (age 9 plus)	750	15	0	35	525
105	Is Art	Classroom	1088	15	0	54	810
109A	Supervisor	Office Space	270	20	0	2	40
107	Is Art Storage	Classroom	234	20	0	1	20
	Corridor 1st Floor West	Corridors	2800	0	0.1	0	280
246	Medical Suite	Patient rooms	702	25	0	6	150
241	Custodian Shop	Classrooms	364	15	0	3	45
207B	Storage	modeled as corridor	104	0	0.1	0	11
205A	Office Work Room	Office Space	331	20	0	3	60
207	Staff Development/Literacy Coache	Conference/meeting	954	20	0	47	940
207A	Office	Office Space	77	20	0	1	20
205B	A/V Storage	modeled as a corridor	89	0	0.1	0	9
205C	Tech Center	Telecom	412	20	0	10	200
205	Library	Libraries	3883	15	0	48	720
242	Physical Therapy	Patient Rooms	477	25	0	4	100
206	Office	Office Space	203	20	0	2	40
209	Cw - Activities for Daily Living	Classrooms	500	15	0	12	180
	Corridor 2nd Floor South	Corridors	1230	0	0.1	0	123
308	Guidance Suite	modeled as a corridor	120	0	0.1	0	12
308A	Office	Office Space	150	20	0	1	20
308B	Office	Office Space	128	20	0	1	20
308D	Meeting	Conference/meeting	150	20	0	6	120
301	Is Classroom	Classrooms	684	15	0	34	510
303	Is Classroom	Classrooms	684	15	0	34	510
305	Is Classroom	Classrooms	688	15	0	34	510
307	Records	modeled as a Classroom	208	15	0	1	15
311	Gen Office	Office Space	494	20	0	5	100
315	Principal	Office Space	394	20	0	3	60
309A	Waiting	Reception areas	144	15	0	6	90
309	Mail	Office Space	288	20	0	2	40
	Corridor 3rd Floor West	Corridors	1350	0	0.1	0	135
401	Hs Classroom	Classrooms	680	15	0	34	510
403	Hs Classroom	Classrooms	744	15	0	31	465
405	Hs Classroom	Classrooms	752	15	0	31	465
407	Records	modeled as a classroom	208	15	0	1	15
411	Gen Office	Office Space	494	20	0	5	100
415	Principal	Office Space	394	20	0	2	40
311A	Copy	Office Space	144	20	0	1	20
411A	Copy	Office Space	144	20	0	1	20
409	Mail	Office Space	288	20	0	2	40
409A	Waiting	Reception areas	144	15	0	6	90
	Corridor 4th Floor West	Corridors	1350	0	0.1	0	135
524	Hs Receiving	Office Space	428	20	0	2	40
522	Hs Receiving Vestibule	Reception areas	386	15	0	2	30
518	Hs College Suite	Office Space	180	20	0	2	40
518A	Hs College Office	Office Space	110	20	0	2	40
518B	Hs College Conference	Conference/meeting	114	20	0	5	100

516	Hs Guidance Suite	Reception areas	194	15	0	3	45
516A	Hs Guidance Conf	Conference/meeting	110	20	0	6	120
516B	Hs Guidance Office	Office Space	120	20	0	2	40
516C	Hs Guidance Office	Office Space	120	20	0	2	40
	Corridor 5th Floor East	Corridors	2060	0	0.1	0	206
508	Hs Supervisory	Office Space	224	20	0	2	40
506	Mediation	Conference/meeting	99	20	0	4	80
245	Office	Office Space	164	20	0	2	40
308B	Guidance Room	Office Space	250	20	0	2	40
113	Hs Parents/Community Office	Office Space	400	20	0	5	100
115	Is Parents Coordinator Room	Office Space	400	20	0	5	100
L1C	Vestibule	Corridors	460	0	0.1	0	46
126A	Furniture Storage	modeled as a corridor	512	0	0.1	0	52
126B	Storage	modeled as a corridor	288	0	0.1	0	29
126C	Vault W. Anteroom	modeled as a corridor	300	0	0.1	0	30
119	Custodial Office	Office Space	314	20	0	3	60
116	School Safety Office/Locker Rooms	Office Space	479	20	0	3	60
118	Is Receiving Room	Reception areas	153	20	0	2	40
120	Is General Supply Room	modeled as cooridor	333	0	0.1	0	34
	Corridor 1st Floor East	Corridors	1060	0	0.1	0	106
213	Special Education Classroom	Classrooms (age 9 plus)	496	15	0	25	375
215	Special Education Classroom	Classrooms (age 9 plus)	496	15	0	25	375
219	Special Education Classroom	Classrooms (age 9 plus)	496	15	0	25	375
221	Special Education Classroom	Classrooms (age 9 plus)	496	15	0	25	375
217	Special Education Clasroom	Classrooms	500	15	0	25	375
225	Special Education Clasroom	Classrooms	659	15	0	31	465
226	Special Education Clasroom	Classrooms	505	15	0	25	375
224	Special Education Clasroom	Classrooms	530	15	0	26	390
222	Hs Book Store	modeled as a Classroom	489	15	0	4	60
220	Classroom Speech	Classrooms	190	15	0	9	135
218	Classroom Speech	Classrooms	190	15	0	9	135
216	Is Book Store	modeled as Classroom	489	15	0	4	60
214	Is Audio/Video Security Storage Roo	modeled as Corridor	361	0	0.1	0	37
	Corridor 2nd Floor East	Corridors	1450	0	0.1	0	145
318	Is Music	Classrooms	536	15	0	27	405
318A	Is Music Storage	modeled as a corridor	103	0	0.1	0	11
318B	Is Music Storage	modeled as a corridor	126	0	0.1	0	13
318C	Is Music Storage	modeled as a corridor	86	0	0.1	0	9
320	Is Resource	Classrooms	323	15	0	16	240
322	Is Resource	Classrooms	311	15	0	15	225
	Corridor 3rd Floor East	Corridors	830	0	0.1	0	83
324	Is Classroom	Classrooms	726	15	0	34	510
325	Is Special Education	Classrooms	467	15	0	23	345
323	Is Science Lab	Laboratories	903	20	0	30	600
321	Is Science Prep	Laboratories	374	20	0	1	20
319	Is Science Lab	Laboratories	900	20	0	30	600
317	Is Classroom	Classrooms	726	15	0	36	540
	Corridor 4th Floor East	Corridors	830	0	0.1	0	83
417	Hs Project Room	Classrooms (age 9 plus)	768	15	0	34	510
419	Hs Project Room	Classrooms (age 9 plus)	768	15	0	34	510
421	Hs Classroom	Classrooms (age 9 plus)	720	15	0	31	465
423	Hs Classroom	Classrooms (age 9 plus)	720	15	0	35	525
425	Hs Classroom	Classrooms (age 9 plus)	720	15	0	35	525
424	Hs Classroom	Classrooms	685	15	0	34	510

422	Hs Resource	Classrooms	356	15	0	17	255
420	Hs Music Storage	modeled as a corridor	383	0	0.1	0	39
418	Hs Music	Classrooms	947	15	0	23	345
418A	Hs Music Storage	modeled as a corridor	70	0	0.1	0	7
418B	Hs Music Storage	modeled as a corridor	120	0	0.1	0	12
418C	Hs Music Storage	modeled as a corridor	56	0	0.1	0	6
517	Hs Special Education	Classrooms	468	15	0	23	345
519	Hs Science Lab	Laboratories	1261	20	0	38	760
521	Science Prep	Laboratories	501	20	0	5	100
523	Science Lab Demo	Laboratories	996	20	0	30	600
525	Science Lab Demo	Laboratories	1010	20	0	30	600
361	Is Classroom	Classroom (age 9 plus)	740	15	0	30	450
359	Is Classroom	Classroom (age 9 plus)	768	15	0	30	450
357	Is Classroom	Classroom (age 9 plus)	768	15	0	30	450
355	Is Classroom	Classroom (age 9 plus)	768	15	0	30	450
353	Is Classroom	Classrooms	780	15	0	39	585
351	Is Classroom	Classroom (age 9 plus)	750	15	0	30	450
349	Is Classroom	Classroom (age 9 plus)	750	15	0	30	450
347	Is Special Education	Classrooms	438	15	0	21	315
341	Is Staff Locker	Locker rooms	280	0	0.5	0	140
	Corridor 3rd Floor South	Corridors	3125	0	0.1	0	313
461	Hs Classroom	Classrooms	690	15	0	30	450
459	Hs Classroom	Classrooms	705	15	0	30	450
457	Hs Classroom	Classrooms	705	15	0	30	450
455	Hs Classroom	Classrooms	705	15	0	30	450
453	Hs Classroom	Classrooms	780	15	0	39	585
451	Hs Classroom	Classroom (age 9 plus)	720	15	0	31	465
449	Hs Classroom	Classroom (age 9 plus)	720	15	0	31	465
447	Hs Special Education	Classrooms	389	15	0	12	180
441	Hs Staff Locker	Locker rooms	280	0	0.5	0	140
	Corridor 4th Floor South	Corridors	3125	0	0.1	0	313
	Corridor 5th Floor South	Corridors	1540	0	0.1	0	154
539	Men's Kitchen Locker Rooms	locker rooms	165	0	0.5	0	83
541	Women's Kitchen Locker Rooms	Locker rooms	165	0	0.5	0	83
545	Guidance Records	Office Space	165	20	0	1	20
547	Program Office	Office Space	110	20	0	1	20
547A	Program Office	Office Space	110	20	0	1	20
549	Hs Store	modeled as a classroom	200	15	0	1	15
549A	Hs Store	modeled as a classroom	110	15	0	1	15
551	Government & Club House	Office Space	240	20	0	6	120
551A	Government & Club Office	Office Space	96	20	0	1	20
551B	Government & Club Office	Office Space	96	20	0	1	20
552	Hs Art Room	Classrooms	1051	15	0	52	780
						total	33269

Appendix F – Comparing Ventilation Requirements

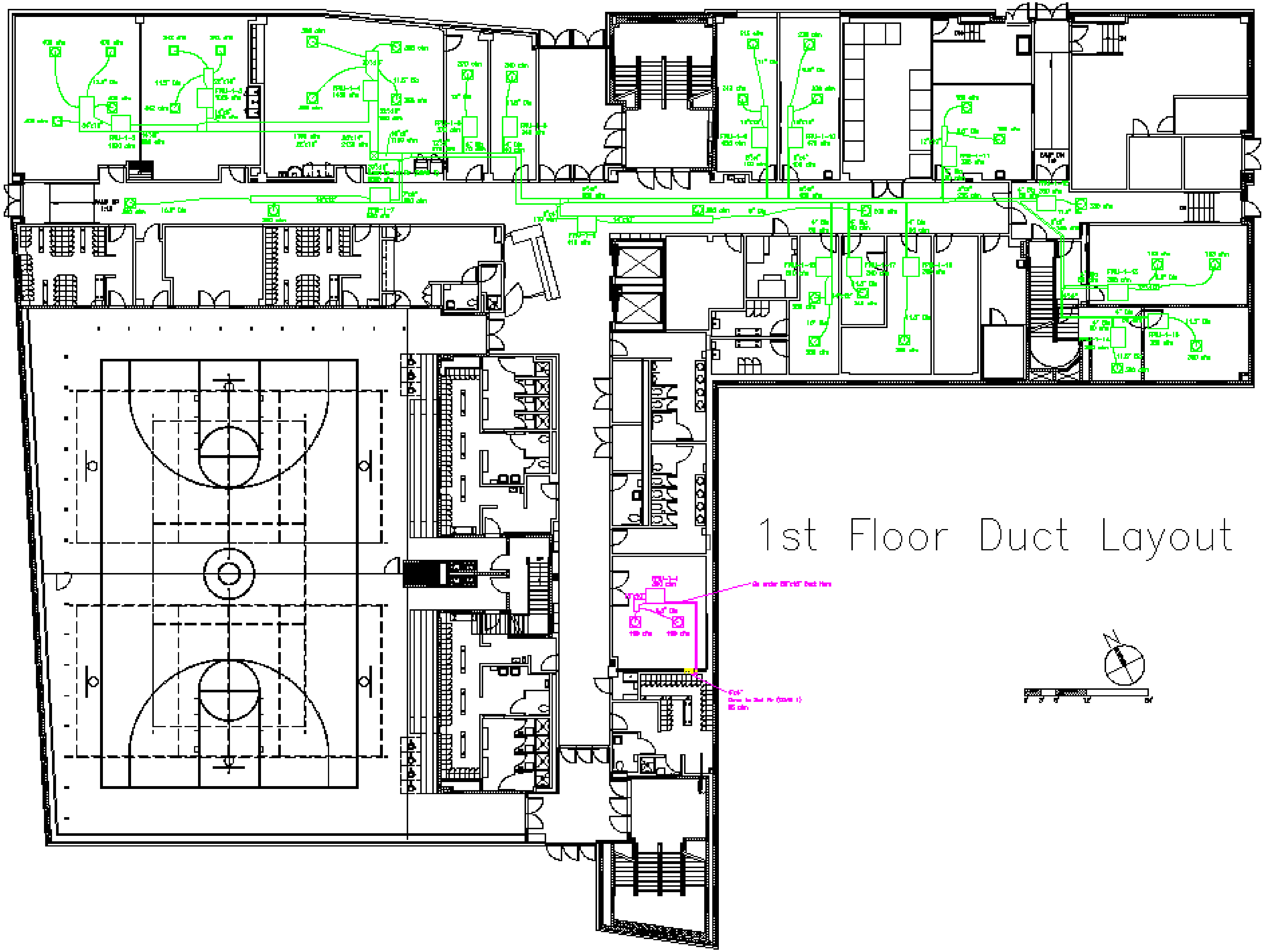
Room No.	Room Name	NYS Mechancial Code	30% above ASHRAE Std 62.1	Latent Load	Max Required CFM	Round Up to a multiple of 5 CFM
101	Is Project Room	525	580	507	580	580
103	Is Project Room	525	572	507	572	575
105	Is Art	810	957	978	978	980
107	Is Art Storage	20	69	18	69	70
113	Hs Parents/Community Office	100	64	72	100	100
115	Is Parents Coordinator Room	100	64	72	100	100
116	School Safety Office/Locker Rooms	60	57	43	60	60
118	Is Receiving Room	40	26	29	40	40
119	Custodial Office	60	44	54	60	60
120	Is General Supply Room	34	52	0	52	55
141	Custodian Storage	45	64	54	64	65
205	Library	720	615	696	720	720
206	Office	40	30	29	40	40
207	Staff Development/Literacy Coaches	940	761	681	940	940
209	Cw - Activities for Daily Living	180	234	174	234	235
213	Special Education Classroom	375	403	362	403	405
214	Is Audio/Video Security Storage Room	37	57	0	57	60
215	Special Education Classroom	375	403	362	403	405
216	Is Book Store	60	129	58	129	130
217	Special Education Clasroom	375	403	362	403	405
218	Classroom Speech	135	147	130	147	150
219	Special Education Classroom	375	403	362	403	405
220	Classroom Speech	135	147	130	147	150
221	Special Education Classroom	375	403	362	403	405
222	Hs Book Store	60	129	58	129	130
224	Special Education Clasroom	390	421	377	421	425
225	Special Education Clasroom	465	507	449	507	510
226	Special Education Clasroom	375	404	362	404	405
241	Custodian Shop	45	48	43	48	50
242	Physical Therapy	100	142	72	142	145
245	Office	40	26	29	40	40
246	Medical Suite	150	243	109	243	245
301	Is Classroom	510	550	493	550	550
303	Is Classroom	510	550	493	550	550
305	Is Classroom	510	550	493	550	550
307	Records	15	33	14	33	35
308	Guidance Suite	12	10	0	12	15
309	Mail	40	36	29	40	40
311	Gen Office	100	72	72	100	100
315	Principal	60	51	43	60	60
317	Is Classroom	540	582	522	582	585
318	Is Music	405	436	489	489	490

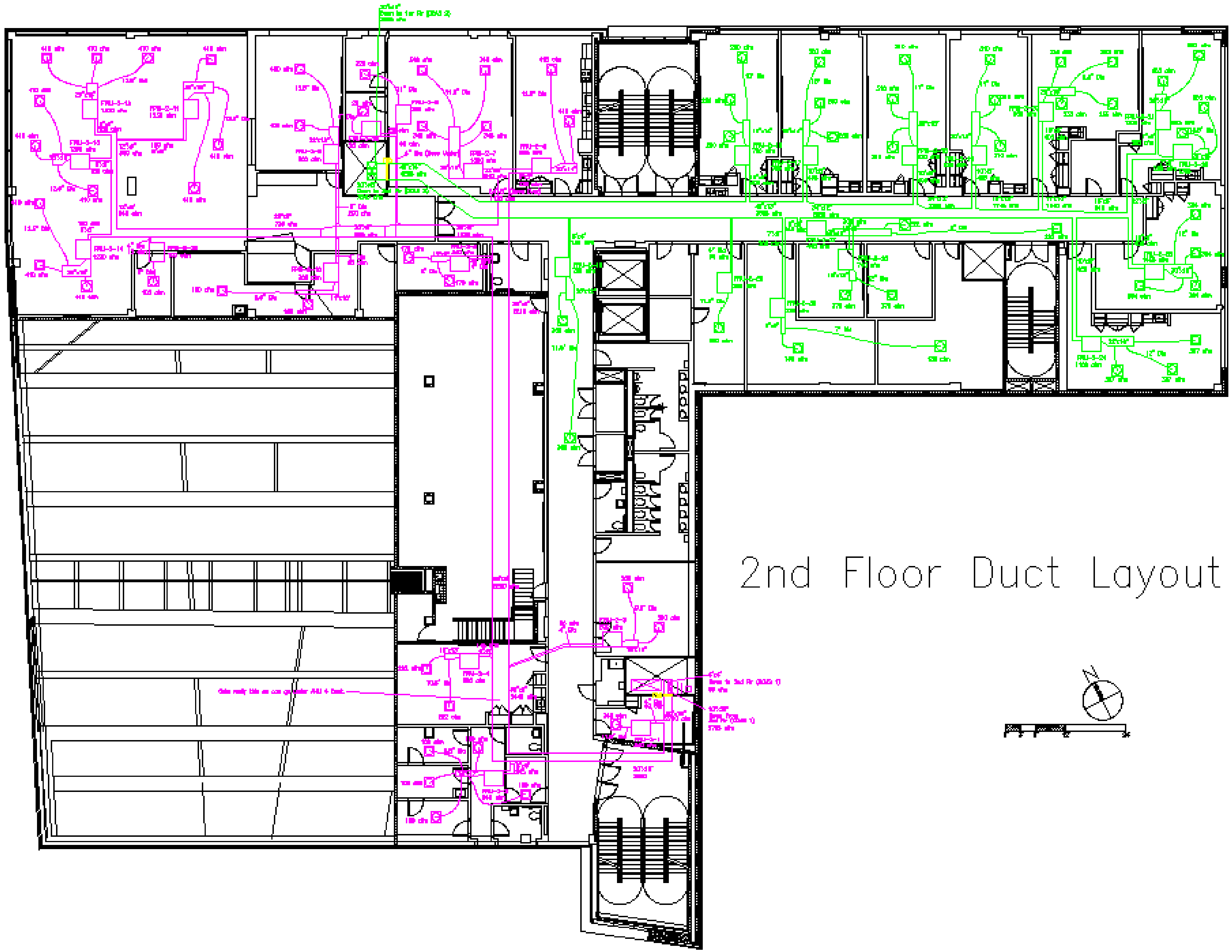
319	Is Science Lab	600	601	435	601	605
320	Is Resource	240	259	232	259	260
321	Is Science Prep	20	101	14	101	105
322	Is Resource	225	244	217	244	245
323	Is Science Lab	600	602	435	602	605
324	Is Classroom	510	556	493	556	560
325	Is Special Education	345	373	333	373	375
341	Is Staff Locker	140	44	0	140	140
347	Is Special Education	315	342	304	342	345
349	Is Classroom	450	507	435	507	510
351	Is Classroom	450	507	435	507	510
353	Is Classroom	585	629	565	629	630
355	Is Classroom	450	511	435	511	515
357	Is Classroom	450	511	435	511	515
359	Is Classroom	450	511	435	511	515
361	Is Classroom	450	506	435	506	510
401	Hs Classroom	510	549	493	549	550
403	Hs Classroom	465	520	449	520	520
405	Hs Classroom	465	521	449	521	525
407	Records	15	33	14	33	35
409	Mail	40	36	29	40	40
411	Gen Office	100	72	72	100	100
415	Principal	40	44	29	44	45
417	Hs Project Room	510	563	493	563	565
418	Hs Music	345	447	333	447	450
419	Hs Project Room	510	563	493	563	565
420	Hs Music Storage	39	60	0	60	60
421	Hs Classroom	465	516	449	516	520
422	Hs Resource	255	277	246	277	280
423	Hs Classroom	525	568	507	568	570
424	Hs Classroom	510	550	493	550	550
425	Hs Classroom	525	568	507	568	570
441	Hs Staff Locker	140	44	0	140	140
447	Hs Special Education	180	217	174	217	220
449	Hs Classroom	465	516	449	516	520
451	Hs Classroom	465	516	449	516	520
453	Hs Classroom	585	629	565	629	630
455	Hs Classroom	450	501	435	501	505
457	Hs Classroom	450	501	435	501	505
459	Hs Classroom	450	501	435	501	505
461	Hs Classroom	450	498	435	498	500
506	Mediation	80	34	58	80	80
508	Hs Supervisory	40	31	29	40	40
516	Hs Guidance Suite	45	35	43	45	45

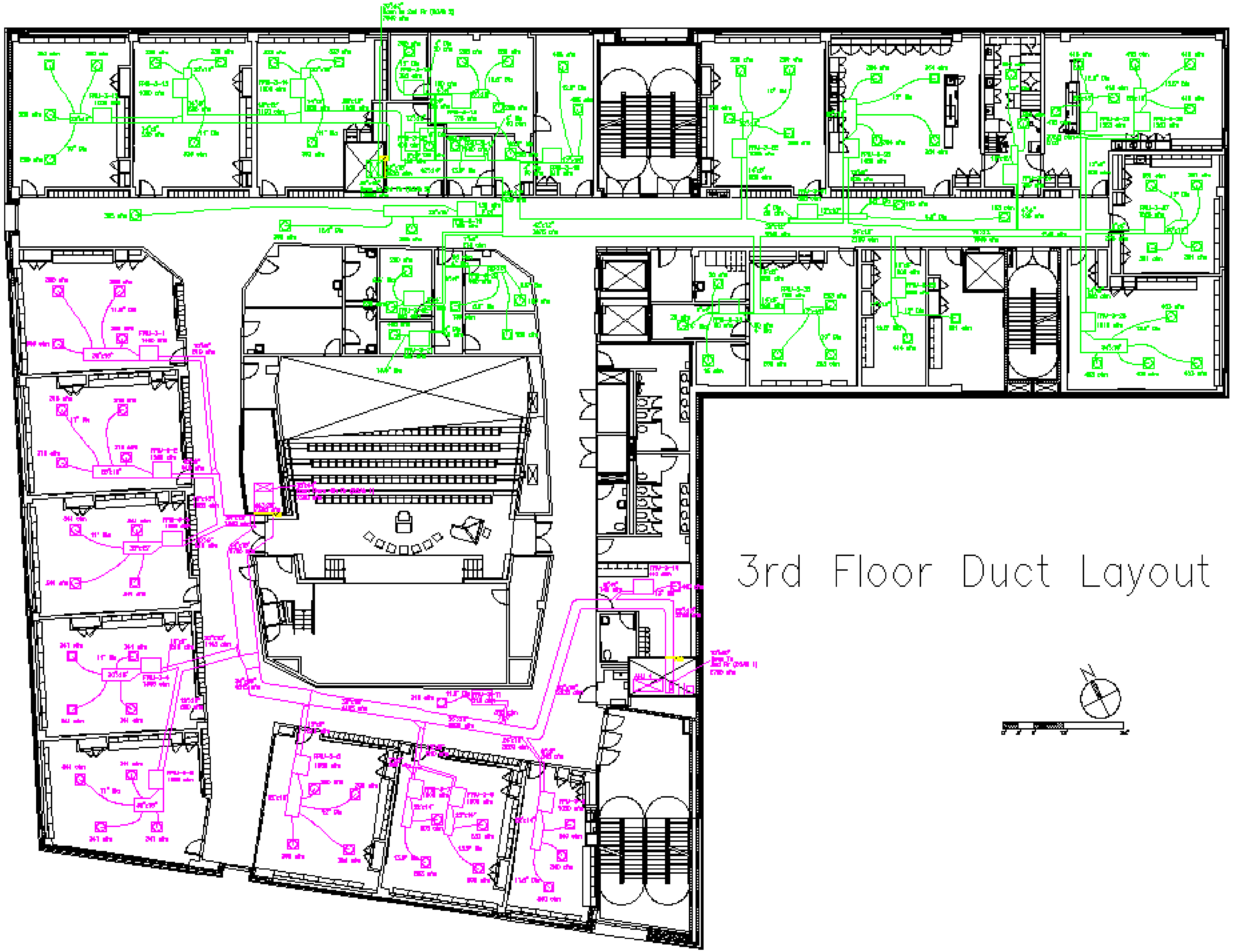
517	Hs Special Education	345	373	333	373	375
518	Hs College Suite	40	27	29	40	40
519	Hs Science Lab	760	789	551	789	790
521	Science Prep	100	183	72	183	185
522	Hs Receiving Vestibule	30	44	29	44	45
523	Science Lab Demo	600	624	435	624	625
524	Hs Receiving	40	47	29	47	50
525	Science Lab Demo	600	627	435	627	630
539	Men's Kitchen Locker Rooms	83	26	0	83	85
541	Women's Kitchen Locker Rooms	83	26	0	83	85
545	Guidance Records	20	20	14	20	20
547	Program Office	20	16	14	20	20
549	Hs Store	15	44	14	44	45
551	Government & Club House	120	59	87	120	120
552	Hs Art Room	780	923	942	942	945
109A	Supervisor	40	35	29	40	40
126A	Furniture Storage	52	81	0	81	85
126B	Storage	29	46	0	46	50
126C	Vault W. Anteroom	30	47	0	47	50
205A	Office Work Room	60	46	43	60	60
205B	A/V Storage	9	14	0	14	15
205C	Tech Center	200	195	145	200	200
207A	Office	20	13	14	20	20
207B	Storage	11	17	0	17	20
308A	Office	20	18	14	20	20
308B	Office	20	17	14	20	20
308B	Guidance Room	40	33	29	40	40
308D	Meeting	120	51	87	120	120
309A	Waiting	90	51	87	90	90
311A	Copy	20	18	14	20	20
318A	Is Music Storage	11	17	0	17	20
318B	Is Music Storage	13	21	0	21	25
318C	Is Music Storage	9	14	0	14	15
409A	Waiting	90	51	87	90	90
411A	Copy	20	18	14	20	20
418A	Hs Music Storage	7	12	0	12	15
418B	Hs Music Storage	12	20	0	20	20
418C	Hs Music Storage	6	9	0	9	10
516A	Hs Guidance Conf	120	48	87	120	120
516B	Hs Guidance Office	40	23	29	40	40
516C	Hs Guidance Office	40	23	29	40	40
518A	Hs College Office	40	22	29	40	40
518B	Hs College Conference	100	42	72	100	100
547A	Program Office	20	16	14	20	20
549A	Hs Store	15	31	14	31	35
551A	Government & Club Office	20	14	14	20	20
551B	Government & Club Office	20	14	14	20	20

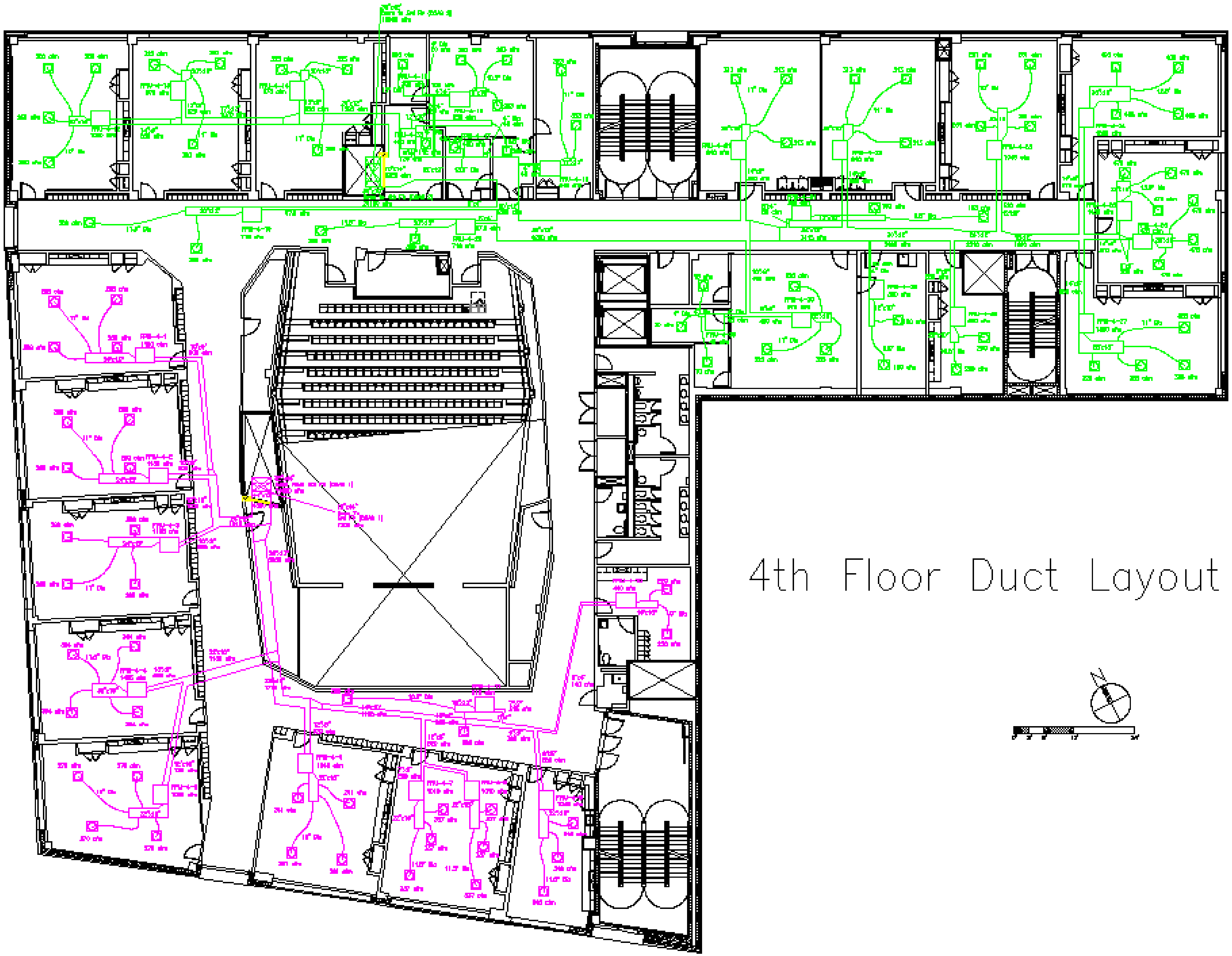
L1C	Vestibule	46	36	0	46	50
	Corridor 1st Floor West	280	218	0	280	280
	Corridor 2nd Floor South	123	96	0	123	125
	Corridor 3rd Floor West	135	105	0	135	135
	Corridor 4th Floor West	135	105	0	135	135
	Corridor 5th Floor East	206	161	0	206	210
	Corridor 1st Floor East	106	83	0	106	110
	Corridor 2nd Floor East	145	113	0	145	145
	Corridor 3rd Floor East	83	65	0	83	85
	Corridor 4th Floor East	83	65	0	83	85
	Corridor 3rd Floor South	313	244	0	313	315
	Corridor 4th Floor South	313	244	0	313	315
	Corridor 5th Floor South	154	121	0	154	155

Appendix G – New Duct Layouts

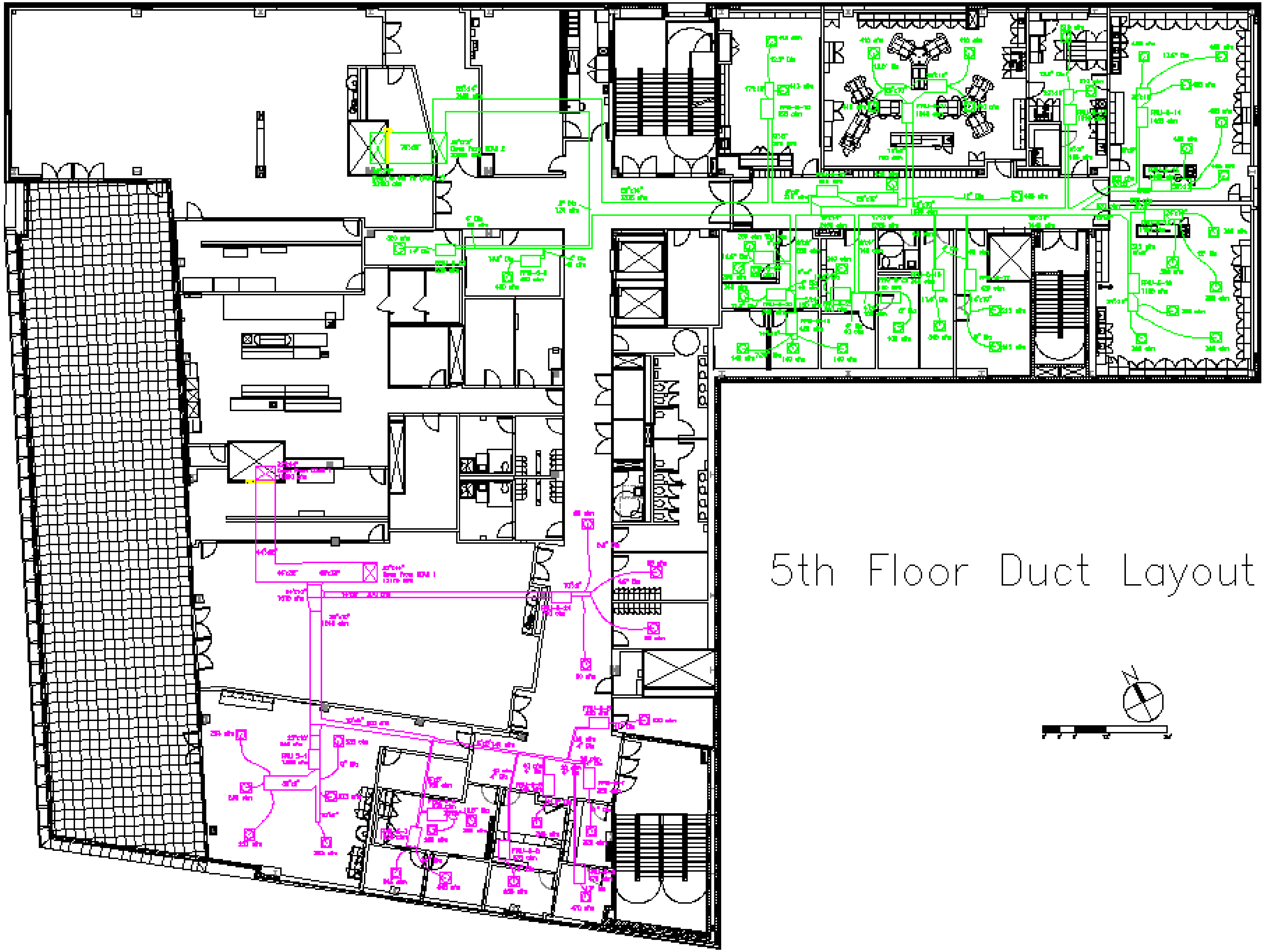



2nd Floor Duct Layout


3rd Floor Duct Layout



4th Floor Duct Layout



5th Floor Duct Layout

Appendix H – ESP Supply Fan DOAS 1

Section	Type	Run type	Air velocity (fpm)	Q (cfm)	Duct (inches x inches)	Length of Run (ft)	Friction Loss (in. wg per 100 ft run)	FRICTION LOSSES (in wg)	2009 Fundamentals Page/Type	Pv (velocity pressure, in wg)	C (local loss coefficient)	DYNAMIC LOSSES (in wg)	
1	Fan Discharge	n/a	1700	14975	32 x 44	0	0	0		0.18	0	0.18	
2	Control Damper	n/a	1700	14975	32 x 44	0	0	0	21.57/CR9-4	0.18	0.18	0.0324	
3	Fire Smoke Damper (FSD)	Riser	1700	14975	32 x 44	0	0	0	21.57/CR9-6	0.18	0.19	0.0342	
4	Duct - AHU to 5th Flr	Riser	1700	14975	32 x 44	5	0.08	0.004		0.18	0	0	
5	90 Deg Elbow with Vanes	Riser to Main	1500	14975	32 x 44	0	0	0	21.54/CR3-12	0.18	0.33	0.0594	
6	Duct - 5th Flr	Main	1500	14975	46 x 32	11.5	0.06	0.0069		0.14	0	0	
7	Tee Transition	Main	1500	13090	44 x 32	0	0	0	21.63/SR5-5	0.14	0.019	0.00266	
8	Duct - 5th Flr	Main	1500	13090	44 x 32	9	0.065	0.00585		0.14			
9	90 Deg Elbow with Vanes	Main	1500	13090	44 x 32	0	0	0	21.54/CR3-12	0.14	0.33	0.0462	
10	Duct - 5th Flr	Main	1500	13090	44 x 32	19.5	0.065	0.012675		0.14	0	0	
11	Fire Smoke Damper (FSD)	Main	1500	13090	44 x 32	0	0	0	21.57/CR9-6	0.14	0.19	0.0266	
12	90 Deg Elbow with Vanes	Main to Riser	1700	13090	44 x 32	0	0	0	21.54/CR3-12	0.18	0.33	0.0594	
13	Duct - 5th to 4th Flr	Riser	1700	13090	32 x 44	15	0.09	0.0135		0.18	0	0	
14	Tee Transition	Riser	1700	8125	18 x 44	0	0	0	21.64/SR5-13	0.18	0.0232	0.004176	
15	Duct - 4th to 3rd Flr	Riser	1700	8125	18 x 44	14	0.12	0.0168		0.18	0	0	
16	90 Deg Elbow with Vanes	Riser to Main	1500	8125	18 x 44	0	0	0	21.54/CR3-12	0.14	0.33	0.0462	
17	Duct - 3rd Flr	Main	1500	8125	44 x 20	6.5	0.09	0.00585		0.14	0	0	
18	Fire Smoke Damper (FSD)	Main	1500	8125	44 x 20	0	0	0	21.57/CR9-6	0.14	0.19	0.0266	
19	Tee Transition	Main	1500	6385	44 x 16	0	0	0	21.64/SR5-13	0.14	0.044	0.00616	
20	Elbow 45 Deg	Main	1500	6385	44 x 16	0	0	0	21.52/CR3-1	0.14	0.157	0.02198	
21	Duct - 3rd Flr	Main	1500	6385	44 x 16	6.5	0.1	0.0065		0.14	0	0	
22	Elbow 45 Deg	Main	1500	6385	44 x 16	0	0	0	21.52/CR3-1	0.14	0.157	0.02198	
23	Duct - 3rd Flr	Main	1500	6385	44 x 16	20	0.1	0.02		0.14	0	0	
24	Tee Transition	Main	1500	5050	34 x 16	0	0	0	21.64/SR5-13	0.14	0.036	0.00504	
25	Duct - 3rd Flr	Main	1500	5050	34 x 16	4	0.12	0.0048		0.14	0	0	
26	Elbow 90 Deg	Main	1500	5050	34 x 16	0	0	0	21.52/CR3-1	0.14	0.25	0.035	
27	Duct - 3rd Flr	Main	1500	5050	34 x 16	10.5	0.12	0.0126		0.14	0	0	
28	Tee Transition	Main	1500	4470	30 x 16	0	0	0	21.64/SR5-13	0.14	0.041	0.00574	
29	Duct - 3rd Flr	Main	1500	4470	30 x 16	23	0.12	0.0276		0.14	0	0	
30	Tee Transition	Main	1500	3890	26 x 16	0	0	0	21.64/SR5-13	0.14	0.042	0.00588	
31	Duct - 3rd Flr	Main	1500	3890	26 x 16	18	0.13	0.0234		0.14	0	0	
32	Tee Transition	Main	1500	3575	24 x 16	0	0	0	21.64/SR5-13	0.14	0.039	0.00546	
33	Duct - 3rd Flr	Main	1500	3575	24 x 16	4.5	0.14	0.0063		0.14	0	0	
34	Wye 45 Deg Diverging	Main	1500	3165	22 x 16	0	0	0	21.49/SD5-1	0.14	0.133	0.01862	
35	90 Deg Elbow	Main	1500	3165	22 x 16	0	0	0	21.52/CR3-1	0.14	0.232	0.03248	
36	Duct - 3rd Flr	Main	1500	3165	22 x 16	27	0.14	0.0378		0.14	0	0	
37	90 Deg Elbow	Main	1500	3165	22 x 16	0	0	0	21.52/CR3-1	0.14	0.232	0.03248	
38	Duct - 3rd Flr	Main	1500	3165	22 x 16	18	0.14	0.0252		0.14	0	0	
39	Wye 45 Deg Diverging	Main	1500	3025	22 x 16	0	0	0	21.49/SD5-1	0.14	0.146	0.02044	
40	90 Deg Elbow	Main	1500	3025	22 x 16	0	0	0	21.52/CR3-1	0.14	0.232	0.03248	
41	Duct Run	Main	1500	3025	22 x 16	16	0.14	0.0224		0.14	0	0	
42	Fire Smoke Damper (FSD)	Main	1500	3025	22 x 16	0	0	0	21.57/CR9-6	0.14	0.19	0.0266	
43	90 Deg Elbow	Main to Riser	1700	3025	10 x 30	0	0	0	21.54/CR3-12	0.18	0.33	0.0594	
44	Duct - 3rd to 2nd Flr	Riser	1700	3025	10 x 30	14	0.2	0.028		0.18	0	0	
45	Tee Transition	Riser	1700	2950	20 x 16	0	0	0	21.64/SR5-13	0.18	0.75	0.135	
46	Fire Smoke Damper (FSD)	Main	1500	2950	22 x 16	0	0	0	21.57/CR9-6	0.14	0.19	0.0266	
47	Balancing Damper	Main	1500	2950	20 x 16	0	0	0	21.57/CR9-4	0.14	0.18	0.0252	
48	Duct - 2nd Flr	Main	1500	2950	20 x 16	14	0.16	0.0224		0.14	0	0	
49	Tee Transition	Main	1500	2910	20 x 16	0	0	0	21.64/SR5-13	0.14	0.025	0.0035	
50	90 Deg Elbow	Main	1500	2910	20 x 16	0	0	0	21.52/CR3-1	0.14	0.226	0.03164	
51	Duct - 2nd Flr	Main	1500	2910	20 x 16	33.5	0.16	0.0536		0.14	0	0	
52	Tee Transition	Main	1500	2665	38 x 8	0	0	0	21.64/SR5-13	0.14	0.044	0.00616	
53	90 Deg Elbow	Main	1500	2665	38 x 8	0	0	0	21.52/CR3-1	0.14	0.27	0.0378	
54	Duct - 2nd Flr	Main	1500	2665	38 x 8	104.5	0.17	0.17765		0.14	0	0	
55	Wye 45 Deg Diverging	Main	1500	2605	38 x 8	0	0	0	21.49/SD5-1	0.14	0.1423	0.019922	
56	Tee Transition	Main	1500	2460	38 x 8	0	0	0	21.63/SR5-5	0.14	0.0084	0.001176	
57	Tee Transition	Main	1500	2420	38 x 8	0	0	0	21.63/SR5-5	0.14	0.0024	0.000336	
58	Tee Transition	Main to Branch	1000	1245	28 x 8	0	0	0	21.64/SR5-13	0.06	1.54	0.0924	
59	Duct - 2nd Flr	Branch	1000	1245	28 x 8	20.5	0.17	0.03485		0.06	0	0	
60	Tee Transition	Branch	1000	1205	26 x 8	0	0	0	21.64/SR5-13	0.06	0.023	0.00138	
61	Duct - 2nd Flr	Branch	1000	1205	26 x 8	12	0.19	0.0228		0.06	0	0	
62	SD5-24 Cross, Diverging	Branch	1000	945	20 x 8	0	0	0	21.50/SD5-24	0.06	0.135	0.0081	
63	Duct - 2nd Flr	Branch	1000	945	20 x 8	28	0.11	0.0308		0.06	0	0	
64	Tee Transition	Branch	1000	930	20 x 8	0	0	0	21.64/SR5-13	0.06	0.67	0.0402	
65	Duct - 2nd Flr	Branch	1000	930	20 x 8	9	0.11	0.0099		0.06	0	0	
66	FPIU Inlet					0	0	0				0.5	
								0.632175	in. wg			1.77699	in. wg
										Total E.S.P. :	2.409165	in. wg	
										Safety Factor =	15	%	
									E.S.P. w/ Safety Factor:		2.7705398	in. wg	

Appendix I – ESP Return Fan DOAS 1

Section	Type	Run type	Air velocity (fpm)	Q (cfm)	Duct (inches x inches)	Length of Run (ft)	Friction Loss (in. wg per 100 ft run)	FRICTION LOSSES (in wg)	2009 Fundamentals Page/Type	Pv (velocity pressure, in wg)	C (local loss coefficient)	DYNAMIC LOSSES (in wg)	
1	Grille											0.02	
2	Elbow 90 Deg	Riser	1700	56	4 x 4	0	0	0	21.52/CR3-1	0.18	0.21	0.0378	
3	Fire Smoke Damper (FSD)	Riser	1700	56	4 x 4	0	0	0	21.57/CR9-6	0.18	0.19	0.0342	
4	Shaft - 1st to 2nd	Riser	1700	56	4 x 4	10	1.6	0.16			0	0	
5	Tee Transition	Riser	1700	56	4 x 4	0	0	0	21.42/ED5-3	0.18	1.63	0.2934	
6	Shaft - 2nd to 3rd	Riser	1700	2266	22 x 10	14	0.24	0.0336			0	0	
7	Tee Transition	Riser	1700	2266	22 x 10	0	0	0	21.43/ED5-3	0.18	1.07	0.1926	
8	Shaft - 3rd to 4th	Riser	1700	6086	26 x 22	14	0.14	0.0196			0	0	
9	Tee Transition	Riser	1700	6086	26 x 22	0	0	0	21.43/ED5-3	0.18	0.7	0.126	
10	Shaft - 4th to 5th	Riser	1700	9805	30 x 30	15	0.1	0.015		0.18	0	0	
11	90 Deg Elbow with Vanes	Riser	1700	9805	30 x 30	0	0	0	21.54/CR3-12	0.18	0.33	0.0594	
12	Fire Smoke Damper (FSD)	Riser	1700	9805	30 x 30	0	0	0	21.57/CR9-6	0.18	0.19	0.0342	
13	90 Deg Elbow with Vanes	Riser	1700	11217	36 x 30	0	0	0	21.54/CR3-12	0.18	0.33	0.0594	
14	Shaft - 5th to AHU	Riser	1700	11217	36 x 30	5	0.08	0.004		0.18	0	0	
15	Fire Smoke Damper (FSD)	Riser	1700	11217	36 x 30	0	0	0	21.57/CR9-6	0.18	0.19	0.0342	
16	Inlet to Fan	Riser	1700					0		0.18	0	0.18	
								0.2322	in. wg			1.0712	in. wg
										Total E.S.P. :	1.3034	in. wg	
										Safety Factor =	15	%	
									E.S.P. w/ Safety Factor:		1.49891	in. wg	

Appendix J – ESP Supply Fan DOAS 2

Section	Type	Run type	Air velocity (fpm)	Q (cfm)	Duct (inches x inches)	Length of Run (ft)	Friction Loss (in. wg per 100 ft run)	FRICTION LOSSES (in wg)	2009 Fundamentals Page/Type	Pv (velocity pressure, in wg)	C (local loss coefficient)	DYNAMIC LOSSES (in wg)	
1	Fan Discharge	n/a	1700	26795	36 x 72	0	0	0		0.18	0	0.18	
2	Control Damper	n/a	1700	26796	36 x 72	0	0	0	21.57/CR9-4	0.18	0.18	0.0324	
3	Fire Smoke Damper (FSD)	Riser	1700	26796	36 x 72	0	0	0	21.57/CR9-6	0.18	0.19	0.0342	
4	Duct - AHU to 5th Flr	Riser	1700	26796	36 x 72	5	0.06	0.003		0.18	0	0	
5	90 Deg Elbow with Vanes	Riser to Main	1500	23255	70 x 36	0	0	0	21.54/CR3-12	0.14	0.33	0.0462	
6	Duct - 5th Flr	Main	1500	23255	70 x 36	12	0.045	0.0054		0.14	0	0	
7	Fire Smoke Damper (FSD)	Main	1500	23255	70 x 36	0	0	0	21.57/CR9-6	0.14	0.19	0.0266	
8	90 Deg Elbow with Vanes	Main to Riser	1700	23255	36 x 70	0	0	0	21.54/CR3-12	0.18	0.33	0.0594	
9	Duct - 5th to 4th Flr	Riser	1700	23255	36 x 70	15	0.06	0.009		0.18	0	0	
10	Tee Transition	Riser	1700	15990	36 x 42	0	0	0	21.64/SR5-13	0.18	0.036	0.00648	
11	Duct - 4th to 3rd Flr	Riser	1700	15990	36 x 42	14	0.08	0.0112		0.18	0	0	
12	Tee Transition	Riser	1700	8765	20 x 42	0	0	0	21.64/SR5-13	0.18	0.045	0.0081	
13	Duct - 3rd to 2nd Flr	Riser	1700	8765	20 x 42	14	0.2	0.028		0.18	0	0	
14	Tee Transition	Riser	1700	3810	20 x 18	0	0	0	21.64/SR5-13	0.18	0.05	0.009	
15	Duct 2nd to 1st Flr	Riser	1700	3810	20 x 18	14	0.18	0.0252		0.18	0	0	
16	Fire Smoke Damper (FSD)	Riser	1700	3810	20 x 18	0	0	0	21.57/CR9-6	0.18	0.19	0.0342	
17	Balancing Damper	Riser	1700	3810	20 x 18	0	0	0	21.57/CR9-4	0.18	0.18	0.0324	
18	90 Deg Elbow with Vanes	Riser to Main	1500	1165	16 x 8	0	0	0	21.54/CR3-12	0.14	0.33	0.0462	
19	Duct - 1 st Flr	Main	1500	1165	16 x 8	5	0.22	0.011		0.14	0	0	
20	Tee Transition	Main	1500	885	12 x 8	0	0	0	21.64/SR5-13	0.14	0.042	0.00588	
21	Duct - 1 st Flr	Main	1500	885	12 x 8	23	0.3	0.069		0.14	0	0	
22	Tee Transition	Main	1500	815	12 x 8	0	0	0	21.63/SR5-5	0.14	0.012	0.00168	
23	Tee Transition	Main	1500	775	12 x 8	0	0	0	21.63/SR5-5	0.14	0.0074	0.001036	
24	90 Deg Elbow	Main	1500	775	12 x 8	0	0	0	21.52/CR3-1	0.14	0.237	0.03318	
25	Duct - 1st Flr	Main	1500	775	12 x 8	9	0.32	0.0288		0.14	0	0	
26	90 Deg Elbow	Main	1500	775	12 x 8	0	0	0	21.52/CR3-1	0.14	0.237	0.03318	
27	Duct - 1st Flr	Main	1500	775	12 x 8	8	0.32	0.0256		0.14	0	0	
28	Tee Transition	Main	1500	665	9 x 8	0	0	0	21.64/SR5-13	0.14	0.021	0.00294	
29	Duct - 1st Flr	Main	1500	665	9 x 8	46	0	0		0.14	0	0	
30	Tee Transition	Main	1500	565	9 x 8	0	0	0	21.63/SR5-5	0.14	0.0225	0.00315	
31	Tee Transition	Main	1500	465	9 x 6	0	0	0	21.64/SR5-13	0.14	0.0266	0.003724	
32	Duct - 1st Flr	Main	1500	465	9 x 6	30	0	0		0.14	0	0	
33	Tee Transition	Main	1500	405	9 x 6	0	0	0	21.63/SR5-5	0.14	0.0194	0.002716	
34	Tee Transition	Main	1500	365	9 x 6	0	0	0	21.63/SR5-5	0.14	0.015	0.0021	
35	Tee Transition	Main	1500	310	9 x 6	0	0	0	21.63/SR5-5	0.14	0.0225	0.00315	
36	Tee Transition	Main	1500	235	5 x 5	0	0	0	21.64/SR5-13	0.14	0.003	0.00042	
37	Duct - 1st Flr	Main	1500	235	5 x 5	15	0.6	0.09		0.14	0	0	
38	Wye 45 Deg Diverging	Branch	1000	185	5 x 5	0	0	0	21.49/SD5-1	0.06	0.648	0.03888	
39	Duct - 1st Flr	Branch	1000	185	5 x 5	11	0.28	0.0308		0.06	0	0	
40	Elbow 45 Deg	Branch	1000	185	5 x 5	0	0	0	21.52/CR3-1	0.06	0.126	0.00756	
41	Duct - 1st Flr	Branch	1000	185	5 x 5	16	0.28	0.0448		0.06	0	0	
42	Tee Transition	Branch	1000	100	4 x 4	0	0	0	21.64/SR5-13	0.06	0.262	0.01572	
43	90 Deg Elbow	Branch	1000	100	4 x 4	0	0	0	21.52/CR3-1	0.06	0.21	0.0126	
44	Duct - 1st Flr	Branch	1000	100	4 x 4	8	0.4	0.032		0.06	0	0	
45	FPIU Inlet					0	0	0				0.5	
								0.4138	in. wg			1.183096	in. wg
										Total E.S.P. :	1.596896	in. wg	
										Safety Factor =	15	%	
									E.S.P. w/ Safety Factor:		1.83643	in. wg	

Appendix K – ESP Return Fan DOAS 2

Section	Type	Run type	Air velocity (fpm)	Q (cfm)	Duct (inches x inches)	Length of Run (ft)	Friction Loss (in. wg per 100 ft run)	FRICTION LOSSES (in wg)	2009 Fundamentals Page/Type	Pv (velocity pressure, in wg)	C (local loss coefficient)	DYNAMIC LOSSES (in wg)	
1	Grille											0.02	
2	Elbow 90 Deg	Riser	1700	2898	18 x 15	0	0	0	21.52/CR3-1	0.18	0.22	0.0396	
3	Fire Smoke Damper (FSD)	Riser	1700	2898	18 x 15	0	0	0	21.57/CR9-6	0.18	0.19	0.0342	
4	Shaft - 1st to 2nd	Riser	1700	2898	18 x 15	10	0.22	0.022		0.18	0	0	
5	Tee Transition	Riser	1700	2898	18 x 15	0	0	0	21.43/ED5-3	0.18	1.1	0.198	
6	Shaft - 2nd to 3rd	Riser	1700	6667	32 x 30	14	0.13	0.0182		0.18	0	0	
7	Tee Transition	Riser	1700	6667	32 x 30	0	0	0	21.43/ED5-3	0.18	0.96	0.1728	
8	Shaft - 3rd to 4th	Riser	1700	12162	38 x 30	14	0.09	0.0126		0.18	0	0	
9	Tee Transition	Riser	1700	12162	38 x 30	0	0	0	21.43/ED5-3	0.18	0.7	0.126	
10	Shaft - 4th to 5th	Riser	1700	17687	50 x 34	15	0.08	0.012		0.18	0	0	
11	90 Deg Elbow with Vanes	Riser	1700	17687	50 x 34	0	0	0	21.54/CR3-12	0.18	0.33	0.0594	
12	Fire Smoke Damper (FSD)	Riser	1700	17687	50 x 34	0	0	0	21.57/CR9-6	0.18	0.19	0.0342	
13	90 Deg Elbow with Vanes	Riser	1700	20379	50 x 38	0	0	0	21.54/CR3-12	0.18	0.33	0.0594	
14	Shaft - 5th to AHU	Riser	1700	20379	50 x 38	5	0.07	0.0035		0.18	0	0	
15	Fire Smoke Damper (FSD)	Riser	1700	20379	50 x 38	0	0	0	21.57/CR9-6	0.18	0.19	0.0342	
16	Inlet to Fan	Riser	1700					0		0.18	0	0.18	
								0.0683	in. wg			0.9578	in. wg
										Total E.S.P. :	1.0261	in. wg	
										Safety Factor =	15	%	
									E.S.P. w/ Safety Factor:		1.180015	in. wg	

Appendix L – DOAS 1 Manufacturer's Specifications

VISION AIR HANDLING UNIT TECHNICAL DATA

Date Saved : February 29 2012

QUOTE ID	8IUVJ6(XX.000)	REP. OFFICE	Havtech (DC)
JOB NAME	TEST BUILDING	SALESPERSON	GG
MODEL NUMBER	CAH028GDGM	ENGINEER	
UNIT TAGGING	ERU-1	VERSION	9.53

Unit configuration	Side by side with opposed air flows		
Drive (handing) location	Right		
	SUPPLY	RETURN / EXHAUST	
Air volume	13230	9436	s cfm
Altitude	0	0	ft
Turning loss	0.00	0.00	in WC.
External static	2.80	1.50	in WC.
Total static	7.71	3.42	in WC.
External H x W	84 x 66	84 x 66 (Not including base rails)	ins

CASING DETAILS	
Outer panel	Standard G90 galv steel (unpainted)
Liner	Galvanized steel (Unless noted per section)
Insulation	R-13 Injected Foam (Unless noted per section)
Frame	2 ins
Base	8" formed channel
Sound baffles	None (Unless noted per section)
Tread Plate floor liner	None (unless noted per section)
Shrink wrapping	No

Exhaust Air Stream

1 ACCESS SECTION(24 ins) SECTION 4

Drip pan	None		Drip side	-	
			Air pressure drop	0.00	Ins WC

DOOR DATA

Door location	Drive side		Window size	None
Door width	20	ins	Light	None
Door opening	Outward			

2 PANEL FILTER(12 ins) SECTION 4

Type	Pleated		Clean air press. drop	0.23	ins WC
Efficiency	MERV 8		Mean air press. drop	0.62	ins WC
Face velocity	325	fpm	**Dirty air press. drop**	**1.00**	**ins WC**
Face area	29.0	ft2	Access	Side	
Air volume	9436	cfm			

BANK ARRANGEMENT

No. of Filters	Size H x W x D	
3.0	24 x 20 x 2	Ins
6.0	20 x 20 x 2	
2.0	12 x 24 x 2	

DOOR DATA

Door location	Drive side		Window size	None
Door width	8	ins	Light	None
Door opening	Outward			

SPECIAL

Intersept Antimicrobial treatment

Tread Plate floor liner	None
Liner	(As casing details)
Insulation	(As casing details)

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2 PANEL FILTER(12 ins) — SECTION 4

Sound baffles	None			
Special static pressure	-	ins WC	Filter Gauge	None

3 ACCESS SECTION(30 ins) — SECTION 4

Drip pan	None		Drip side	-	
			Air pressure drop	0.00	Ins WC

DOOR DATA

Door location	Drive side		Window size	None
Door width	26	ins	Light	None
Door opening	Outward			

4 ENERGY RECOVERY SECTION (24 ins) — SECTION 3

Heat Wheel Model	ECW 726				
Media Type	Synthetic fiber - 4 angstrom		Electrical Supply Volt	115/60/1	Volt
Wheel Diameter	72.00	ins	Bypass Damp Opening	No Bypass	ins
Supply air CFM	13230	CFM	Supply air PD Sum/Win	1.28 / 1.17	ins WC
Supply air FV Sum/Win	1036 / 1034	ft/min	Exhaust air CFM	9436	CFM
Return air PD Sum/Win	0.91 / 0.83	ins WC	Motor HP	1	
Segmented Wheel	No				

Summer Conditions			**Winter Conditions**		
Outside air DB	89.7	F	Outside air DB	12.8	F
Outside air WB	76.8	F	Outside air WB	10.0	F
Return air DB	75.0	F	Return air DB	72.0	F
Return air WB	62.5	F	Return air WB	59.9	F
Supply air DB	82.2	F	Supply air DB	43.6	F
Supply air WB	70.8	F	Supply air WB	39.9	F
Exhaust air DB	85.7	F	Exhaust air DB	28.1	F
Exhaust air WB	73.0	F	Exhaust air WB	28.0	F
Latent effectiveness	68.62	%	Latent effectiveness	70.81	%
Sensible effectiveness	75.30	%	Sensible effectiveness	77.20	%
Total effectiveness	70.75	%	Total effectiveness	74.55	%
Total Energy Recovered	345881	Btu/hr	Total Energy Recovered	675484	Btu/hr

5 ACCESS SECTION(16 ins) — SECTION 1

Drip pan	None		Drip side	-	
			Air pressure drop	0.01	Ins WC

DOOR DATA

Door location	Drive side		Window size	None
Door width	12	ins	Light	None
Door opening	Outward			

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6 RETURN/EXHAUST FAN SECTION(40 ins)					SECTION 1
Air volume	9436	cfm	Motor power	15.0	HP
External static pressure	1.50	ins WC	Motor type	ODP	
Total static pressure	3.42	ins WC	Frame size	215 T frame	
Cabinet static pressure	0	ins WC	Electrical supply	460/60/3	
Type	Centrifugal - Plenum		Motor efficiency	Premium	
Blade type/Class	Airfoil / 2		Motor speed	3500	rpm
Quantity of Fans	1		Block-off Plate	No	
Fan wheel diameter	18.25	ins	Motor pole	4	
Brake horsepower	11.56	HP	Full load current	17.8	A
Operating/Max speed	3233 / 3650	rpm	Lock rotor current	116	A
Discharge	Axial		Motor supplier	Generic	
Air modulation	None		Actual drive service fac.	1.34	
Drip pan	None		Bearing type	N/A	
Drip pan side	-		Outlet velocity	-	ft/m
Wheel guard	None		Inlet screen	None	
Belt guard	None		Outlet screen	None	
Inspection port	None		Motor location	Behind Fan	
Material type	Aluminium		Number of blades	12	

DRIVES *			
Fan sheave	N/A	Motor sheave	N/A
Number of belts	0	Belt	N/A

* McQuay reserves the right to provide a different but equivalent drive package.

ANTI-VIBRATION MOUNTS / SPRINGS	
Type	Spring
Seismic restraint	None

DOOR DATA				
Door location	Drive side		Window size	None
Door width	26	ins	Light	None
Door opening	Outward			

VFD / STARTER / DISCONNECT DATA				
Selection type	VFD - NEMA 1	Vendor	ABB	
Auxiliary Control	None	Voltage	460	
-	None			
Mounting	Door Side	H x W x D	19.09 x 7.42 x 9.89	ins
Enclosure	NEMA 1	Coil Voltage	N/A	
Line Reactor	None	Hand Off Auto Switch	None	
24V Ctrl Transformer	None			
VFD Quantity	1			

Supply Air Stream

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1 MIXING BOX(50 ins) — SECTION 2

Drip pan	None	Drip side	-	
Floor grating	No			
	OUTSIDE AIR	**RETURN AIR**		
Length x Width	42.00 x 62.00	No opening		ins
Location	End	-		
Dampers	UltraSeal Low Leak	None		
Actuation	-	-		
Rated cfm	13230	13230		cfm
Air pressure drop	0.07			in WC
Quantity	1	1		

FILTER DATA

Type	Pleated		**Clean air press. drop**	**0.36**	**ins WC**
Efficiency	MERV 8		Mean air press. drop	0.68	ins WC
Face velocity	456	fpm	Dirty air press. drop	1.00	ins WC
Face area	29.0	ft2	Access	Side	
Air volume	13230	cfm			

BANK ARRANGEMENT

No. of filters	Size H x W x D	
3.0	24 x 20 x 2	ins
6.0	20 x 20 x 2	
2.0	12 x 24 x 2	

DOOR DATA

Door location	Drive side		Window size	None
Door width	30	ins	Light	None
Door opening	Outward			

SPECIAL

Intersept Antimicrobial treatment

Tread Plate floor liner	None			
Liner	(As casing details)			
Insulation	(As casing details)			
Sound baffles	None			
Special static pressure	-	ins WC	Filter Gauge	None

2 PANEL FILTER(14 ins) — SECTION 2

Type	Pleated		**Clean air press. drop**	**0.32**	**ins WC**
Efficiency	MERV 8		Mean air press. drop	0.66	ins WC
Face velocity	434	fpm	Dirty air press. drop	1.00	ins WC
Face area	30.5	ft2	Access	Side	
Air volume	13230	cfm			

BANK ARRANGEMENT

No. of Filters	Size H x W x D	
1.0	24 x 24 x 4	Ins
2.0	24 x 20 x 4	
2.0	20 x 24 x 4	
4.0	20 x 20 x 4	
2.0	12 x 24 x 4	

DOOR DATA

Door location	Drive side		Window size	None
Door width	10	ins	Light	None
Door opening	Outward			

SPECIAL

Intersept Antimicrobial treatment
MERV 13 FINAL FILTER

Tread Plate floor liner	None

VISION AIR HANDLING UNIT TECHNICAL DATA

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2 PANEL FILTER(14 ins) — SECTION 2

Liner	(As casing details)			
Insulation	(As casing details)			
Sound baffles	None			
Special static pressure	1.00	ins WC	Filter Gauge	None

3 ACCESS SECTION(30 ins) — SECTION 2

Drip pan	None		Drip side	-	
			Air pressure drop	0.00	Ins WC

DOOR DATA

Door location	Drive side		Window size	None
Door width	26	ins	Light	None
Door opening	Outward			

4 ENERGY RECOVERY SECTION (24 ins) — SECTION 3

5 ACCESS SECTION(24 ins) — SECTION 5

Drip pan	None		Drip side	-	
			Air pressure drop	0.00	Ins WC

DOOR DATA

Door location	Drive side		Window size	None
Door width	20	ins	Light	None
Door opening	Outward			

6 CHILLED WATER COIL(36 ins) — SECTION 5

Coil model	5WS1212B		Number of coils	2	
Total capacity	977702	Btu/h	Number of rows	12	
Sensible capacity	518295	Btu/h	Fins per inch	12	
Air volume	13230	cfm			
Entering db/wb	82.2 / 70.8	F	Entering water	44.0	F
Leaving db/wb	46.4 / 46.2	F	Leaving water	51.7	F
Finned height x length	36 x 53	ins	Water flow rate	255.60	gpm
Face area	26.50	ft2	Water pressure drop	26.80	ftHD
Face velocity	499	ft/m	Water velocity	5.70	ft/s
Coil air pressure drop	1.67	ins WC			
			Fluid volume	42.0	gal
			Fluid weight	356.00	lb
Connection type	Threaded		Fin material	Aluminum (.0075)	
Connection Qty x size	2 x 2.50	ins	Tube material	Copper (.020)	
Connection location	Drive side		Header material	Copper	
Connection material	Carbon steel		Case material	Galv. steel	
Glycol type (%)	- (0 %)		Drain pan	Microbial resistant coated galvanized	
Fouling Factor	0		Drain pan side	Drive side	
			Turbospirals	No	
Coil code	5WS1212B		Electro-fin coat	None	

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7 HOT WATER COIL(12 ins) SECTION 5

Coil model	5WQ1201C		Number of coils	2	
Capacity	545074	Btu/h	Number of rows	1	
			Fins per inch	12	
Air volume	13230	cfm			
Entering db	28.1	F	Entering water	140.0	F
Leaving db	65.8	F	Leaving water	119.6	F
Finned height x length	36 x 50	ins	Water flow rate	53.40	gpm
Face area	25.00	ft2	Water pressure drop	7.10	ftHD
Face velocity	529	ft/m	Water velocity	4.70	ft/s
Coil air pressure drop	0.21	ins WC			
			Fluid volume	6.0	gal
			Fluid weight	58.00	lb
Connection type	Threaded		Fin material	Aluminum (.0075)	
Connection Qty x size	2 x 1.50	ins	Tube material	Copper (.020)	
Connection location	Drive side		Header material	Copper	
Connection material	Carbon steel		Case material	Galvanized track	
Glycol type (%)	- (0 %)		Drip pan	None	
Fouling Factor	0		Drip pan side	-	
			Turbospirals	No	
Coil code	5WQ1201C		Electro-fin coat	None	

8 ACCESS SECTION(24 ins) SECTION 5

Drip pan	None		Drip side	-	
			Air pressure drop	0.00	Ins WC

DOOR DATA

Door location	Drive side		Window size	None
Door width	20	ins	Light	None
Door opening	Outward			

VISION AIR HANDLING UNIT TECHNICAL DATA   Date Saved : February 29 2012

9 SUPPLY FAN SECTION(52 ins)					SECTION 6
Air volume	13230	cfm	Motor power	30.0	HP
External static pressure	2.80	ins WC	Motor type	ODP	
Total static pressure	7.71	ins WC	Frame size	286 T frame	
Cabinet static pressure	0	ins WC	Electrical supply	460/60/3	
Type	Centrifugal - Plenum		Motor efficiency	Premium	
Blade type/Class	Airfoil / 2		Motor speed	1750	rpm
Quantity of Fans	1		Block-off Plate	No	
Fan wheel diameter	27.00	ins	Motor pole	4	
Brake horsepower	22.65	HP	Full load current	34.3	A
Operating/Max speed	1938 / 1981	rpm	Lock rotor current	217.5	A
Discharge	Axial		Motor supplier	Generic	
Air modulation	None		Actual drive service fac.	1.32	
Drip pan	None		Bearing type	N/A	
Drip pan side	-		Outlet velocity	-	ft/m
Wheel guard	None		Inlet screen	None	
Belt guard	None		Outlet screen	None	
Inspection port	None		Motor location	Behind Fan	
Material type	Aluminium		Number of blades	9	

DRIVES *				
Fan sheave	N/A		Motor sheave	N/A
Number of belts	0		Belt	N/A

* McQuay reserves the right to provide a different but equivalent drive package.

ANTI-VIBRATION MOUNTS / SPRINGS	
Type	Spring
Seismic restraint	None

DOOR DATA				
Door location	Drive side		Window size	None
Door width	30	ins	Light	None
Door opening	Outward			

VFD / STARTER / DISCONNECT DATA				
Selection type	VFD - NEMA 1	Vendor	ABB	
Auxiliary Control	None	Voltage	460	
-	None			
Mounting	Door Side	H x W x D	23.58 x 10.49 x 10.25	ins
Enclosure	NEMA 1	Coil Voltage	N/A	
Line Reactor	None	Hand Off Auto Switch	None	
24V Ctrl Transformer	None			
VFD Quantity	1			

NOTES

Supply fan performance is certified in accordance with the Central Station Air-Handling Unit Certification Program, which is based on ARI Standard 430.
Important Notice

This unit may not meet ASHRAE Standard 90.1 - 2007 fan motor power limitations. If that code applies, alternate fan selections may be required.

The designer and installer must ensure compliance with applicable codes. A component supplier cannot determine the brake horsepower ("BHP") for other motors in the air handling system.

Before approving this unit, determine whether ASHRAE Standard 90.1 - 2007 has been adopted in the specific jurisdiction or contract specifications in which the unit will be installed.

VISION AIR HANDLING UNIT TECHNICAL DATA

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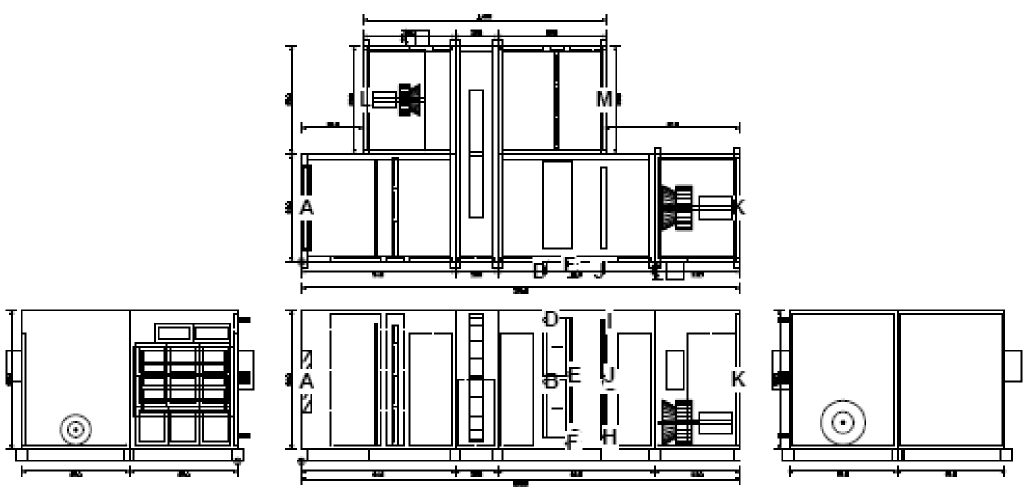
SHIPPING SECTION DETAILS			
	Length (inches)	Weight (lb)	
Section 1	56	1133	
Section 2	94	1178	
Section 3	26	2050	
Section 4	66	751	
Section 5	96	2899	
Section 6	52	1455	
TOTALS	**268.00 (Lower level total)**	**9466 (Entire unit weight)**	

UNIT SOUND	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Radiated	83	79	87	86	73	70	55	42
Unit discharge	91	89	98	94	94	94	92	79
Unit return	86	86	89	106	85	86	83	75

Appendix M – DOAS 1 Dimensions

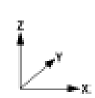
	Opening	X	Y	Z	W(Width)	H(Height)
A	Damper	0.00	2.00	28.00	62.00	42.00
B	Cold water outlet	148.90	-7.00	48.69	2.50ins. MPS	-
C	Cold water inlet	163.18	-7.00	15.31	2.50ins. MPS	-
D	Cold water outlet	148.90	-7.00	86.69	2.50ins. MPS	-
E	Cold water inlet	163.18	-7.00	53.31	2.50ins. MPS	-
F	Condensate drain conn.	162.00	-2.90	11.00	1.25ins. MPS	-
G	Hot water outlet	184.57	-7.00	48.55	1.50ins. MPS	-
H	Hot water inlet	184.57	-7.00	14.90	1.50ins. MPS	-
I	Hot water outlet	184.57	-7.00	85.95	1.50ins. MPS	-
J	Hot water inlet	184.57	-7.00	52.30	1.50ins. MPS	-
K	Supply outlet	268.00	2.00	10.00	62.00	80.00
L	Exhaust outlet	40.00	68.00	10.00	62.00	80.00
M	Exhaust inlet	186.00	68.00	10.00	62.00	80.00

Dimensions measured from ⊕



NOTE: Base 8.00ins deep, Cross members extend 4ins on each side of the unit.

VIEW: General Arrangement
DRAWN: February-29-2012 (15:21)
JOB NAME: TEST BUILDING
UNIT TAGGING: ERU-1
MODEL: CAH028GDGM



Appendix N – DOAS 2 Manufacturer's Specifications

VISION AIR HANDLING UNIT TECHNICAL DATA

Date Saved : February 29 2012

QUOTE ID	8IUVJ6(XX.001)	REP. OFFICE	Havtech (DC)
JOB NAME	TEST BUILDING	SALESPERSON	GG
MODEL NUMBER	CAH049GDGM	ENGINEER	
UNIT TAGGING	ERU-2	VERSION	9.53

Unit configuration	Side by side with opposed air flows		
Drive (handing) location	Right		
	SUPPLY	RETURN / EXHAUST	
Air volume	23635	16856	s cfm
Altitude	0	0	ft
Turning loss	0.00	0.00	in WC.
External static	2.00	1.20	in WC.
Total static	6.99	3.13	in WC.
External H x W	108 x 84	108 x 74 (Not including base rails)	ins

CASING DETAILS	
Outer panel	Standard G90 galv steel (unpainted)
Liner	Galvanized steel (Unless noted per section)
Insulation	R-13 Injected Foam (Unless noted per section)
Frame	2 ins
Base	8" formed channel
Sound baffles	None (Unless noted per section)
Tread Plate floor liner	None (unless noted per section)
Shrink wrapping	No

Exhaust Air Stream

1 PANEL FILTER(12 ins) — SECTION 4

Type	Pleated		Clean air press. drop	0.26	ins WC
Efficiency	MERV 8		Mean air press. drop	0.63	ins WC
Face velocity	355	fpm	**Dirty air press. drop**	**1.00**	**ins WC**
Face area	47.5	ft2	Access	Side	
Air volume	16856	cfm			

BANK ARRANGEMENT

No. of Filters	Size H x W x D	
15.0	20 x 24 x 2	Ins

DOOR DATA

Door location	Drive side		Window size	None
Door width	8	ins	Light	None
Door opening	Outward			

SPECIAL

Intersept Antimicrobial treatment

Tread Plate floor liner	None			
Liner	(As casing details)			
Insulation	(As casing details)			
Sound baffles	None			
Special static pressure	-	ins WC	Filter Gauge	None

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2 ACCESS SECTION(36 ins)					SECTION 4
Drip pan	None		Drip side	-	
			Air pressure drop	0.00	Ins WC
DOOR DATA					
Door location	Drive side		Window size	None	
Door width	28	ins	Light	None	
Door opening	Outward				

3 ENERGY RECOVERY SECTION (24 ins)					SECTION 3
Heat Wheel Model	ECW 966				
Media Type	Synthetic fiber - 4 angstrom		Electrical Supply Volt	115/60/1	Volt
Wheel Diameter	96.00	ins	Bypass Damp Opening	No Bypass	ins
Supply air CFM	23635	CFM	Supply air PD Sum/Win	1.29 / 1.18	ins WC
Supply air FV Sum/Win	1045 / 1042	ft/min	Exhaust air CFM	16856	CFM
Return air PD Sum/Win	0.91 / 0.83	ins WC	Motor HP	1.5	
Segmented Wheel	No				
Summer Conditions			**Winter Conditions**		
Outside air DB	89.7	F	Outside air DB	12.8	F
Outside air WB	76.8	F	Outside air WB	10.0	F
Return air DB	75.0	F	Return air DB	72.0	F
Return air WB	62.5	F	Return air WB	59.9	F
Supply air DB	82.2	F	Supply air DB	43.6	F
Supply air WB	70.8	F	Supply air WB	39.9	F
Exhaust air DB	85.7	F	Exhaust air DB	28.0	F
Exhaust air WB	73.0	F	Exhaust air WB	28.0	F
Latent effectiveness	68.67	%	Latent effectiveness	70.86	%
Sensible effectiveness	75.34	%	Sensible effectiveness	77.24	%
Total effectiveness	70.80	%	Total effectiveness	74.59	%
Total Energy Recovered	618195	Btu/hr	Total Energy Recovered	1207247	Btu/hr

4 ACCESS SECTION(16 ins)					SECTION 1
Drip pan	None		Drip side	-	
			Air pressure drop	0.02	Ins WC
DOOR DATA					
Door location	Drive side		Window size	None	
Door width	12	ins	Light	None	
Door opening	Outward				

VISION AIR HANDLING UNIT TECHNICAL DATA

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5 RETURN/EXHAUST FAN SECTION(54 ins)					SECTION 1
Air volume	16856	cfm	Motor power	20.0	HP
External static pressure	1.20	ins WC	Motor type	ODP	
Total static pressure	3.13	ins WC	Frame size	256 T frame	
Cabinet static pressure	0	ins WC	Electrical supply	460/60/3	
Type	Centrifugal - Plenum		Motor efficiency	Premium	
Blade type/Class	Airfoil / 2		Motor speed	1750	rpm
Quantity of Fans	1		Block-off Plate	No	
Fan wheel diameter	30.00	ins	Motor pole	4	
Brake horsepower	13.38	HP	Full load current	23.3	A
Operating/Max speed	1408 / 1783	rpm	Lock rotor current	145	A
Discharge	Axial		Motor supplier	Generic	
Air modulation	None		Actual drive service fac.	1.31	
Drip pan	None		Bearing type	N/A	
Drip pan side	-		Outlet velocity	-	ft/m
Wheel guard	None		Inlet screen	None	
Belt guard	None		Outlet screen	None	
Inspection port	None		Motor location	Behind Fan	
Material type	Aluminium		Number of blades	9	

DRIVES *			
Fan sheave	N/A	Motor sheave	N/A
Number of belts	0	Belt	N/A

* McQuay reserves the right to provide a different but equivalent drive package.

ANTI-VIBRATION MOUNTS / SPRINGS	
Type	Spring
Seismic restraint	None

DOOR DATA				
Door location	Drive side		Window size	None
Door width	30	ins	Light	None
Door opening	Outward			

VFD / STARTER / DISCONNECT DATA				
Selection type	VFD - NEMA 1	Vendor	ABB	
Auxiliary Control	None	Voltage	460	
-	None			
Mounting	Door Side	H x W x D	23.58 x 10.49 x 10.25	ins
Enclosure	NEMA 1	Coil Voltage	N/A	
Line Reactor	None	Hand Off Auto Switch	None	
24V Ctrl Transformer	None			
VFD Quantity	1			

Supply Air Stream

VISION AIR HANDLING UNIT TECHNICAL DATA

Date Saved : February 29 2012

1 MIXING BOX(68 ins)				SECTION 2
Drip pan	None	Drip side	-	
Floor grating	No			
	OUTSIDE AIR	RETURN AIR		
Length x Width	60.00 x 80.00	No opening		ins
Location	End	-		
Dampers	UltraSeal Low Leak	None		
Actuation	-	-		
Rated cfm	23635	23635		cfm
Air pressure drop	0.07			in WC
Quantity	1	1		

FILTER DATA					
Type	Pleated		**Clean air press. drop**	**0.35**	**ins WC**
Efficiency	MERV 8		Mean air press. drop	0.67	ins WC
Face velocity	448	fpm	Dirty air press. drop	1.00	ins WC
Face area	52.8	ft2	Access	Side	
Air volume	23635	cfm			

BANK ARRANGEMENT

No. of filters	Size H x W x D	
20.0	20 x 20 x 2	ins

DOOR DATA				
Door location	Drive side		Window size	None
Door width	30	ins	Light	None
Door opening	Outward			

SPECIAL

Intersept Antimicrobial treatment

Tread Plate floor liner	None			
Liner	(As casing details)			
Insulation	(As casing details)			
Sound baffles	None			
Special static pressure	-	ins WC	Filter Gauge	None

2 PANEL FILTER(14 ins)					SECTION 2
Type	Pleated		**Clean air press. drop**	**0.35**	**ins WC**
Efficiency	MERV 8		Mean air press. drop	0.68	ins WC
Face velocity	453	fpm	Dirty air press. drop	1.00	ins WC
Face area	52.1	ft2	Access	Side	
Air volume	23635	cfm			

BANK ARRANGEMENT

No. of Filters	Size H x W x D	
20.0	20 x 20 x 4	Ins

DOOR DATA				
Door location	Drive side		Window size	None
Door width	10	ins	Light	None
Door opening	Outward			

SPECIAL

Intersept Antimicrobial treatment
MERV 13 FINAL FILTER

Tread Plate floor liner	None			
Liner	(As casing details)			
Insulation	(As casing details)			
Sound baffles	None			
Special static pressure	1.00	ins WC	Filter Gauge	None

VISION AIR HANDLING UNIT TECHNICAL DATA

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3 ACCESS SECTION(36 ins)					SECTION 2
Drip pan	None		Drip side	-	
			Air pressure drop	0.00	Ins WC
DOOR DATA					
Door location	Drive side		Window size	None	
Door width	28	ins	Light	None	
Door opening	Outward				

4 ENERGY RECOVERY SECTION (24 ins)	SECTION 3

5 ACCESS SECTION(24 ins)					SECTION 5
Drip pan	None		Drip side	-	
			Air pressure drop	0.00	Ins WC
DOOR DATA					
Door location	Drive side		Window size	None	
Door width	20	ins	Light	None	
Door opening	Outward				

6 CHILLED WATER COIL(46 ins)					SECTION 5
Coil model	5WM1212B		Number of coils	2	
Total capacity	1737241	Btu/h	Number of rows	12	
Sensible capacity	921508	Btu/h	Fins per inch	12	
Air volume	23635	cfm			
Entering db/wb	82.2 / 70.8	F	Entering water	44.0	F
Leaving db/wb	46.5 / 46.3	F	Leaving water	51.6	F
Finned height x length	48 x 71	ins	Water flow rate	456.60	gpm
Face area	47.33	ft2	Water pressure drop	27.10	ftHD
Face velocity	499	ft/m	Water velocity	5.10	ft/s
Coil air pressure drop	1.67	ins WC			
			Fluid volume	75.0	gal
			Fluid weight	625.00	lb
Connection type	Threaded		Fin material	Aluminum (.0075)	
Connection Qty x size	2 x 3.00	ins	Tube material	Copper (.020)	
Connection location	Drive side		Header material	Copper	
Connection material	Carbon steel		Case material	Galv. steel	
Glycol type (%)	- (0 %)		Drain pan	Microbial resistant coated galvanized	
Fouling Factor	0		Drain pan side	Drive side	
			Turbospirals	No	
Coil code	5WM1212B		Electro-fin coat	None	

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7 HOT WATER COIL(12 ins)						SECTION 5
Coil model	5WB1401C		Number of coils	3		
Capacity	570741	Btu/h	Number of rows	1		
			Fins per inch	14		
Air volume	23635	cfm				
Entering db	43.6	F	Entering water	140.0	F	
Leaving db	65.7	F	Leaving water	119.4	F	
Finned height x length	30 x 68	ins	Water flow rate	55.30	gpm	
Face area	42.50	ft2	Water pressure drop	2.80	ftHD	
Face velocity	556	ft/m	Water velocity	3.90	ft/s	
Coil air pressure drop	0.25	ins WC				
			Fluid volume	7.0	gal	
			Fluid weight	63.00	lb	
Connection type	Threaded		Fin material	Aluminum (.0075)		
Connection Qty x size	2 x 1.50	ins	Tube material	Copper (.020)		
Connection location	Drive side		Header material	Copper		
Connection material	Carbon steel		Case material	Galvanized track		
Glycol type (%)	- (0 %)		Drip pan	None		
Fouling Factor	0		Drip pan side	-		
			Turbospirals	No		
Coil code	5WB1401C		Electro-fin coat	None		

8 ACCESS SECTION(24 ins)						SECTION 5
Drip pan	None		Drip side	-		
			Air pressure drop	0.00	Ins WC	

DOOR DATA				
Door location	Drive side		Window size	None
Door width	20	ins	Light	None
Door opening	Outward			

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9 SUPPLY FAN SECTION(68 ins)				SECTION	6
Air volume	23635	cfm	Motor power	50.0	HP
External static pressure	2.00	ins WC	Motor type	ODP	
Total static pressure	6.99	ins WC	Frame size	365 T frame	
Cabinet static pressure	0	ins WC	Electrical supply	460/60/3	
Type	Centrifugal - Plenum		Motor efficiency	Premium	
Blade type/Class	Airfoil / 2		Motor speed	1160	rpm
Quantity of Fans	1		Block-off Plate	No	
Fan wheel diameter	40.25	ins	Motor pole	4	
Brake horsepower	36.64	HP	Full load current	57.8	A
Operating/Max speed	1184 / 1329	rpm	Lock rotor current	362.5	A
Discharge	Axial		Motor supplier	Generic	
Air modulation	None		Actual drive service fac.	1.36	
Drip pan	None		Bearing type	N/A	
Drip pan side	-		Outlet velocity	-	ft/m
Wheel guard	None		Inlet screen	None	
Belt guard	None		Outlet screen	None	
Inspection port	None		Motor location	Behind Fan	
Material type	Aluminium		Number of blades	9	

DRIVES *			
Fan sheave	N/A	Motor sheave	N/A
Number of belts	0	Belt	N/A

* McQuay reserves the right to provide a different but equivalent drive package.

ANTI-VIBRATION MOUNTS / SPRINGS	
Type	Spring
Seismic restraint	None

DOOR DATA				
Door location	Drive side		Window size	None
Door width	30	ins	Light	None
Door opening	Outward			

VFD / STARTER / DISCONNECT DATA				
Selection type	VFD - NEMA 1	Vendor	ABB	
Auxiliary Control	None	Voltage	460	
-	None			
Mounting	Door Side	H x W x D	27.75 x 10.49 x 11.45	ins
Enclosure	NEMA 1	Coil Voltage	N/A	
Line Reactor	None	Hand Off Auto Switch	None	
24V Ctrl Transformer	None			
VFD Quantity	1			

NOTES

Supply fan performance is certified in accordance with the Central Station Air-Handling Unit Certification Program, which is based on ARI Standard 430.
Important Notice

This unit may not meet ASHRAE Standard 90.1 - 2007 fan motor power limitations. If that code applies, alternate fan selections may be required.

The designer and installer must ensure compliance with applicable codes. A component supplier cannot determine the brake horsepower ("BHP") for other motors in the air handling system.

Before approving this unit, determine whether ASHRAE Standard 90.1 - 2007 has been adopted in the specific jurisdiction or contract specifications in which the unit will be installed.

VISION AIR HANDLING UNIT TECHNICAL DATA

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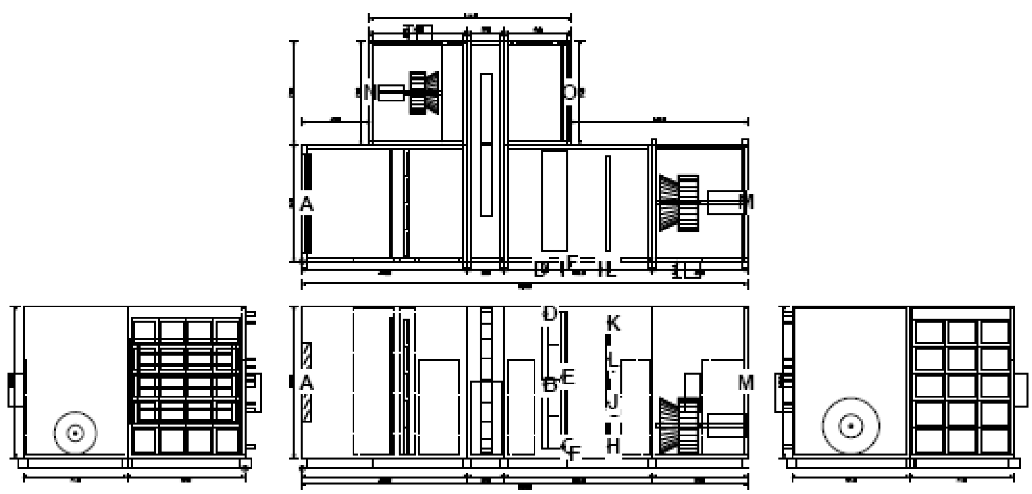
SHIPPING SECTION DETAILS			
	Length (inches)	Weight (lb)	
Section 1	70	1845	
Section 2	118	1873	
Section 3	26	3461	
Section 4	48	715	
Section 5	106	4492	
Section 6	68	2761	
TOTALS	**318.00 (Lower level total)**	**15147 (Entire unit weight)**	

UNIT SOUND	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Radiated	81	83	87	74	72	70	52	39
Unit discharge	92	92	97	93	93	95	86	77
Unit return	79	81	97	87	87	87	81	72

Appendix O – DOAS 2 Dimensions

	Opening	X	Y	Z	W(Width)	H(Height)
A	Damper	0.00	2.00	32.00	80.00	60.00
B	Cold water outlet	173.54	-7.00	60.44	3.00ins. MPS	-
C	Cold water inlet	186.54	-7.00	15.56	3.00ins. MPS	-
D	Cold water outlet	173.54	-7.00	110.44	3.00ins. MPS	-
E	Cold water inlet	186.54	-7.00	65.56	3.00ins. MPS	-
F	Condensate drain conn.	191.00	-2.90	11.00	1.25ins. MPS	-
G	Hot water outlet	218.57	-7.00	41.80	1.50ins. MPS	-
H	Hot water inlet	218.57	-7.00	15.65	1.50ins. MPS	-
I	Hot water outlet	218.57	-7.00	73.20	1.50ins. MPS	-
J	Hot water inlet	218.57	-7.00	47.05	1.50ins. MPS	-
K	Hot water outlet	218.57	-7.00	104.60	1.50ins. MPS	-
L	Hot water inlet	218.57	-7.00	78.45	1.50ins. MPS	-
M	Supply outlet	318.00	2.00	10.00	80.00	104.00
N	Exhaust outlet	50.00	86.00	10.00	70.00	104.00
O	Exhaust inlet	192.00	86.00	10.00	70.00	104.00

Dimensions measured from ⊕



NOTE: Base 8.00ins deep, Cross members extend 4ins on each side of the unit.

VIEW: General Arrangement
DRAWN: February-29-2012 (15:22)
JOB NAME: TEST BUILDING
UNIT TAGGING: ERU-2
MODEL: CAH049GDGM

Appendix P – Cooling Calculations FPIU

Room No.	Room Name	Primary CFM Suppy to Room	Max Sensible Cooling Load for each Room (Btu/h)	Cooling Done by Supply Air (Btu/h)	Further Cooling Needed (Btu/h)	FPIU Number	Unit Size:	Rows of Coils:	Head Loss (in wg)	Airside D PS	Cooling Coil Can Meet (from design sheet, Btu/hr)	CFM Recirculated For Cooling	GPM Through Cooling Coil	Total CFM For Box
141	Custodian Storage	80	2965	2464	501	FPIU-1-1	3	2	0.24	0.03	2200	300	1	380
205	Library	180	67769	5544	45593	FPIU-2-11	5	6	7.00	0.11	11400	850	4	1030
		180		5544		FPIU-2-12	5	6	7.00	0.11	11400	850	4	1030
		180		5544		FPIU-2-13	5	6	7.00	0.11	11400	850	4	1030
		180		5544		FPIU-2-14	5	6	7.00	0.11	11400	850	4	1030
206	Office	40	2015	1232	783	FPIU-2-5	3	2	0.24	0.03	2200	300	1	340
207	Staff Development/Literacy Coaches	470	22511	14476	-6441	FPIU-2-7	5	0	No further cooling needed					470
		470		14476		FPIU-2-30	5	0	No further cooling needed					470
209	Cw - Activities for Daily Living	235	9866	7238	2628	FPIU-2-6	3	2	0.24	0.08	2700	525	1	760
241	Custodian Shop	50	4561	1540	3021	FPIU-2-3	3	2	0.82	0.06	3400	450	2	500
242	Physical Therapy	145	3641	4466	-825	FPIU-2-4	3	0	No further cooling needed					145
245	Office	40	2012	1232	780	FPIU-2-1	3	2	0.24	0.03	2200	300	1	340
246	Medical Suite	245	5626	7546	-1920	FPIU-2-2	3	0	No further cooling needed					245
341	Is Staff Locker	140	4058	4312	-254	FPIU-3-10	3	0	No further cooling needed					140
347	Is Special Education	345	15743	10626	5117	FPIU-3-9	3	4	1.62	0.08	5400	525	2	870
349	Is Classroom	255	27172	7854	11464	FPIU-3-7	3	4	1.62	0.10	5800	600	2	855
		255		7854		FPIU-3-8	3	4	1.62	0.10	5800	600	2	855
351	Is Classroom	510	25024	15708	9316	FPIU-3-6	5	6	7.00	0.07	9500	650	4	1160
353	Is Classroom	630	18486	19404	-918	FPIU-3-5	5	0	No further cooling needed					630
355	Is Classroom	515	21185	15862	5323	FPIU-3-4	5	4	0.70	0.07	5500	850	1	1365
357	Is Classroom	515	21185	15862	5323	FPIU-3-3	5	4	0.70	0.07	5500	850	1	1365
359	Is Classroom	515	19984	15862	4122	FPIU-3-2	5	4	0.70	0.02	4500	450	1	965
361	Is Classroom	510	18562	15708	2854	FPIU-3-1	5	2	0.40	0.01	3300	450	1	960
441	Hs Staff Locker	140	4058	4312	-254	FPIU-4-10	3	0	No further cooling needed					140
447	Hs Special Education	220	13118	6776	6342	FPIU-4-9	3	4	5.52	0.08	6500	525	4	745
449	Hs Classroom	260	27193	8008	11177	FPIU-4-7	3	4	5.52	0.06	5800	450	4	710
		260		8008		FPIU-4-8	3	4	5.52	0.06	5800	450	4	710
451	Hs Classroom	520	25045	16016	9029	FPIU-4-6	5	6	2.10	0.11	9100	850	2	1370
453	Hs Classroom	630	18486	19404	-918	FPIU-4-5	5	0	No further cooling needed					630
455	Hs Classroom	505	20687	15554	5133	FPIU-4-4	5	4	0.70	0.06	5300	750	1	1255
457	Hs Classroom	505	19486	15554	3932	FPIU-4-3	3	2	0.47	0.08	4000	525	1	1030
459	Hs Classroom	505	19486	15554	3932	FPIU-4-2	3	2	0.47	0.08	4000	525	1	1030
461	Hs Classroom	500	19368	15400	3968	FPIU-4-1	3	2	0.47	0.08	4000	525	1	1025
539	Men's Kitchen Locker Rooms	55	1226	1694	-468	with Corridor 5th Floor South								
541	Women's Kitchen Locker Rooms	55	1226	1694	-468	with Corridor 5th Floor South								
545	Guidance Records	20	1590	616	974	FPIU-5-6	3	2	0.24	0.03	2200	300	1	320
547	Program Office	20	982	616	366	FPIU-5-7	3	2	0.24	0.03	2200	300	1	320
549	Hs Store	45	1725	1386	339	FPIU-5-8	3	2	0.24	0.03	2200	300	1	345
551	Government & Club House	120	3096	3696	-600	FPIU-5-4	3	0	No further cooling needed					120
552	Hs Art Room	472.5	20922	14553	-8184	FPIU-5-1	5	0	No further cooling needed					473
		472.5		14553		FPIU-5-27	5	0	No further cooling needed					473
205A	Office Work Room	60	3220	1848	1372	FPIU-2-10	3	2	0.24	0.03	2200	300	1	360
205B	A/V Storage	15	602	462	140	FPIU-2-29	3	2	0.24	0.03	2200	300	1	315

205C	Tech Center	200	8194	6160	2034	FPIU-2-9	3	2	0.82	0.10	3800	600	2	800
207A	Office	20	2605	616	1989	FPIU-2-8	3	2	0.24	0.03	2200	300	1	320
207B	Storage	20	367	616	-249	FPIU-2-28	3	0	No further cooling needed					20
547A	Program Office	20	5355	616	4739	FPIU-5-2	3	4	1.62	0.06	5000	450	2	470
549A	Hs Store	35	5028	1078	3950	FPIU-5-5	3	2	0.82	0.06	4000	675	2	710
551A	Government & Club Office	20	7616	616	7000	FPIU-5-3	5	6	14.40	0.15	14300	1050	6	1090
551B	Government & Club Office	20	7616	616	7000	with 551A								
	Corridor 3rd Floor South	315	8847	9702	-855	FPIU-3-11	5	0	No further cooling needed					630
	Corridor 4th Floor South	315	8878	9702	-824	FPIU-4-11	5	0	No further cooling needed					475
	Corridor 5th Floor South	160	3518	4928	-1410	FPIU-5-24	3	0	No further cooling needed					270
101	Is Project Room	580	19577	17864	1713	FPIU-1-2	5	2	0.40	0.03	3300	450	1	1030
103	Is Project Room	575	15236	17710	-2474	FPIU-1-3	5	0	No further cooling needed					575
105	Is Art	490	22908	15092	-7276	FPIU-1-4	3	0	No further cooling needed					490
		490		15092		FPIU-1-19	3	0	No further cooling needed					490
107	Is Art Storage	70	2342	2156	186	FPIU-1-5	3	2	0.24	0.03	2200	300	1	370
113	Hs Parents/Community Office	100	4896	3080	1816	FPIU-1-9	3	2	0.24	0.08	2700	525	1	625
115	Is Parents Coordinator Room	100	5257	3080	2177	FPIU-1-10	3	2	0.24	0.03	2200	300	1	400
116	School Safety Office/Locker Rooms	60	4616	1848	2768	FPIU-1-18	3	2	0.82	0.03	2800	300	2	360
118	Is Receiving Room	40	1646	1232	414	FPIU-1-17	3	2	0.24	0.01	2200	300	1	340
119	Custodial Office	60	3102	1848	1254	FPIU-1-11	3	2	0.24	0.03	2200	300	1	360
120	Is General Supply Room	55	1806	1694	112	FPIU-1-16	3	2	0.24	0.01	2200	300	1	355
213	Special Education Classroom	405	11969	12474	-505	FPIU-2-16	3	0	No further cooling needed					405
214	Is Audio/Video Security Storage Roo	60	1555	1848	-293	FPIU-2-26	3	0	No further cooling needed					60
215	Special Education Classroom	405	11969	12474	-505	FPIU-2-17	3	0	No further cooling needed					405
216	Is Book Store	130	2564	4004	-1440	FPIU-2-30	3	0	No further cooling needed					130
217	Special Education Clasroom	405	12480	12474	6	FPIU-2-18	3	0	No further cooling needed					405
218	Classroom Speech	150	3813	4620	-807	FPIU-2-25	3	0	No further cooling needed					150
219	Special Education Classroom	405	12447	12474	-27	FPIU-2-19	3	0	No further cooling needed					405
220	Classroom Speech	150	3813	4620	-807	with 218								150
221	Special Education Classroom	405	13072	12474	598	FPIU-2-20	3	2	0.24	0.03	2200	300	1	705
222	Hs Book Store	130	2564	4004	-1440	With 216 Is Book Store								
224	Special Education Clasroom	425	17327	13090	4237	FPIU-2-24	3	4	0.47	0.12	4300	675	1	1100
225	Special Education Clasroom	255	28559	7854	12851	FPIU-2-21	5	4	2.40	0.03	6500	550	2	805
		255		7854		FPIU-2-22	5	4	2.40	0.03	6500	550	2	805
226	Special Education Clasroom	405	21602	12474	9128	FPIU-2-23	5	4	4.00	0.06	9300	750	4	1155
301	Is Classroom	550	17017	16940	77	FPIU-3-12	5	2	0.40	0.03	3300	450	1	1000
303	Is Classroom	550	16804	16940	-136	FPIU-3-13	5	0	No further cooling needed					550
305	Is Classroom	550	16862	16940	-78	FPIU-3-14	5	0	No further cooling needed					550
307	Records	35	734	1078	-344	FPIU-3-32	3	0	No further cooling needed					35
308	Guidance Suite	15	545	462	83	FPIU-3-20	3	2	0.24	0.03	2200	300	1	355

309	Mail	40	2649	1232	1417	FPIU-3-17	3	4	5.52	0.06	5800	450	4	490
311	Gen Office	100	8213	3080	5133	FPIU-3-15	3	4	1.62	0.12	6100	675	2	775
315	Principal	60	5394	1848	3546	FPIU-3-18	3	2	0.82	0.07	3600	525	2	585
317	Is Classroom	585	17682	18018	-336	FPIU-3-22	3	0	No further cooling needed					585
318	Is Music	490	11007	15092	-4085	FPIU-3-30	3	0	No further cooling needed					490
319	Is Science Lab	605	21240	18634	2606	FPIU-3-23	5	2	0.40	0.03	3300	450	1	1055
320	Is Resource	260	6571	8008	-1437	with 322								
321	Is Science Prep	105	6254	3234	3020	FPIU-3-24	3	2	0.82	0.02	3100	375	2	480
322	Is Resource	245	6245	7546	-1301	FPIU-3-29	3	0	No further cooling needed					245
323	Is Science Lab	302.5	30001	9317	11367	FPIU-3-25	5	4	2.40	0.02	5800	450	2	753
		302.5		9317		FPIU-3-26	5	4	2.40	0.02	5800	450	2	753
324	Is Classroom	560	25121	17248	7873	FPIU-3-28	5	4	5.00	0.04	8000	650	3	1210
325	Is Special Education	375	23094	11550	11544	FPIU-3-27	5	6	14.40	0.18	12300	850	6	1225
401	Hs Classroom	550	17016	16940	76	FPIU-4-12	5	2	0.40	0.03	3300	450	1	1000
403	Hs Classroom	520	17024	16016	1008	FPIU-4-13	5	2	0.40	0.03	3300	450	1	970
405	Hs Classroom	525	16578	16170	408	FPIU-4-14	5	2	0.40	0.03	3300	450	1	975
407	Records	35	734	1078	-344	FPIU-4-32	3	0	No further cooling needed					35
409	Mail	40	2649	1232	1417	FPIU-4-17	3	2	0.24	0.03	2200	300	1	340
411	Gen Office	100	7322	3080	4242	FPIU-4-15	3	2	2.81	0.04	4400	525	4	625
415	Principal	45	5188	1386	3802	FPIU-4-18	3	4	1.62	0.03	3900	300	2	345
417	Hs Project Room	565	17515	17402	113	FPIU-4-21	5	2	0.40	0.03	3300	450	1	1015
418	Hs Music	450	14265	13860	405	FPIU-4-30	5	2	0.40	0.03	3300	450	1	900
419	Hs Project Room	565	17515	17402	113	FPIU-4-22	5	2	0.40	0.03	3300	450	1	1015
420	Hs Music Storage	60	1770	1848	-78	FPIU-4-29	3	0	No further cooling needed					60
421	Hs Classroom	520	16849	16016	833	FPIU-4-23	5	2	0.40	0.03	3300	450	1	970
422	Hs Resource	280	7080	8624	-1544	FPIU-4-28	3	0	No further cooling needed					280
423	Hs Classroom	570	25537	17556	7981	FPIU-4-24	5	4	5.00	0.04	8000	650	3	1220
424	Hs Classroom	550	22679	16940	5739	FPIU-4-27	5	2	2.70	0.03	6000	750	3	1300
425	Hs Classroom	285	30232	8778	12676	FPIU-4-25	5	4	2.40	0.03	6500	550	2	835
		285		8778		FPIU-4-26	5	4	2.40	0.03	6500	550	2	835
506	Mediation	80	1707	2464	-757	FPIU-5-23	3	0	No further cooling needed					80
508	Hs Supervisory	40	1993	1232	761	FPIU-5-9	3	2	0.24	0.03	2200	300	1	340
516	Hs Guidance Suite	45	2229	1386	843	FPIU-5-20	3	2	0.24	0.03	2200	300	1	345
517	Hs Special Education	375	11541	11550	-9	FPIU-5-10	3	0	No further cooling needed					375
518	Hs College Suite	40	1162	1232	-70	FPIU-5-22	3	0	No further cooling needed					40
519	Hs Science Lab	395	28339	12166	4007	FPIU-5-11	5	2	1.30	0.01	4200	450	2	845
		395		12166		FPIU-5-28	5	2	1.30	0.01	4200	450	2	845
521	Science Prep	185	8982	5698	3284	FPIU-5-12	3	2	0.82	0.03	3400	450	2	635
522	Hs Receiving Vestibule	45	2586	1386	1200	FPIU-5-18	3	2	0.24	0.03	2200	300	1	345
523	Science Lab Demo	312.5	37069	9625	17819	FPIU-5-13	5	6	2.10	0.11	9100	850	2	1163

		312.5		9625		FPIU-5-14	5	6	2.10	0.11	9100	850	2	1163
524	Hs Receiving	50	3427	1540	1887	FPIU-5-17	3	2	0.24	0.03	2200	300	1	350
525	Science Lab Demo	315	33602	9702	14198	FPIU-5-15	5	4	2.40	0.04	7100	650	2	965
		315		9702		FPIU-5-16	5	4	2.40	0.04	7100	650	2	965
109A	Supervisor	40	2833	1232	1601	FPIU-1-6	3	2	0.24	0.03	2200	300	1	340
126A	Furniture Storage	85	2166	2618	-452	FPIU-1-13	3	0	No further cooling needed					85
126B	Storage	50	1255	1540	-285	FPIU-1-14	3	0	No further cooling needed					50
126C	Vault W. Anteroom	50	1875	1540	335	FPIU-1-15	3	2	0.24	0.03	2200	300	1	350
308A	Office	20	1369	616	753	with 308								
308B	Office	20	1205	616	589	with 308								
308B	Guidance Room	40	2366	1232	1134	FPIU-3-21	3	2	0.24	0.03	2200	300	1	340
308D	Meeting	120	2693	3696	-1003	FPIU-3-32	3	0	No further cooling needed					120
309A	Waiting	90	2124	2772	-648	with 307 Records								
311A	Copy	20	2812	616	2196	FPIU-3-16	3	2	0.24	0.03	2200	300	1	320
318A	Is Music Storage	20	369	616	-247	FPIU-3-33	3	0	No further cooling needed					20
318B	Is Music Storage	25	452	770	-318	with 318A								
318C	Is Music Storage	15	573	462	111	with 318A								
409A	Waiting	90	2124	2772	-648	with 407								
411A	Copy	20	2812	616	2196	FPIU-4-16	3	2	0.24	0.03	2200	300	1	320
418A	Hs Music Storage	15	251	462	-211	FPIU-4-33	3	0	No further cooling needed					15
418B	Hs Music Storage	20	430	616	-186	with 418A								
418C	Hs Music Storage	10	378	308	70	with 418A								
516A	Hs Guidance Conf	120	2286	3696	-1410	FPIU-5-26	3	0	No further cooling needed					
516B	Hs Guidance Office	40	1339	1232	107	FPIU-5-19	3	2	0.24	0.03	2200	300	1	420
516C	Hs Guidance Office	40	1339	1232	107	with 516B								
518A	Hs College Office	40	1299	1232	67	with 516B								
518B	Hs College Conference	100	2105	3080	-975	FPIU-5-25	3	0	No further cooling needed					100
L1C	Vestibule	50	1364	1540	-176	FPIU-1-12	3	0	No further cooling needed					50
	Corridor 1st Floor West	280	7813	8624	-811	FPIU-1-7	5	0	No further cooling needed					280
	Corridor 2nd Floor South	125	9566	3850	5716	FPIU-2-15	3	4	5.52	0.06	5800	450	4	575
	Corridor 3rd Floor West	135	15495	4158	11337	FPIU-3-19	5	6	7.00	0.11	11400	850	4	985
	Corridor 4th Floor West	67.5	21993	2079	17835	FPIU-4-19	5	6	2.10	0.07	9100	850	2	918
		67.5		2079		FPIU-4-20	5	6	2.10	0.07	9100	850	2	918
	Corridor 5th Floor East	210	7421	6468	953	FPIU-5-21	3	2	0.24	0.03	2200	300	1	510
	Corridor 1st Floor East	110	2931	3388	-457	FPIU-1-8	3	0	No further cooling needed					110
	Corridor 2nd Floor East	145	4009	4466	-457	FPIU-2-27	3	0	No further cooling needed					145
	Corridor 3rd Floor East	85	2295	2618	-323	FPIU-3-31	3	0	No further cooling needed					85
	Corridor 4th Floor East	85	2295	2618	-323	FPIU-4-31	3	0	No further cooling needed					85

*Note: Negative means that the space needs heating. The heating coil in each FPIU is well oversized to meet this need because it is sized based on heating needed in winter.

Appendix Q – Cooling Coil FPIU Sizing

Model: KLPS-D

Sensible Water Coil Data

Unit Size	Rows	G.P.M.	Head Loss	Sensible Cooling Coil Air Flow, CFM & Resulting Sensible MBH								
				200	250	300	350	400	450	500	550	600
1	2	1.0	0.20	-1.7	-1.9	-2.1	-2.2	-2.3	-2.4	-2.4	-2.5	-2.6
		2.0	0.68	-2.1	-2.4	-2.6	-2.8	-3.0	-3.1	-3.3	-3.4	-3.5
		3.0	1.40	-2.3	-2.6	-2.9	-3.1	-3.4	-3.6	-3.7	-3.9	-4.0
		4.0	2.33	-2.3	-2.7	-3.0	-3.3	-3.6	-3.8	-4.0	-4.2	-4.4
		Airside D PS		0.01	0.01	0.02	0.02	0.03	0.04	0.05	0.06	0.06
	4	1.0	0.40	-2.5	-2.8	-3.1	-3.3	-3.5	-3.6	-3.7	-3.8	-3.9
		2.0	1.36	-2.9	-3.3	-3.8	-4.1	-4.5	-4.7	-5.0	-5.2	-5.4
		4.0	4.65	-3.1	-3.7	-4.2	-4.7	-5.2	-5.6	-6.0	-6.3	-6.7
		6.0	9.54	-3.1	-3.8	-4.4	-4.9	-5.4	-5.9	-6.4	-6.8	-7.2
		Airside D PS		0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.11	0.13

Unit Size	Rows	G.P.M.	Head Loss	Sensible Cooling Coil Air Flow, CFM & Resulting Sensible MBH								
				300	375	450	525	600	675	750	825	900
3	2	1.0	0.24	-2.2	-2.4	-2.6	-2.7	-2.8	-2.9	-3.0	-3.0	-3.1
		2.0	0.82	-2.8	-3.1	-3.4	-3.6	-3.8	-4.0	-4.1	-4.3	-4.4
		3.0	1.69	-3.1	-3.5	-3.8	-4.1	-4.4	-4.6	-4.8	-5.0	-5.1
		4.0	2.81	-3.2	-3.7	-4.1	-4.4	-4.7	-5.0	-5.2	-5.5	-5.7
		Airside D PS		0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.10
	4	1.0	0.47	-3.2	-3.6	-3.8	-4.0	-4.2	-4.3	-4.5	-4.6	-4.6
		2.0	1.62	-3.9	-4.5	-5.0	-5.4	-5.8	-6.1	-6.3	-6.6	-6.8
		4.0	5.52	-4.3	-5.1	-5.8	-6.5	-7.0	-7.5	-8.0	-8.4	-8.8
		6.0	11.33	-4.5	-5.4	-6.2	-6.9	-7.5	-8.1	-8.7	-9.2	-9.7
		Airside D PS		0.03	0.04	0.06	0.08	0.10	0.12	0.14	0.17	0.20

Unit Size	Rows	G.P.M.	Head Loss	Sensible Cooling Coil Air Flow, CFM & Resulting Sensible MBH								
				450	550	650	750	850	950	1050	1150	1250
5	2	1.0	0.4	-3.3	-3.5	-3.7	-3.8	-3.9	-4.0	-4.1	-4.2	-4.3
		2.0	1.3	-4.2	-4.6	-5.0	-5.3	-5.5	-5.8	-6.0	-6.1	-6.3
		3.0	2.7	-4.6	-5.2	-5.6	-6.0	-6.4	-6.7	-7.0	-7.2	-7.5
		4.0	4.4	-4.9	-5.5	-6.0	-6.5	-6.9	-7.3	-7.7	-8.0	-8.3
		Airside D PS		0.01	0.02	0.02	0.03	0.04	0.04	0.05	0.06	0.07
	4	1.0	0.7	-4.5	-4.9	-5.1	-5.3	-5.5	-5.6	-5.7	-5.8	-5.9
		2.0	2.4	-5.8	-6.5	-7.1	-7.6	-8.0	-8.4	-8.7	-9.0	-9.2
		3.0	5.0	-6.3	-7.2	-8.0	-8.7	-9.3	-9.8	-10.3	-10.7	-11.1
		4.0	8.3	-6.5	-7.6	-8.5	-9.3	-10.1	-10.7	-11.3	-11.9	-12.3
		Airside D PS		0.02	0.03	0.04	0.06	0.07	0.09	0.10	0.12	0.14
	6	1.0	0.6	-5.0	-5.4	-5.7	-5.9	-6.0	-6.2	-6.3	-6.3	-6.4
		2.0	2.1	-6.4	-7.3	-8.0	-8.6	-9.1	-9.5	-9.8	-10.1	-10.4
		4.0	7.0	-7.1	-8.4	-9.5	-10.5	-11.4	-12.2	-13.0	-13.6	-14.2
		6.0	14.4	-7.3	-8.7	-10.0	-11.2	-12.3	-13.3	-14.3	-15.1	-16.0
		Airside D PS		0.03	0.05	0.07	0.09	0.11	0.13	0.15	0.18	0.21

NOTE: All data is based on 75.0°F entering air, 58.0°F entering water, at an altitude of 0 ft. Program calculations assume 30% propylene glycol. Water temperature of must be above dew point throughout the building to prevent condensation on coil. Typical entering water temperature for cooling coil ranges from 55°F to 62°F.

The MBH values listed above is the sensible MBH for the CFM that is induced throught the cooling coil. Total Cooling MBH will include the latent MBH that is provided and by the primary air. The latent MBH is addeed to the sensible MBH to create the Total Coolig MBH.

Appendix R – FPIU Specifications

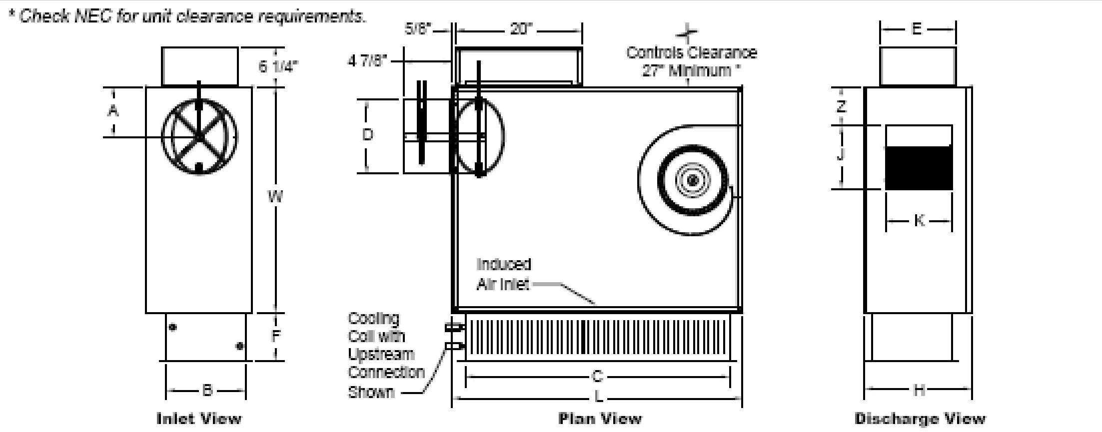
KRUEGER
Excellence in Air Distribution

FAN POWERED TERMINAL UNITS C

KLPS | Low Profile, Series Flow

KLPS-D Base Unit Dimensional Information

KLPS-D BASE UNIT, INLET, PLAN, AND DISCHARGE VIEWS



KLPS-D BASE UNIT, DIMENSIONAL DETAILS

Unit Size	Max Primary CFM	Max Fan CFM	HP	Inlet Size	L	W	H	A	Cooling Coil		D	E	Discharge		Z	F	
									B	C			J	K		1 Row	2 Row
3	230	1100	1/3	06	40"	26"	11"	5"	8 3/4"	36"	5 7/8"	9 5/8"	9"	6 7/8"	2 1/4"	5 3/4"	7 7/8"
3	920	1100	1/3	08	40"	26"	11"	6"	8 3/4"	36"	7 7/8"	9 5/8"	9"	6 7/8"	2 1/4"	5 3/4"	7 7/8"
5	515	1660	1/2	06	46"	36"	17"	5"	12 1/2"	42 1/8"	5 7/8"	12"	10"	10 5/8"	6 1/4"	5"	8"
5	920	1660	1/2	08	46"	36"	17"	6"	12 1/2"	42 1/8"	7 7/8"	12"	10"	10 5/8"	6 1/4"	5"	8"
5	1430	1660	1/2	10	46"	36"	17"	7"	12 1/2"	42 1/8"	9 7/8"	12"	10"	10 5/8"	6 1/4"	5"	8"

NOTE: Left-hand base unit with electronic control enclosure shown; right-hand is available.

KLPS-D Base Unit Features & Options

STANDARD FEATURES

- 20 gage galvanized steel casing construction.
- Available in unit sizes 3 and 5.
- Control enclosure for electronic components.
- 1/2" thick, dual density fiberglass insulation meeting NFPA 90A and UL 181 safety requirements.
- [120, 208/240, or 277 volt, single-voltage] ECM motor.
- Field adjustable VCU or remote adjustable ACU controller.
- Removable bottom panel allows easy access to all internal components for maintenance.
- Linear averaging airflow sensor.
- Electronic controls include 24 volt control transformer.
- Sensible Cooling Coil factory installed on induced air inlet with drip tray.
- Construction type air fliter, two per unit, size 3: 18 1/2"x10"x1"; size 5: 22" x 14 1/2" x 1".
- ETL listed; adherence to UL 1995 and CSA C22.2 No. 236.95
- AHRI certified sound ratings.

OPTIONAL FEATURES

- Liners: 3/8" Cellular insulation, 1/2" or 1" (size 5 only), Foil encapsulated fiberglass insulation, Sterilwall, Perforated doublewall, 1" Dual density fiberglass (size 5 only).
- Four quadrant, center averaging airflow sensor.
- Left or right-hand control enclosure.
- Upstream or downstream cooling coil connection.
- Motor toggle disconnect switch.
- Motor fusing.
- MERV 8 air filter, two per unit, size 3: 18 1/2" x 10" x 1"; size 5: 22" x 14 1/2" x 1".
- Dust tight control enclosure.
- Hanger brackets.
- Dual access panels with optional Cam locks.

Appendix S – Heating Calculations FPIU

Room No.	Room Name	Primary CFM Suppy to Room	Sensible Space Heating Max Load (Btu/hr)	Primary Air Cooling in Winter, Since Supplying 47 deg Air (Btu/hr)	Total Heating Needed (Btu/hr)	FPIU Number	Unit Size:	Rows of Coils:	Head Loss (in wg)	Airside D PS	Heating Can Meet (from design sheet, Btu/hr)	CFM Recirculated For Heating	GPM Through Coil	Total CFM For Box
141	Custodian Storage	80	-2642	-2200	-4842	FPIU-1-1	3	1	0.20	0.07	5800	440	1	520
205	Library	180	-31443	-4950	-51243	FPIU-2-11	5	2	6.10	0.01	12900	275	3	455
		180		-4950		FPIU-2-12	5	2	6.10	0.01	12900	275	3	455
		180		-4950		FPIU-2-13	5	2	6.10	0.01	12900	275	3	455
		180		-4950		FPIU-2-14	5	2	6.10	0.01	12900	275	3	455
206	Office	40	-991	-1100	-2091	FPIU-2-5	3	1	0.20	0.07	5800	440	1	480
207	Staff Development/Literacy Coaches	470	-7706	-12925	-33556	FPIU-2-7	5	2	6.10	0.03	17700	450	3	1390
		470		-12925		FPIU-2-30	5	2	6.10	0.03	17700	450	3	
209	Cw - Activities for Daily Living	235	-4864	-6463	-11327	FPIU-2-6	3	2	0.15	0.12	11700	650	1	885
241	Custodian Shop	50	-2330	-1375	-3705	FPIU-2-3	3	1	0.20	0.07	5800	440	1	490
242	Physical Therapy	145	-2328	-3988	-6316	FPIU-2-4	3	1	0.20	0.06	6400	580	1	725
245	Office	40	-1158	-1100	-2258	FPIU-2-1	3	1	0.20	0.07	5800	440	1	480
246	Medical Suite	245	-4283	-6738	-11021	FPIU-2-2	3	2	0.40	0.12	11300	580	1	825
341	Is Staff Locker	140	-2091	-3850	-5941	FPIU-3-10	3	1	0.20	0.05	6100	510	1	650
347	Is Special Education	345	-3857	-9488	-13345	FPIU-3-9	3	2	2.70	0.07	14000	440	3	785
349	Is Classroom	255	-6738	-7013	-20763	FPIU-3-7	3	2	0.40	0.10	10800	510	1	765
		255		-7013		FPIU-3-8	3	2	0.40	0.10	10800	510	1	765
351	Is Classroom	510	-6408	-14025	-20433	FPIU-3-6	5	2	6.10	0.05	21200	625	3	1135
353	Is Classroom	630	-6941	-17325	-24266	FPIU-3-5	5	2	6.10	0.11	26400	975	3	1605
355	Is Classroom	515	-6827	-14163	-20990	FPIU-3-4	5	2	6.10	0.05	21200	625	3	1140
357	Is Classroom	515	-6827	-14163	-20990	FPIU-3-3	5	2	6.10	0.05	21200	625	3	1140
359	Is Classroom	515	-6437	-14163	-20600	FPIU-3-2	5	2	6.10	0.05	21200	625	3	1140
361	Is Classroom	510	-5910	-14025	-19935	FPIU-3-1	5	2	6.10	0.05	21200	625	3	1135
441	Hs Staff Locker	140	-2061	-3850	-5911	FPIU-4-10	3	1	0.20	0.10	6100	510	1	650
447	Hs Special Education	220	-3617	-6050	-9667	FPIU-4-9	3	1	2.40	0.08	9700	650	4	870
449	Hs Classroom	260	-6591	-7150	-20891	FPIU-4-7	3	1	2.40	0.11	10500	790	4	1050
		260		-7150		FPIU-4-8	3	1	2.40	0.11	10500	790	4	1050
451	Hs Classroom	520	-6261	-14300	-20561	FPIU-4-6	5	2	6.10	0.05	21200	625	3	1145
453	Hs Classroom	630	-6941	-17325	-24266	FPIU-4-5	5	2	15.00	0.08	26600	800	5	1430
455	Hs Classroom	505	-6517	-13888	-20405	FPIU-4-4	5	2	6.10	0.05	21200	625	3	1130
457	Hs Classroom	505	-6128	-13888	-20016	FPIU-4-3	3	2	6.60	0.21	20600	790	5	1295
459	Hs Classroom	505	-6128	-13888	-20016	FPIU-4-2	3	2	6.60	0.21	20600	790	5	1295
461	Hs Classroom	500	-6054	-13750	-19804	FPIU-4-1	3	2	6.60	0.21	20600	790	5	1290
539	Men's Kitchen Locker Rooms	55	-634	-1513		with Corridor 5th Floor South								
541	Women's Kitchen Locker Rooms	55	-634	-1513		with Corridor 5th Floor South								
545	Guidance Records	20	-691	-550	-1241	FPIU-5-6	3	1	0.20	0.07	5800	440	1	460
547	Program Office	20	-308	-550	-858	FPIU-5-7	3	1	0.20	0.07	5800	440	1	460
549	Hs Store	45	-560	-1238	-1798	FPIU-5-8	3	1	0.20	0.07	5800	440	1	485
551	Government & Club House	120	-672	-3300	-3972	FPIU-5-4	3	1	0.20	0.07	5800	440	1	560

552	Hs Art Room	472.5	-3548	-12994	-29536	FPIU-5-1	5	2	0.90	0.05	15100	625	1	1570
		472.5		-12994		FPIU-5-27	5	2	0.90	0.05	15100	625	1	
205A	Office Work Room	60	-1615	-1650	-3265	FPIU-2-10	3	1	0.20	0.07	5800	440	1	500
205B	A/V Storage	15	-434	-413	-847	FPIU-2-29	3	1	0.20	0.07	5800	440	1	455
205C	Tech Center	200	-4479	-5500	-9979	FPIU-2-9	3	2	0.40	0.07	10300	440	1	640
207A	Office	20	-1393	-550	-1943	FPIU-2-8	3	1	0.20	0.07	5800	440	1	460
207B	Storage	20	-507	-550	-1057	FPIU-2-28	3	1	0.20	0.07	5800	440	1	460
547A	Program Office	20	-1278	-550	-1828	FPIU-5-2	3	1	0.20	0.07	5800	440	1	460
549A	Hs Store	35	-1316	-963	-2279	FPIU-5-5	3	1	0.20	0.07	5800	440	1	475
551A	Government & Club Office	20	-1704	-550	-2254	FPIU-5-3	5	1	0.20	0.07	5800	440	1	480
551B	Government & Club Office	20	-1704	-550	-2254	with 551A								
	Corridor 3rd Floor South	315	-15669	-8663	-24332	FPIU-3-11	5	2	6.10	0.11	26400	975	3	1290
	Corridor 4th Floor South	315	-15675	-8663	-24338	FPIU-4-11	5	2	6.10	0.11	26400	975	3	1290
	Corridor 5th Floor South	160	-4311	-4400	-13004	FPIU-5-24	3	2	2.70	0.07	14000	440	3	710

101	Is Project Room	580	-9064	-15950	-25014	FPIU-1-2	5	2	15.00	0.08	26600	800	5	1380
103	Is Project Room	575	-4413	-15813	-20226	FPIU-1-3	5	2	6.10	0.05	21200	625	3	1200
105	Is Art	490	-6418	-13475	-33368	FPIU-1-4	3	2	6.60	0.12	17700	580	5	1560
		490		-13475		FPIU-1-19	3	2	6.60	0.12	17700	580	5	
107	Is Art Storage	70	-2416	-1925	-4341	FPIU-1-5	3	1	0.20	0.07	5800	440	1	510
113	Hs Parents/Community Office	100	-3125	-2750	-5875	FPIU-1-9	3	1	0.20	0.10	6100	510	1	610
115	Is Parents Coordinator Room	100	-3514	-2750	-6264	FPIU-1-10	3	1	0.20	0.12	6400	580	1	680
116	School Safety Office/Locker Rooms	60	-2679	-1650	-4329	FPIU-1-18	3	1	0.20	0.07	5800	440	1	500
118	Is Receiving Room	40	-761	-1100	-1861	FPIU-1-17	3	1	0.20	0.07	5800	440	1	480
119	Custodial Office	60	-1561	-1650	-3211	FPIU-1-11	3	1	0.20	0.07	5800	440	1	500
120	Is General Supply Room	55	-2191	-1513	-3704	FPIU-1-16	3	1	0.20	0.07	5800	440	1	495
213	Special Education Classroom	405	-4111	-11138	-15249	FPIU-2-16	3	2	2.70	0.12	16100	580	3	985
214	Is Audio/Video Security Storage Roo	60	-2063	-1650	-3713	FPIU-2-26	3	1	0.20	0.07	5800	440	1	500
215	Special Education Classroom	405	-4111	-11138	-15249	FPIU-2-17	3	2	2.70	0.12	16100	580	3	985
216	Is Book Store	130	-3205	-3575	-13545	FPIU-2-30	3	2	2.70	0.07	14000	440	3	700
217	Special Education Clasroom	405	-4520	-11138	-15658	FPIU-2-18	3	2	2.70	0.12	16100	580	3	985
218	Classroom Speech	150	-944	-4125	-10138	FPIU-2-25	3	2	0.40	0.07	10300	440	1	740
219	Special Education Classroom	405	-4500	-11138	-15638	FPIU-2-19	3	2	2.70	0.12	16100	580	3	985
220	Classroom Speech	150	-944	-4125		with Room 218								
221	Special Education Classroom	405	-5068	-11138	-16206	FPIU-2-20	3	2	6.60	0.10	16500	510	5	915
222	Hs Book Store	130	-3190	-3575		With 216 Is Book Store								
224	Special Education Clasroom	425	-5322	-11688	-17010	FPIU-2-24	3	2	12.00	0.10	17200	510	5	935
225	Special Education Clasroom	255	-8211	-7013	-22236	FPIU-2-21	5	1	1.40	0.03	11200	625	2	880
		255		-7013		FPIU-2-22	5	1	1.40	0.03	11200	625	2	880
226	Special Education Clasroom	405	-5173	-11138	-16311	FPIU-2-23	5	2	6.10	0.03	17700	450	3	855
301	Is Classroom	550	-6998	-15125	-22123	FPIU-3-12	5	2	15.00	0.05	23100	625	5	1175

303	Is Classroom	550	-6000	-15125	-21125	FPIU-3-13	5	2	6.10	0.05	21200	650	3	1200
305	Is Classroom	550	-6079	-15125	-21204	FPIU-3-14	5	2	6.10	0.05	21200	650	3	1200
307	Records	35	-1015	-963	-5156	FPIU-3-32	3	1	0.20	0.07	5800	440	1	565
308	Guidance Suite	15	-586	-413	-3456	FPIU-3-20	3	1	0.20	0.07	5800	440	1	495
309	Mail	40	-1405	-1100	-2505	FPIU-3-17	3	1	0.20	0.07	5800	440	1	480
311	Gen Office	100	-4984	-2750	-7734	FPIU-3-15	3	1	0.70	0.06	8000	580	2	680
315	Principal	60	-3448	-1650	-5098	FPIU-3-18	3	1	0.20	0.07	5800	440	1	500
317	Is Classroom	585	-6301	-16088	-22389	FPIU-3-22	5	2	15.00	0.05	23100	625	5	1210
318	Is Music	490	-3320	-13475	-16795	FPIU-3-30	3	2	6.60	0.12	17700	580	5	1070
319	Is Science Lab	605	-7734	-16638	-24372	FPIU-3-23	5	2	15.00	0.08	26600	800	5	1405
320	Is Resource	260	-2023	-7150		with 322								
321	Is Science Prep	105	-3534	-2888	-6422	FPIU-3-24	3	1	0.20	0.15	6600	650	1	755
322	Is Resource	245	-2023	-6738	-17934	FPIU-3-29	3	2	12.00	0.15	18500	580	7	1085
323	Is Science Lab	302.5	-10560	-8319	-27198	FPIU-3-25	5	2	0.90	0.05	15100	625	1	928
		302.5		-8319		FPIU-3-26	5	2	0.90	0.05	15100	625	1	928
324	Is Classroom	560	-7284	-15400	-22684	FPIU-3-28	5	2	15.00	0.05	23100	625	5	1185
325	Is Special Education	375	-5373	-10313	-15686	FPIU-3-27	5	2	0.90	0.08	16300	800	1	1175
401	Hs Classroom	550	-7046	-15125	-22171	FPIU-4-12	5	2	15.00	0.05	23100	625	5	1175
403	Hs Classroom	520	-6682	-14300	-20982	FPIU-4-13	5	2	15.00	0.05	23100	625	5	1145
405	Hs Classroom	525	-6252	-14438	-20690	FPIU-4-14	5	2	15.00	0.05	23100	625	5	1150
407	Records	35	-1015	-963	-5156	FPIU-4-32	3	1	0.20	0.07	5800	440	1	565
409	Mail	40	-1405	-1100	-2505	FPIU-4-17	3	1	0.20	0.07	5800	440	1	480
411	Gen Office	100	-4594	-2750	-7344	FPIU-4-15	3	1	0.70	0.10	7600	510	2	610
415	Principal	45	-3448	-1238	-4686	FPIU-4-18	3	1	0.20	0.07	5800	440	1	485
417	Hs Project Room	565	-6480	-15538	-22018	FPIU-4-21	5	2	15.00	0.05	23100	625	5	1190
418	Hs Music	450	-5482	-12375	-17857	FPIU-4-30	5	2	15.00	0.03	18900	450	5	900
419	Hs Project Room	565	-6480	-15538	-22018	FPIU-4-22	5	2	15.00	0.05	23100	625	5	1190
420	Hs Music Storage	60	-2321	-1650	-3971	FPIU-4-29	3	1	0.20	0.07	5800	440	1	500
421	Hs Classroom	520	-6631	-14300	-20931	FPIU-4-23	5	2	15.00	0.05	23100	625	5	1145
422	Hs Resource	280	-2216	-7700	-9916	FPIU-4-28	3	2	0.40	0.07	10300	440	1	720
423	Hs Classroom	570	-8633	-15675	-24308	FPIU-4-24	5	2	15.00	0.08	26600	800	5	1370
424	Hs Classroom	550	-6631	-15125	-21756	FPIU-4-27	5	2	15.00	0.05	23100	625	5	1175
425	Hs Classroom	285	-7199	-7838	-22874	FPIU-4-25	5	2	6.10	0.01	12900	275	3	560
		285		-7838		FPIU-4-26	5	2	6.10	0.01	12900	275	3	560
506	Mediation	80	-274	-2200	-2474	FPIU-5-23	3	1	0.20	0.07	5800	440	1	520
508	Hs Supervisory	40	-619	-1100	-1719	FPIU-5-9	3	1	0.20	0.07	5800	440	1	480
516	Hs Guidance Suite	45	-900	-1238	-2138	FPIU-5-20	3	1	0.20	0.07	5800	440	1	485
517	Hs Special Education	375	-3277	-10313	-13590	FPIU-5-10	3	2	2.70	0.07	14000	440	3	815
518	Hs College Suite	40	-497	-1100	-1597	FPIU-5-22	3	1	0.20	0.07	5800	440	1	480
519	Hs Science Lab	395	-7905	-10863	-29630	FPIU-5-11	3	2	2.70	0.10	15100	510	3	1300
		395		-10863		FPIU-5-28	3	2	2.70	0.10	15100	510	3	
521	Science Prep	185	-3344	-5088	-8432	FPIU-5-12	3	1	2.40	0.05	8700	510	4	695
522	Hs Receiving Vestibule	45	-1201	-1238	-2439	FPIU-5-18	3	1	0.20	0.07	5800	440	1	485
523	Science Lab Demo	312.5	-9246	-8594	-26434	FPIU-5-13	5	2	0.90	0.03	13300	450	1	763
		312.5		-8594		FPIU-5-14	5	2	0.90	0.03	13300	450	1	763

		312.5		-8594		FPIU-5-14	5	2	0.90	0.03	13300	450	1	763
524	Hs Receiving	50	-1470	-1375	-2845	FPIU-5-17	3	1	0.20	0.07	5800	440	1	490
525	Science Lab Demo	315	-6872	-8663	-24197	FPIU-5-15	5	2	6.10	0.01	12900	275	3	590
		315		-8663		FPIU-5-16	5	2	6.10	0.01	12900	275	3	590
109A	Supervisor	40	-2060	-1100	-3160	FPIU-1-6	3	1	0.20	0.07	5800	440	1	480
126A	Furniture Storage	85	-3022	-2338	-5360	FPIU-1-13	3	1	0.20	0.07	5800	440	1	525
126B	Storage	50	-1729	-1375	-3104	FPIU-1-14	3	1	0.20	0.07	5800	440	1	490
126C	Vault W. Anteroom	50	-2534	-1375	-3909	FPIU-1-15	3	1	0.20	0.07	5800	440	1	490
308A	Office	20	-732	-550		with 308								
308B	Office	20	-625	-550		with 308								
308B	Guidance Room	40	-1220	-1100	-2320	FPIU-3-21	3	1	0.20	0.07	5800	440	1	480
308D	Meeting	120	-732	-3300	-4032	FPIU-3-32	3	1	0.20	0.07	5800	440	1	
309A	Waiting	90	-703	-2475		with 307 Records								
311A	Copy	20	-1720	-550	-2270	FPIU-3-16	3	1	0.20	0.07	5800	440	1	460
318A	Is Music Storage	20	-512	-550	-3484	FPIU-3-33	3	1	0.20	0.07	5800	440	1	500
318B	Is Music Storage	25	-626	-688		with 318A								
318C	Is Music Storage	15	-696	-413		with 318A								
409A	Waiting	90	-703	-2475		with 407								
411A	Copy	20	-1720	-550	-2270	FPIU-4-16	3	1	0.20	0.07	5800	440	1	460
418A	Hs Music Storage	15	-348	-413	-2639	FPIU-4-33	3	1	0.20	0.07	5800	440	1	485
418B	Hs Music Storage	20	-596	-550		with 418A								
418C	Hs Music Storage	10	-457	-275		with 418A								
516A	Hs Guidance Conf	120	-304	-3300	-3604	FPIU-5-26	3	1	0.20	0.07	5800	440	1	
516B	Hs Guidance Office	40	-523	-1100	-4860	FPIU-5-19	3	1	0.20	0.07	5800	440	1	560
516C	Hs Guidance Office	40	-523	-1100		with 516B								
518A	Hs College Office	40	-514	-1100		with 516B								
518B	Hs College Conference	100	-468	-2750	-3218	FPIU-5-25	3	1	0.20	0.07	5800	440	1	540
L1C	Vestibule	50	-2465	-1375	-3840	FPIU-1-12	3	1	0.20	0.07	5800	440	1	490
	Corridor 1st Floor West	280	-14247	-7700	-21947	FPIU-1-7	5	2	15.00	0.05	23100	625	5	905
	Corridor 2nd Floor South	125	-7528	-3438	-10966	FPIU-2-15	3	2	0.40	0.12	11300	580	1	705
	Corridor 3rd Floor West	135	-9331	-3713	-13044	FPIU-3-19	5	2	0.90	0.03	13300	450	1	585
	Corridor 4th Floor West	67.5	-10699	-1856	-12555	FPIU-4-19	5	2	0.90	0.03	13300	450	1	518
		67.5		-1856	-1856	FPIU-4-20	5	1	0.40	0.01	4500	100	1	168
	Corridor 5th Floor East	210	-7607	-5775	-13382	FPIU-5-21	3	2	2.70	0.07	14000	440	3	650
	Corridor 1st Floor East	110	-5269	-3025	-8294	FPIU-1-8	3	1	0.70	0.15	8300	650	2	760
	Corridor 2nd Floor East	145	-7207	-3988	-11195	FPIU-2-27	3	2	0.40	0.12	11300	580	1	725
	Corridor 3rd Floor East	85	-4126	-2338	-6464	FPIU-3-31	3	1	0.20	0.15	6600	650	1	735
	Corridor 4th Floor East	85	-4126	-2338	-6464	FPIU-4-31	3	1	0.20	0.15	6600	650	1	735

Appendix T – Heating Coil FPIU Sizing

Model: KLPS

Water Coil Data

Unit Size	Rows	G.P.M.	Head Loss	Air Flow, CFM 440	510	580	650	720	790	860	930	1000
3	1 Row	1.0	0.2	5.8	6.1	6.4	6.6	6.8	7.0	7.2	7.3	7.4
		2.0	0.7	7.1	7.6	8.0	8.3	8.6	8.9	9.2	9.5	9.7
		4.0	2.4	8.1	8.7	9.2	9.7	10.1	10.5	10.9	11.3	11.6
		6.0	4.9	8.5	9.2	9.8	10.3	10.8	11.3	11.7	12.1	12.5
		Airside Δ PS		0.04	0.05	0.06	0.08	0.09	0.11	0.13	0.15	0.17
3	2 Row	1.0	0.4	10.3	10.8	11.3	11.7	12.0	12.3	12.6	12.8	13.0
		3.0	2.7	14.0	15.1	16.1	17.0	17.7	18.5	19.1	19.7	20.3
		5.0	6.6	15.2	16.5	17.7	18.8	19.7	20.6	21.5	22.2	23.0
		7.0	12.0	15.8	17.2	18.5	19.7	20.8	21.8	22.7	23.6	24.4
		Airside Δ PS		0.07	0.10	0.12	0.15	0.18	0.21	0.24	0.28	0.32

Unit Size	Rows	G.P.M.	Head Loss	Air Flow, CFM 100	275	450	625	800	975	1150	1325	1500
5	1 Row	1.0	0.4	4.6	7.2	8.4	9.1	9.7	10.3	10.7	11.1	11.5
		2.0	1.4	5.0	8.4	10.1	11.2	12.2	13.2	14.0	14.7	15.3
		4.0	4.8	5.2	9.2	11.4	12.9	14.1	15.5	16.6	17.6	18.5
		6.0	9.9	5.3	9.6	11.9	13.6	15.0	16.5	17.8	19.0	20.1
		Airside Δ PS		0.01	0.01	0.02	0.03	0.04	0.06	0.08	0.10	0.13
5	2 Row	1.0	0.9	5.6	10.6	13.3	15.1	16.3	17.1	17.8	18.4	18.9
		3.0	6.1	5.9	12.9	17.7	21.2	24.1	26.4	28.3	30.0	31.4
		5.0	15.0	6.0	13.5	18.9	23.1	26.6	29.5	32.0	34.2	36.2
		7.0	27.2	6.1	13.7	19.4	24.0	27.8	31.1	33.9	36.4	38.7
		Airside Δ PS		0.01	0.01	0.03	0.05	0.08	0.11	0.15	0.19	0.24

All data is based on: 72 Deg F Entering Air, 140 Deg F Entering Water, at 0 feet above Sea Level.
Program calculations assume 35 % Glycol

Appendix U – RS Means New Duct Cost Calculation

2012 RS Means Mechanical Data

New Duct (non flex)

Location factor Queens: 128.9

- 6% elevated height 10'-15' high — labor
- over 5000 lb → $7.00 per lb (includes O & P page 303)
- add 11% to labor for 30% fittings

O+P = $2.24 ← 7-4.76

$4.10 = labor

$4.10 × 1.15 × 1.06 × 1.11 = $5.55

(1.15: medium pressure duct; 1.06: elevated height; 1.11: 30% fittings)

$5.55	labor
$2.24	O+P
+ $0.66	material
$8.45	

$8.45 × 1.289 (location factor) = $10.89 per lb rectangular duct

lb = 17869.6 × $10.69 = $194599.94

+ insulation → $1 per sf

194599.94 + 20484.24 = $215,084.18 non flex duct

flex duct new found similar = $12,413.63

total new duct work = $227,498

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Appendix V – Secondary Chilled Water Loop Head Calculation

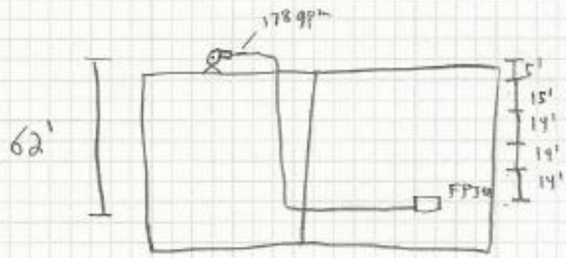
Section	Rate (gpm)	Pipe Size (inches)	Head per 100 ft, ft/100ft	Pipe Length (ft)	Value from Figure	(friction factor)	K	Equiv Length (ft)	Equiv Length (ft)	Lost Head (ft)
Pump to 5th	178	4	1.75	5			0	0	5	0.0875
Standard Tee	145	4	1.4		20	0.017	0.34	7.5	7.5	0.105
5th to 4th	145	4	1.4	15			0		15	0.21
Standard Tee	98	4	0.7		20	0.017	0.34	7.5	7.5	0.0525
4th to 3rd	98	4	0.7	14			0		14	0.098
Standard Tee	52	2.5	2		20	0.018	0.36	5.5	5.5	0.11
3rd to 2nd	52	2.5	2	14			0		14	0.28
Standard Tee	12	1.5	1.75		20	0.021	0.42	3	3	0.0525
2nd to 1st	12	1.5	1.75	14			0		14	0.245
Standard Elbow	12	1.5	1.75		30	0.021	0.63	4	4	0.07
Standard Tee	11	1.25	2		20	0.022	0.44	2.5	2.5	0.05
1st Flr Run	11	1.25	2	17.5			0		17.5	0.35
Standard Tee	10	1.25	1.75		20	0.022	0.44	2.5	2.5	0.04375
1st Flr Run	10	1.25	1.75	7.5			0		7.5	0.13125
Standard Tee	9	1.25	1.5		20	0.022	0.44	2.5	2.5	0.0375
1st Flr Run	9	1.25	1.5	3			0		3	0.045
Standard Elbow	9	1.25	1.5		30	0.022	0.66	3.5	3.5	0.0525
1st Flr Run	9	1.25	1.5	9			0		9	0.135
Standard Elbow	9	1.25	1.5		30	0.022	0.66	3.5	3.5	0.0525
1st Flr Run	9	1.25	1.5	13			0		13	0.195
Standard Tee	8	1.25	1.25		20	0.022	0.44	2.5	2.5	0.03125
1st Flr Run	8	1.25	1.25	40			0		40	0.5
Standard Tee	7	1.25	0.9		20	0.022	0.44	2.5	2.5	0.0225
1st Flr Run	7	1.25	0.9	4			0		4	0.036
Standard Tee	6	1	2.5		20	0.023	0.46	1.75	1.75	0.04375
1st Flr Run	6	1	2.5	8.25			0		8.25	0.20625
Standard Tee	4	1	1.4		20	0.023	0.46	1.75	1.75	0.0245
1st Flr Run	4	1	1.4	3.5			0		3.5	0.049
Standard Tee	3	1	0.8		20	0.023	0.46	1.75	1.75	0.014
1st Flr Run	3	1	0.8	10.75			0		10.75	0.086
Standard Tee	2	0.5	5		20	0.027	0.54	1.1	1.1	0.055
1st Flr Run	2	0.5	5	7			0		7	0.35
Standard Tee	1	0.5	3		20	0.027	0.54	1.1	1.1	0.033
1st Flr Run	1	0.5	3	51.5			0		51.5	1.545
45 Elbow	1	0.5	3		16	0.027	0.432	0.9	0.9	0.027
45 Elbow	1	0.5	3		16	0.027	0.432	0.9	0.9	0.027
Standard Elbow	1	0.5	3		30	0.027	0.81	1.5	1.5	0.045
Ball Valve	1	0.5	3		3	0.027	0.081	0.15	0.15	0.0045
FPIU	1	0.5					0		0	0.02
									total:	5.52 ft

Appendix W – Pump Sizing Schematic

Sizing Pump – for 2nd chilled water

P4h: pump to Vault w/ Anteroom

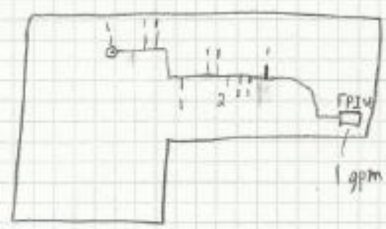
- furthest run times two (for supply and return) (fittings in here)
- include elevation
- include drop across FPIU cooling coil
- include losses from near pump controls → ex. strainer, valves (do so in safety factor)



elevation view

Schematic of longest run

overhead plan



12 spn first floor

length of run = 5.52 ft
drop

× 2 → supply + return

11.05 ft
62 ft (elevation)
+ 29.5 ft (chiller evaporator)

102.5
× 1.1 → safety factor (also includes neglecting valves strainer, and other pieces near pump)

~ 113 ft

Use pump curve for 113 ft, 178 gpm to get → use $7\frac{1}{2}$ hp pump centrifugal

Appendix X – Pump Pricing

Price pump → my pump is 7.5 hp centrifugal
178 gpm
113 ft head

RS Means Mechanical Data centrifugal pump:
rated @ 100 ft head ← closest could find
Vertical split case, single stage:

		O+P
100 gpm	5 hp	$4225
200 gpm	10 hp	$4775

→ 7.5 hp mine

rough cost estimate
interpolate price based on hp: → $4500 × 1.289 = **$5800.50**

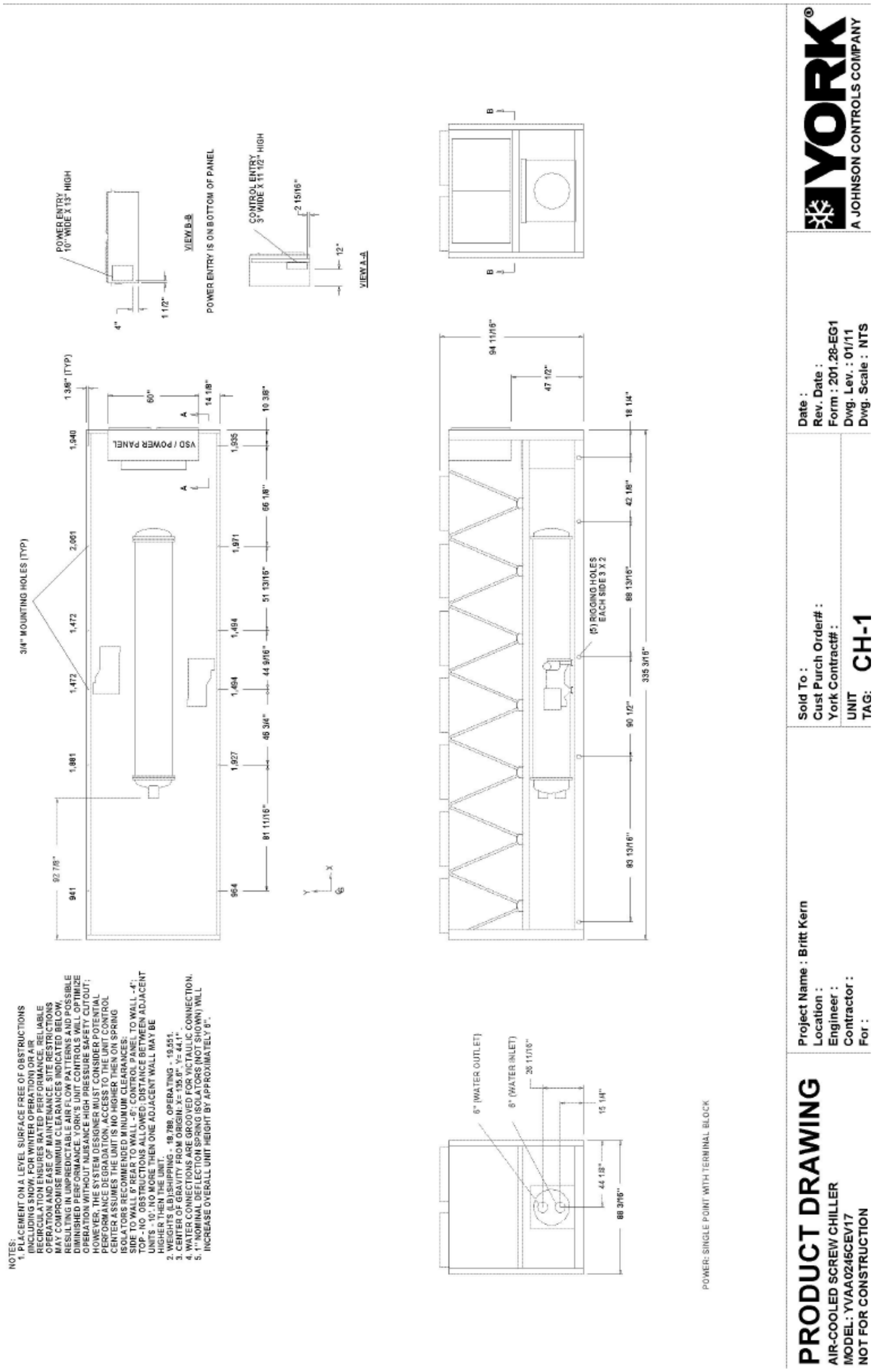
1.289: location factor

$5800.50: price of chilled water 2nd loop pump

5	4225
7.5	y
10	4775

$$y = \frac{(7.5-5)(4775-4225)}{(10-5)} + 4225 = 4500$$

Appendix Y – YVAA0245CEV17 (225 Ton Chiller) Specifications



YORK
A JOHNSON CONTROLS COMPANY

Air Cooled Screw Chiller Performance Specification

Unit Tag	Qty	Model No.	Capacity (Tons)	Volts/Ph/Hz	Refrigerant
CH-1	1	YVAA0245CEV17	225.0	200/3/60	R134a

Pin:

BASE MODEL	POWER	CONTROLS	PIPING	COMP	EVAPORATOR	COND	CABINET	MISC	WARR
YVAA0245CEV17BA	VSXX	XEAXLXXXXXX	44XOSXX	S197W	1SXSA2B	MXV	1X1XX	XXXX	BXS

Evaporator Data		Evaporator Data (Cont.)		Performance Data	
EWT (°F)	53.0	Min. Flow Rate (gpm)	300.0	EER / COP	10.5 / 3.1
LWT (°F)	44.0	Max. Flow Rate (gpm)	1150.0	NPLV	17.4 / 5.1
Design Flow Rate (gpm)	635.2			Minimum Unit Capacity	10 %
Pressure Drop (ft.)	15.8	**Condenser Data**		**Physical Data**	
Fluid	P.G. 30.0%	Ambient Temp. Design (°F)	95.0	Rigging Wt. (lbs.)	18788
Fouling Factor	0.00010	Altitude (ft.)	0	Operating Wt. (lbs.)	19551
Water Volume (gal)	73.0	Ambient Temp. Min (°F)	0.0		

Electrical Data				
Circuit	1	2	3	4
Compressor RLA	399	334		
Fan QTY/FLA (each)	8/5.6	6/5.6		

Single Point				
Min. Circuit Ampacity	919			
Recommended Fuse/CB Rating	1200			
Max. Inverse Time CB Rating	1200			
Max. Dual Element Fuse Size (Amps)	1200			
Unit Short Circuit Withstand (STD)	30kA			
Wire Lugs Per Phase*	4			
Wire Range (Lug Size)	#2 - 600 KCM			
Unit Power Factor	0.95			
Control KVA	2.0		**Operating Condition Electrical Data**	
Starter Type	VSD		Compressor kW	233.0
			Total Fan kW	24.0
			Total kW	257.0

Notes:
RATED OUTSIDE THE SCOPE OF AHRI STANDARD 550/590.
* Use Copper Conductors only

Part Load Rating Data				
Load %	Ambient (°F)	Capacity (Tons)	Compressor kW	Unit Efficiency
100.0	95.0	225.0	233.0	10.5 / 3.1
75.0	80.0	168.7	125.4	14.4 / 4.2
50.0	65.0	112.5	61.4	19.2 / 5.6
25.0	55.0	56.3	25.8	21.8 / 6.4

Project Name: BRITT KERN
Printed: 03/02/2012 AT 16:49
Unit Folder: CH-1

Unit Version: 10.03.FDW (Data Source: v5_79)
YORKworks v.12.01a

York Contract No.:
Performance
Page 1 of 2

YORK
A JOHNSON CONTROLS COMPANY

Air Cooled Screw Chiller Performance Specification

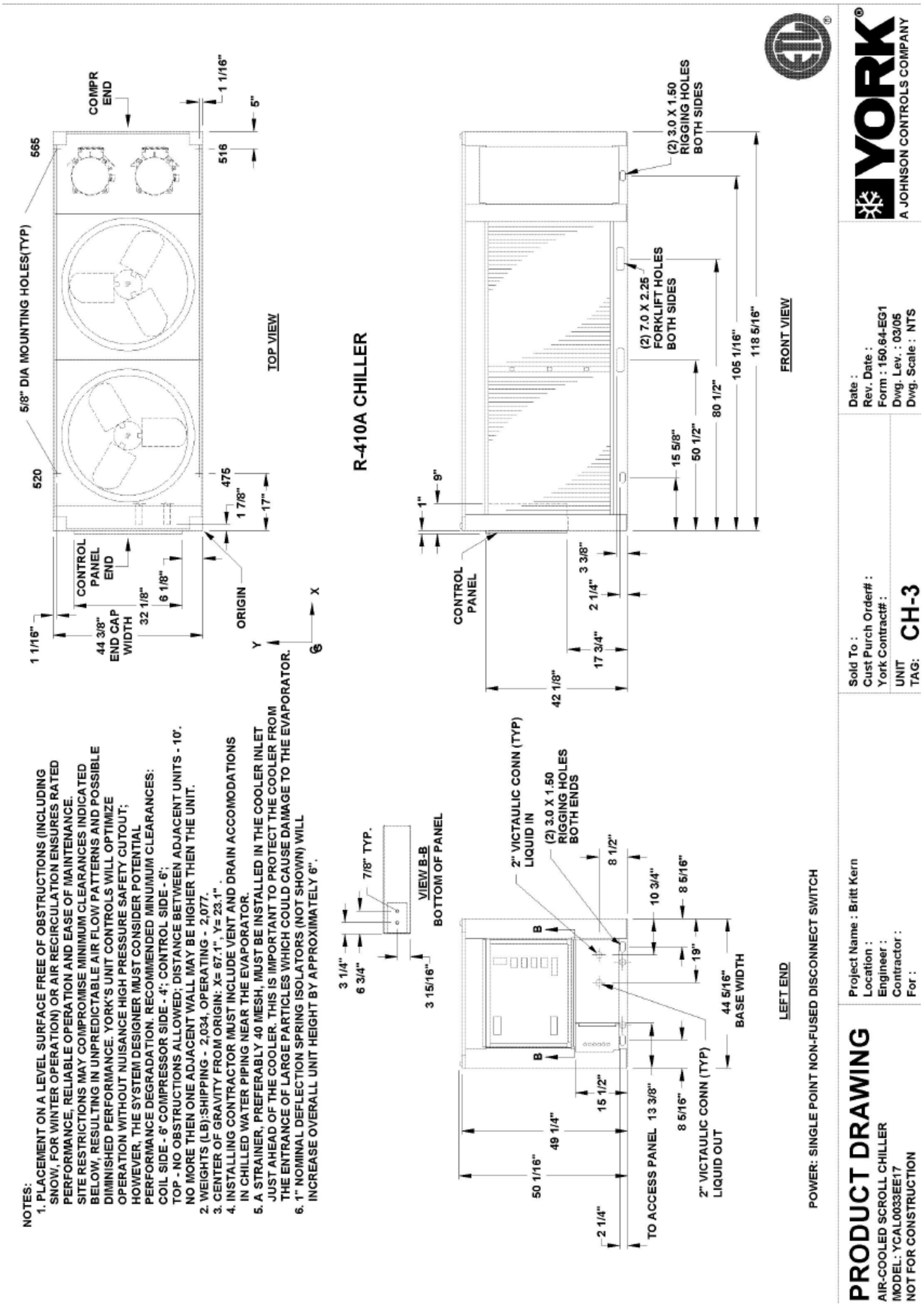
SOUND POWER LEVELS (In Accordance with AHRI 370) – Octave Band Center Frequency, Hz YVAA0245CEV17 (Equipped with Low Sound Fans with Variable Speed Control)										
Load %	Ambient (°F)	63	125	250	500	1K	2K	4K	8K	LWA
100.0	95.0	98.0	98.0	98.0	99.0	96.0	91.0	87.0	83.0	100.0
75.0	80.0	94.0	95.0	95.0	95.0	93.0	86.0	82.0	78.0	97.0
50.0	65.0	90.0	90.0	90.0	91.0	88.0	83.0	79.0	75.0	93.0
25.0	55.0	86.0	89.0	87.0	87.0	85.0	78.0	74.0	70.0	89.0

SOUND PRESSURE LEVELS in dB at 30.0 (ft.) ** YVAA0245CEV17 (Equipped with Low Sound Fans with Variable Speed Control)										
Load %	Ambient (°F)	63	125	250	500	1K	2K	4K	8K	dBA
100.0	95.0	71.0	71.0	71.0	72.0	69.0	64.0	60.0	56.0	73.0
75.0	80.0	67.0	68.0	68.0	68.0	66.0	59.0	55.0	51.0	70.0
50.0	65.0	63.0	63.0	63.0	64.0	61.0	56.0	52.0	48.0	66.0
25.0	55.0	59.0	62.0	60.0	60.0	58.0	51.0	47.0	43.0	62.0

** Chiller is assumed to be a point source on a reflecting surface (hemispherical radiation)

YVAA0245CEV17		Performance at AHRI Conditions			
Evaporator Data		Condenser Data		Performance Data	
EWT (°F)	54.0	Ambient Temp. (°F)	95.0	EER / COP	10.8 / 3.2
LWT (°F)	44.0	Altitude (ft.)	0	EER IPLV/COP IPLV	17.8 / 5.2
Flow Rate (gpm)	564.5			Capacity (Tons)	235.5
Pressure Drop (ft.)	11.5				
Fluid	Water				
Fouling Factor	0.00010				
Water Volume (gal)	73.0				

Appendix Z – YCAL0033EE17(33.4 Ton Chiller) Specifications



YORK® A JOHNSON CONTROLS COMPANY

Air Cooled Scroll Chiller Performance Specification

Unit Tag	Qty	Model No.	Capacity (Tons)	Volts/Ph/Hz	Refrigerant
CH-3	1	YCAL0033EE17	33.4	200/3/60	R410A

Pin:

BASE MODEL	POWER	CONTROLS	COMP PIPING	EVAPORATOR	COND	CABINET	WARR
YCAL0033EE17XEB	SDTX	AXXRLXXXX	54XX1XXXX	XXXSXXX	XXX	1XXXXX1	BXXXXX

Evaporator Data		Condenser Data		Performance Data	
EWT (°F)	62.0	Ambient Temp. (°F)	90.0	EER / COP	12.4 / 3.6
LWT (°F)	54.0	Altitude (ft.)	0	NPLV	16.1 / 4.7
Design Flow Rate (gpm)	105.6	Min. Ambient Temp. (°F)	0.0	Physical Data	
Pressure Drop (ft.)	29.5	Max. Ambient Temp. (°F)	125.0	Rigging Wt. (lbs.)	2034
Fluid	P.G. 30.0%			Operating Wt. (lbs.)	2077
Fouling Factor	0.00010				
Water Volume. (gal)	5.2				

Electrical Data				
Circuit	1	2	3	4
Compressor RLA	59.9/59.9			
Compressor Start Current (LRA)	425.0/425.0			
Fan QTY/FLA (each)	2/7.6			

Single Point				
Min. Circuit Ampacity	150.5			
Min. Non-Fused Disconnect (Amps)	200			
Min. Dual Element Fuse Size (Amps)	175			
Max. Dual Element Fuse Size (Amps)	200			
Min. Circuit Breaker (Amps)	175			
Max. Circuit Breaker (Amps)	200			
Wire Lugs Per Phase*	1			
Wire Range (Lug Size)	(1)#4 - 300			
Total Amps	135.0		Operating Condition Electrical Data	
Inrush (PW) Amps	425.0		Compressor kW	29.3
Starter Type	Across the Line		Total Fan kW	3.0
			Total kW	32.3

Notes:	RATED OUTSIDE THE SCOPE OF AHRI STANDARD 550/590. * Use Copper Conductors only **Installing contractor must include vent and drain accommodations in the chilled water piping near the evaporator.** **A strainer, preferably 40 mesh, must be installed in the cooler inlet just ahead of the cooler. This is important to protect the cooler from the entrance of large particles which could cause damage to the evaporator.**

Part Load Rating Data				
Load %	Ambient (°F)	Capacity (Tons)	Compressor kW	Unit Efficiency
100.0	90.0	33.4	29.3	12.4 / 3.6
50.0	69.5	19.2	11.9	17.2 / 5.0

Project Name: BRITT KERN
Printed: 03/21/2012 AT 12:38
Unit Folder: CH-3

Unit Version: 12.02.FDW (Data Source: v5_81)
YORKworks v.12.02b

York Contract No.:
Performance
Page 1 of 2

YORK
A JOHNSON CONTROLS COMPANY

Air Cooled Scroll Chiller Performance Specification

SOUND POWER LEVELS (In Accordance with AHRI 370) – Octave Band Center Frequency, Hz YCAL0033EE17 (Equipped with Low Sound Fans)										
Load %	Ambient (°F)	63	125	250	500	1K	2K	4K	8K	LWA
100.0	90.0	95.0	90.0	93.0	91.0	85.0	82.0	77.0	74.0	92.0
50.0	69.5	92.0	87.0	90.0	88.0	82.0	79.0	74.0	71.0	89.0

SOUND PRESSURE LEVELS in dB at 30.0 (ft.) ** YCAL0033EE17 (Equipped with Low Sound Fans)										
Load %	Ambient (°F)	63	125	250	500	1K	2K	4K	8K	dBA
100.0	90.0	68.0	63.0	66.0	64.0	58.0	55.0	50.0	47.0	65.0
50.0	69.5	65.0	60.0	63.0	61.0	55.0	52.0	47.0	44.0	62.0

** Chiller is assumed to be a point source on a reflecting surface (hemispherical radiation)

YCAL0033EE17		Performance at AHRI Conditions			
Evaporator Data		Condenser Data		Performance Data	
EWT (°F)	54.0	Ambient Temp. (°F)	95.0	EER / COP	10.5 / 3.1
LWT (°F)	44.0	Altitude (ft.)	0	EER IPLV/COP IPLV	14.5 / 4.2
Flow Rate (gpm)	68.4			Capacity (Tons)	28.6
Pressure Drop (ft.)	11.0				
Fluid	Water				
Fouling Factor	0.00010				
Water Volume (gal)	5.2				

AIR COOLED SCROLL LIQUID CHILLER
YORK YCAL 60 HZ GUIDE SPECIFICATIONS

SOUND POWER LEVELS (In Accordance with AHRI 370) – Octave Band Center Frequency, Hz YCAL0033EE17										
Load %	Ambient (°F)	63	125	250	500	1K	2K	4K	8K	LWA
100.0	90.0	95.0	90.0	93.0	91.0	85.0	82.0	77.0	74.0	92.0
50.0	69.5	92.0	87.0	90.0	88.0	82.0	79.0	74.0	71.0	89.0

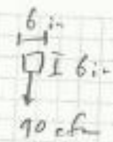
SOUND PRESSURE LEVELS in dB at 30.0 (ft.) ** YCAL0033EE17										
Load %	Ambient (°F)	63	125	250	500	1K	2K	4K	8K	dBA
100.0	90.0	68.0	63.0	66.0	64.0	58.0	55.0	50.0	47.0	65.0
50.0	69.5	65.0	60.0	63.0	61.0	55.0	52.0	47.0	44.0	62.0

** Chiller is assumed to be a point source on a reflecting surface (hemispherical radiation)

Appendix AA – Momentum Method

VAV full flow

4 way: 360 cfm ÷ 4 = 90 cfm



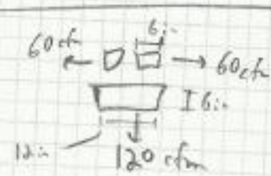
$$V_{z_{mass}} = \frac{90\ cfm}{6\ in \times 6\ in} = 360\ fpm \cdot \left[\frac{1\ min}{60\ sec}\right] \cdot \left(\frac{1\ m}{3.2808399\ ft}\right) = 1.829\ m/s$$

$$V_{z_{mom}} = \frac{1.829}{0.7794} = 2.346\ m/s$$

$$V_{x_{mom}} = \frac{V_{z_{mom}}}{\tan 30^\circ} = \frac{2.346}{\tan 30^\circ} = 4.064\ m/s$$

interface
- nett area ratio 0.7794
- V_y or $V_{x_{mom}} = \pm 4.046\ m/s$
- $V_{z_{mass}} = -1.829\ m/s$

3 way



240 cfm

$$V_{z_{mass}} = \frac{60\ cfm}{6\ in \times 6\ in} = \frac{120\ cfm}{12\ in \times 6\ in} = 240\ fpm = 1.219\ m/s$$

$$V_{z_{mom}} = \frac{V_{z_{mass}}}{0.7794} = \frac{1.219}{0.7794} = 1.564\ m/s$$

net area ratio (0.7794)

$$V_{x_{mom}} = \frac{V_{z_{mom}}}{\tan 30^\circ} = \frac{1.564}{\tan 30^\circ} = 2.709\ m/s$$

interface
- net area ratio: 0.7794
- V_x or $V_{y_{mom}} = \pm 2.709\ m/s$
- $V_{z_{mass}} = -1.219\ m/s$

VAV 30° flow

4 way: $360 \text{ cfm} \cdot 0.3 = 108 \text{ cfm}$

27 cfm ↑ 6 in × 6 in

$$V_{z_{mass}} = \frac{27 \text{ cfm}}{6\text{in} \times 6\text{in}} = 108 \text{ fpm} = 0.5486 \text{ m/s}$$

$$V_{z_{mom}} = \frac{0.5486 \text{ m/s}}{0.7794} = 0.7039 \text{ m/s}$$

$$V_{x_{mom}} = \frac{0.7039}{\tan 30°} = 1.219 \text{ m/s}$$

interface:
- neff area ratio: 0.7794
- V_x or V_y (mom) $= \pm 1.219$ m/s
- $V_{z_{mass}} = -0.5486$ m/s

---

3 way: $240 \text{ cfm} \cdot 0.3 = 72 \text{ cfm}$

18 cfm ↑ 6 in × 6 in

$$V_{z_{mass}} = \frac{18 \text{ cfm}}{6\text{in} \times 6\text{in}} = 72 \text{ fpm} = 0.366 \text{ m/s}$$

$$V_{z_{mom}} = \frac{0.366 \text{ m/s}}{0.7794} = 0.469 \text{ m/s}$$

$$V_{x_{mom}} = \frac{0.469 \text{ m/s}}{\tan 30°} = 0.813 \text{ m/s}$$

interface:
- neff area ratio: 0.7794
- V_x or V_y (mom) $= \pm 0.813$ m/s
- $V_{z_{mass}} = -0.366$ m/s

$\rho_{air} = 1.2041 \frac{kg}{m^3}$

fpm 30° deg

340 cfm @ diffuser

85 cfm

6 in × 6 in

$$V_{z,mass} = \frac{85\ cfm}{6in \times 6in} = 340\ fpm \cdot \left[\frac{1\ min}{60\ sec}\right] \cdot \left[\frac{1\ m}{3.2808399\ ft}\right] = 1.727\ m/s$$

$$V_{z,mass} = 1.727\ m/s \longrightarrow \dot{m}_{in} = \rho A v = \left(1.2041 \frac{kg}{m^3}\right)(0.0232\ m^2)(1.727\ m/s)$$

(A = total, v = $V_{z,mass}$)

6 in × 6 in

$0.25\ sf = 0.0232\ m^2$

$$\boxed{\dot{m}_{in} = 0.0483\ kg/s}$$

$$\dot{m}_{in} = 85 \frac{ft^3}{min} \cdot \rho \cdot \frac{1\ m^3}{(3.28\ ft)^3} \cdot \frac{1\ min}{60\ sec} = 0.0483\ kg/s$$

(ρ = 1.2041 kg/m³)

nett area ratio = 0.7794

$$V_{z,mom} = \frac{V_{z,mass}}{\text{net area ratio}} = \frac{1.727}{0.7794} = \boxed{2.2158\ m/s}$$

$V_{x,mom}$

SohCahToa

$$\tan 30° = \frac{V_{z\,mom}}{V_{x\,mom}}$$

$$V_{x,mom} = \frac{V_{z\,mom}}{\tan 30°} = \frac{2.2158}{\tan 30°}$$

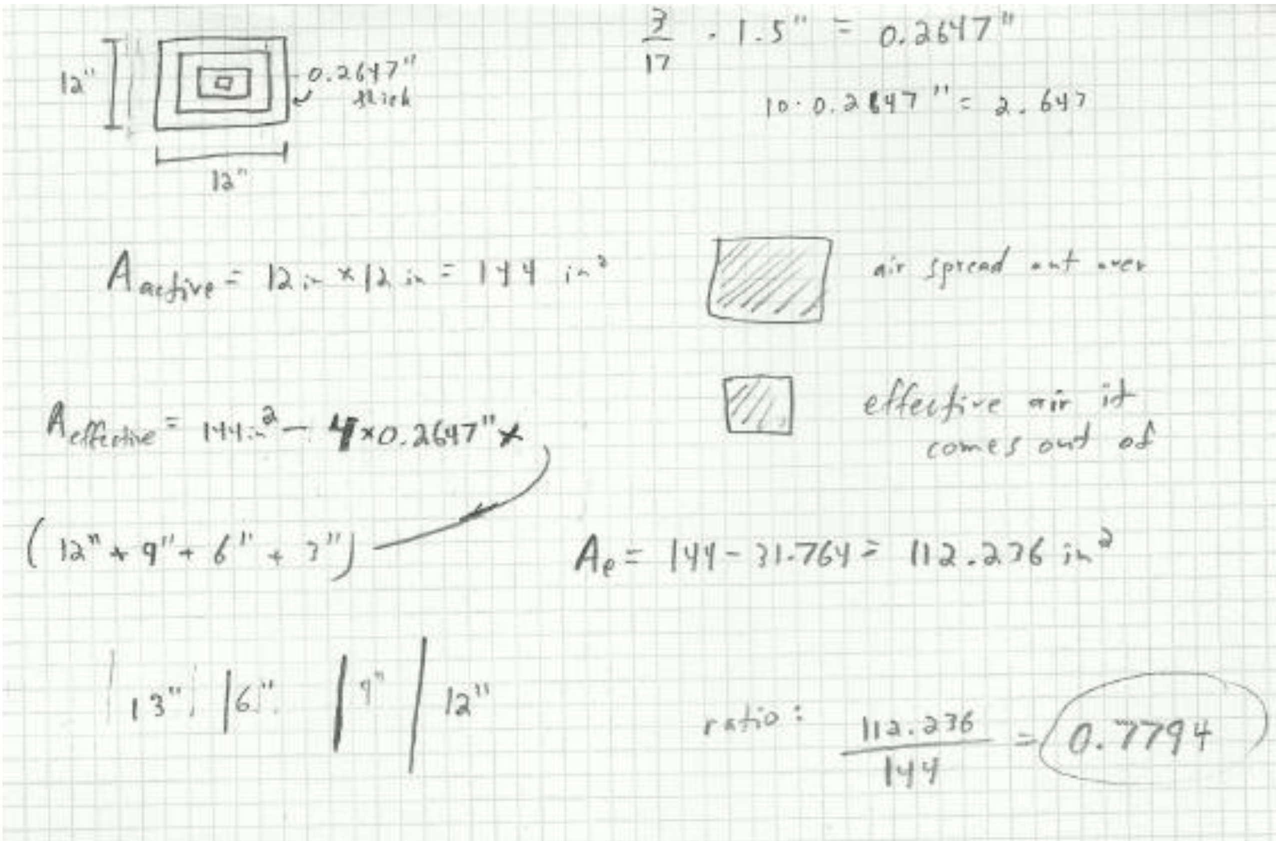
$$V_{x,mom} = \boxed{3.838\ m/s}$$

nett area ratio = 0.7794

$V_{x\ or\ y,\ mom} = \pm 3.838$

$V_{z,mass} = -1.727$

Appendix AB – Net Area Ratio



Appendix AC – SunPower 308 Solar Panel

SUNPOWER

E18 / 308 SOLAR PANEL

EXCEPTIONAL EFFICIENCY AND PERFORMANCE

BENEFITS

Highest Efficiency
SunPower™ Solar Panels are the most efficient photovoltaic panels on the market today.

More Power
Our panels produce more power in the same amount of space—up to 50% more than conventional designs and 100% more than thin film solar panels.

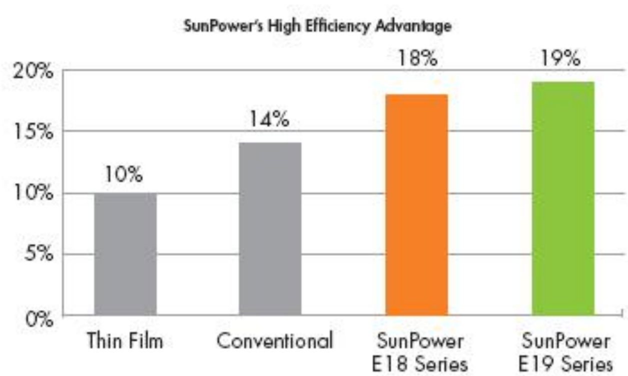
Reduced Installation Cost
More power per panel means fewer panels per install. This saves both time and money.

Reliable and Robust Design
Proven materials, tempered front glass, and a sturdy anodized frame allow panel to operate reliably in multiple mounting configurations.

SPR-308E-WHT-D

E18 SERIES

The SunPower™ 308 Solar Panel provides today's highest efficiency and performance. Utilizing 96 back-contact solar cells, the SunPower 308 delivers a total panel conversion efficiency of 18.9%. The panel's reduced voltage-temperature coefficient and exceptional low-light performance attributes provide outstanding energy delivery per peak power watt.



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SUNPOWER E18 / 308 SOLAR PANEL

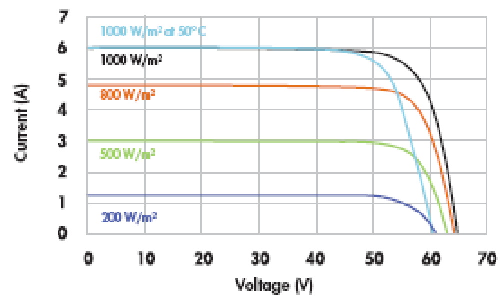
EXCEPTIONAL EFFICIENCY AND PERFORMANCE

Electrical Data

Measured at Standard Test Conditions (STC): irradiance of 1000W/m², AM 1.5, and cell temperature 25°C

Peak Power (+5/-3%)	P_{max}	308 W
Efficiency	η	18.9 %
Rated Voltage	V_{mpp}	54.7 V
Rated Current	I_{mpp}	5.64 A
Open Circuit Voltage	V_{oc}	64.3 V
Short Circuit Current	I_{sc}	6.02 A
Maximum System Voltage	UL	600 V
Temperature Coefficients	Power (P)	-0.38% / K
	Voltage (V_{oc})	-176.6mV / K
	Current (I_{sc})	3.5mA / K
NOCT		45° C +/-2° C
Series Fuse Rating		15 A

I-V Curve



Current/voltage characteristics with dependence on irradiance and module temperature.

Mechanical Data

Solar Cells	96 SunPower all-back contact monocrystalline
Front Glass	high transmission tempered glass
Junction Box	IP-65 rated with 3 bypass diodes
	Dimensions: 32 x 155 x 128 (mm)
Output Cables	1000mm length cables / MultiContact (MC4) connectors
Frame	Anodized aluminum alloy type 6063 (black)
Weight	41 lbs. (18.6 kg)

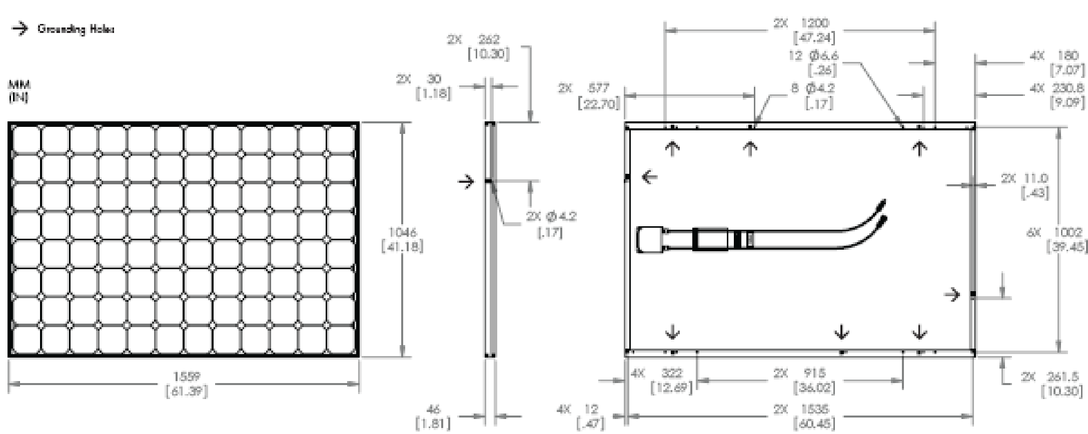
Tested Operating Conditions

Temperature	-40° F to +185° F (-40° C to + 85° C)
Max load	113psf 550 kg/m² (5400 Pa), front (e.g. snow) w/specified mounting configurations 50 psf 245 kg/m² (2400 Pa) front and back – e.g. wind
Impact Resistance	Hail 1 in (25 mm) at 52mph (23 m/s)

Warranties and Certifications

Warranties	25 year limited power warranty
	10 year limited product warranty
Certifications	Tested to UL 1703. Class C Fire Rating

Dimensions



CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.

Visit sunpowercorp.com for details

sunpowercorp.com

Document #001-65243 Rev** / LTR_EN

Appendix AD – SunPower PowerGuard

SUNPOWER

POWERGUARD®

INTERLOCKING SOLAR ROOF TILES PROTECT & INSULATE

BENEFITS

Non-Penetrating
Easily installed solar modules require no roof modifications or attachments

Lightweight
Aerodynamic, lightweight modules are easy to ship, handle, and install

Protects Your Roof
Protects rooftops from harsh weather, UV exposure and thermal cycling

Insulated to Reduce Costs
R-10 insulation saves up to 30% more energy by reducing a building's heating and cooling load

Deploys Rapidly
Interlocking, pre-engineered solar tiles lay directly on rooftop and install quickly without mechanical fastening

Scalable Design
Modular design scales easily for small to large-scale installations

Microsoft - 480 kW - Mountain View, California

PowerGuard is a simple, high-density system for rooftop installations. Its non-penetrating modular design delivers reliable, clean electricity while insulating and protecting your roof. PowerGuard's flat, lightweight solar tiles operate within your existing roof line and electrical system and install rapidly and securely without mechanical fastening.

SUNPOWER POWERGUARD

sunpowercorp.com

SUNPOWER®

POWERGUARD®

INTERLOCKING SOLAR ROOF TILES PROTECT & INSULATE

Specifications and Details (SPR-305)

Attribute	Specification
Tile Weight	4 lb/ft²
Tile Dimensions	Range: 41.5" × 62.6"
R-Value	R-10
Roof Penetrations	None, except high-wind areas
Power Output	1.72 kWp/100 ft²
Deployment Option	Roof
High Wind Resistance	Up to 140 miles per hour
Warranty	Full system warranty

SunPower Solar Cells and Panels

PowerGuard features the most advanced and efficient solar cells and panels on the market

Key Attributes:

- All-back-contact design reduces sun blockage for higher efficiency output up to 22.4%
- 3.2 mm thick high transmission tempered glass enhances product stiffness and impact resistance
- Lower temperature coefficient enhances high temperature operation & energy output

Cell Front

Cell Rear

The PowerGuard technology is protected by US Patent Numbers 5,316,592, 5,505,788, RE 38,988 and 6,061,978. Other US and/or international patents issued or pending may apply.

About SunPower

SunPower designs, manufactures and delivers high-performance solar electric technology worldwide. Our high-efficiency solar cells generate up to 50 percent more power than conventional solar cells. Our high-performance solar panels, roof tiles and trackers deliver significantly more energy than competing systems.

Rev **

Printed on recycled paper

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Appendix AE – Satcon 75 kW Inverter

Satcon

PowerGate® Plus 75 kW

PVS-75 (208 V)
PVS-75 (240 V)
PVS-75 (480 V)

Unparalleled Performance

With their advanced system intelligence, next-generation Edge™ MPPT technology, and industrial-grade engineering, PowerGate Plus inverters maximize system uptime and power production, even in cloudy conditions.

Power Efficiency

Power Level	Output Power[1]	Efficiency[2]
10%	7.5 kW	92.6%
20%	15 kW	95.6%
30%	22.5 kW	96.3%
50%	37.5 kW	96.7%
75%	56.25 kW	96.6%
100%	75 kW	96.3%

[1] 315V minimum [2] 240V model

Edge MPPT

Provides rapid and accurate control that boosts PV plant kilowatt yield

Provides a wide range of operation across all photovoltaic cell technologies

Printed Circuit Board Durability

Wide thermal operating range: -40° C (-40° F) to 85° C (185° F)

Conformal coated to withstand extreme humidity and air-pollution levels

Proven Reliability

Rugged and reliable, PowerGate Plus PV inverters are engineered from the ground up to meet the demands of large-scale installations.

Low Maintenance

Modular components make service efficient

Safety

UBC Seismic Zone 4 compliant

Built-in DC and AC disconnect switches

Integrated DC two-pole disconnect switch isolates the inverter (with the exception of the GFDI circuit) from the photovoltaic power system to allow inspection and maintenance

Built-in isolation transformer

Protective covers over exposed power connections

PV Inverters | PowerGate® Plus 75 kW

PowerGate Plus 75 kW Specifications			UL/CSA
Input Parameters			
Maximum Array Input Voltage	600 VDC (UL)		•
Input Voltage Range (MPPT; Full Power)	315–600 VDC		•
Maximum Input Current	248 ADC		•
Output Parameters			
Output Voltage Range (L-L)	183–229 VAC	208 VAC	•
	211–264 VAC	240 VAC	•
	422–528 VAC	480 VAC	•
Nominal Output Voltage	208 VAC		•
	240 VAC		•
	480 VAC		•
Output Frequency Range	59.3–60.5 Hz		•
AC Voltage Range (Standard)	-12%/+10%		•
Nominal Output Frequency	60 Hz		•
Number of Phases	3		•
Maximum Output Current per Phase	208 A	208 VAC	•
	181 A	240 VAC	•
	91 A	480 VAC	•
CEC-Weighted Efficiency	96%		•
Maximum Continuous Output Power	75 kW (75 kVA)		•
Tare Losses	65.36 W	208 VAC	•
	71.84 W	240 VAC	•
	69.5 W	480 VAC	•
Power Factor at Full Load	>0.99		•
Harmonic Distortion	<3% THD		•

• Standard ○ Optional

Satcon

PowerGate® Plus 75 kW

Satcon®

PowerGate® Plus 75 kW

Output Options

PowerGate Plus 75 kW	
UL/CSA	208 VAC Output
	240 VAC Output
	480 VAC Output

Streamlined Design

With all components encased in a single, space-saving enclosure, PowerGate Plus PV inverters are easy to install, operate, and maintain.

Single Cabinet with Small Footprint

Convenient access to all components

Large in-floor cable glands make access to DC and AC cables easy

Rugged Construction

Engineered for outdoor environments

Output Transformer

Provides galvanic isolation

Matches the output voltage of the PV inverter to the grid

PowerGate Plus 75 kW Specifications		UL/CSA
Temperature		
Operating Ambient Temperature Range (Full Power)	-20° C to +50° C	•
Storage Temperature Range	-30° C to +70° C	•
Cooling	Forced Air	•
Noise		
Noise Level	<65 dB(A)	•
Combiner		
Number of Inputs and Fuse Rating	5 (100 ADC)	o
	6 (80 ADC)	o
Inverter Cabinet		
Enclosure Rating	NEMA 3R	•
Enclosure Finish (14-Gauge, Powder-Coated G90 Steel)	RAL-7032	•
Cabinet Dimensions (Height x Width x Depth)		80" x 57" x 30.84"
Cabinet Weight		2,150 lbs.
Transformer		
Integrated Internal Transformer		•
Low Tap Voltage[1]	20%	•
Testing and Certification		
UL 1741, CSA 107.1-01, IEEE 1547, IEEE C62.41.2, IEEE C62.45, IEEE C37.90.1, IEEE C37.90.2		•
UBC Zone 4 Seismic Rating		•
Warranty		
Five Years		•
Extended Warranty (up to 10, 15, or 20 years)		o
Extended Service Agreement		o
Intelligent Monitoring		
Satcon PV View® Plus		o
Satcon PV Zone		o
Third-Party Compatibility		•

• Standard
o Optional

[1] The 20% boost tap on the isolation transformer increases the AC voltage output range for applications where the solar array DC operating voltage is at or near the lower end of the DC input range. This boost allows for continued inverter operation at lower DC voltage input levels.

Note: Specifications are subject to change.

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Fu Tian District
Shenzhen, China
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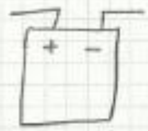
Appendix AF – Wire Sizing Calculations

* Assume all wires are THHW copper @75°C.

Solar Panel:



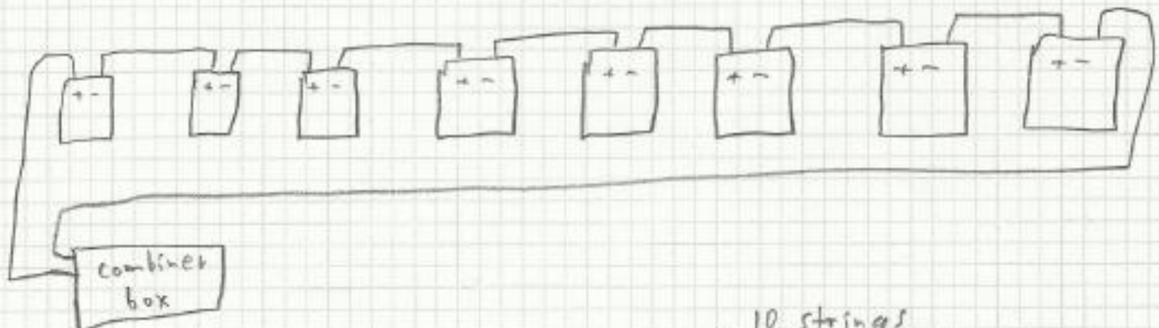
I_{sc} = 6.02 amps (max amps it will see)

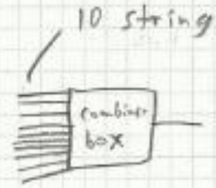
2 DC wires + and −

size off of I = 6.02 amps use NEC Table 310.15 B

14 AWG can hold up to 15 A

String: panels strung in 8's





combiner box:

current in parallel adds

10 × 6.02 amps × 1.25 = 75.25 Amps

(10: strings; 1.25: for continuous load)

↳ fuse is 80 Amps then

wire coming out of combiner box: (size off of fuse)

fuse 100 A, 2 conductors (still DC)

NEC Table 310.15(B) wire size conductors: 3 AWG

NEC Table 250.122 ground wire: 8 AWG
sized of 80A fuse

EMT sizing NEC Table C.1 : (3) 3 AWG → 1" conduit

2-#3 + #8 GW – 1"C

other combiner box:

8 × 6.02 A × 1.25 = 60.2 Amp → 70A fuse

strings continuous

NEC Table 310.15(B): (2) #4 AWG

ground wire → #8AWG
70A fuse

EMT → (3) #4 AWG get 1" conduit

2 – #4 + #8 GW – 1"C

Inverter (AC side)

size is 75 kW → 224 panels × 308 W = 68,992 W

∴ So 75 kW inverter will handle this.

3Φ 208V : $\frac{75 \cdot 10^3 W}{208V \cdot \sqrt{3}} = 208.2$ Amps

equation: PF · VA = Watts
assume PF = 1

$\frac{VA}{V \cdot \sqrt{3}}$ = Amps (for 3Φ)

size wires to 208.2 Amps: NEC Table 310.15(B) 4/0 AWG

ground sized off breaker:

breaker is 225 Amps → covers the amps

NEC Table 250.122 : #10 AWG

· size EMT: 5 wires → 3Φ
1 N
1 G
all at 4/0

(5) 4/0 NEC Table C.1 → EMT 2.5"

cable coming out of inverter:

4 - #4/0 + #10 GW - 2½" C

Appendix AG – NEC Tables used for Wire Sizing

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

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size (AWG or kcmil)	
	Copper	Aluminum or Copper-Clad Aluminum*
15	14	12
20	12	10
60	10	8
100	8	6
200	6	4
300	4	2
400	3	1
500	2	1/0
600	1	2/0
800	1/0	3/0
1000	2/0	4/0
1200	3/0	250
1600	4/0	350
2000	250	400
2500	350	600
3000	400	600
4000	500	750
5000	700	1200
6000	800	1200

30 use → 60 (go up if not here)

circuit breaker size

Table 310.15(B)(16) (formerly Table 310.16) Allowable Ampacities of Insulated Conductors Rated Up to a Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors i Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)*

	Temperature Rating of Conductor [See Table 310.104(A).]					
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM		
18 AWG	—	—	14	—	—	—
16	—	—	18	—	—	—
14**	15	~~20~~ 15	25	—	—	—
12**	20	~~25~~ 20	30	15	20	25
10**	30	~~35~~ 30	40	25	30	35
8	40	50	55	35	40	45
6	55	65	75	40	50	55
4	70	85	95	55	65	75
3	85	100	115	65	75	85
2	95	115	130	75	90	100
1	110	130	145	85	100	115
1/0	125	150	170	100	120	135
2/0	145	175	195	115	135	150
3/0	165	200	225	130	155	175
4/0 AWG	195	230	260	150	180	205
250 kcmil	215	255	290	170	205	230
300	240	285	320	195	230	260
350	260	310	350	210	250	280
400	280	335	380	225	270	305
500	320	380	430	260	310	350
600	350	420	475	285	340	385
700	385	460	520	315	375	425
750	400	475	535	320	385	435
800	410	490	555	330	395	445
900	435	520	585	355	425	480
1000	455	545	615	375	445	500
1250	495	590	665	405	485	545
1500	525	625	705	435	520	585
1750	545	650	735	455	545	615
2000	555	665	750	470	560	630

*Refer to 310.15(B)(2) for the ampacity correction factors where the ambient temperature is other than 30°C (86°F).
**Refer to 240.4(D) for conductor overcurrent protection limitations.

Table C.1 *Continued*

		CONDUCTORS									
	Conductor Size	Metric Designator (Trade Size)									
Type	(AWG kcmil)	16 (½)	21 (¾)	27 (1)	35 (1¼)	41 (1½)	53 (2)	63 (2½)	78 (3)	91 (3½)	103 (4)
RHH*,	6	1	3	4	8	11	18	32	48	63	81
RHW*,	4	1	1	3	6	8	13	24	36	47	60
RHW-2*,	3	1	1	3	5	7	12	20	31	40	52
TW,	2	1	1	2	4	6	10	17	26	34	44
THW,	1	1	1	1	3	4	7	12	18	24	31
THHW,	1/0	0	1	1	2	3	6	10	16	20	26
THW-2	2/0	0	1	1	1	3	5	9	13	17	22
	3/0	0	1	1	1	2	4	7	11	15	19
	4/0	0	0	1	1	1	3	6	9	12	16
	250	0	0	1	1	1	3	5	7	10	13
	300	0	0	1	1	1	2	4	6	8	11
	350	0	0	0	1	1	1	4	6	7	10
	400	0	0	0	1	1	1	3	5	7	9
	500	0	0	0	1	1	1	3	4	6	7
	600	0	0	0	1	1	1	2	3	4	6
	700	0	0	0	0	1	1	1	3	4	5
	750	0	0	0	0	1	1	1	3	4	5
	800	0	0	0	0	1	1	1	3	3	5
	900	0	0	0	0	0	1	1	2	3	4
	1000	0	0	0	0	0	1	1	2	3	4
	1250	0	0	0	0	0	1	1	1	2	3
	1500	0	0	0	0	0	1	1	1	1	2
	1750	0	0	0	0	0	0	1	1	1	2
	2000	0	0	0	0	0	0	1	1	1	1
THHN	14	12	22	35	61	84	138	241	364	476	608

Appendix AH – Balanced Switchboard 2

Voltage: 208 Main Breaker: 2000 A Feeder: 7 sets of [(4) 500 kcmil + 350 kcmil GW - 3.5" C]
(#, size wire & conduit)

Description	LOAD (KVA) A	B	C	Amps	Brk. Trip (A)	Cond. Size	SWBD-2 Ckt. #	Ckt. #	Cond. Size	LOAD (KVA) A	B	C	Amps	Brk. Trip (A)	Description
1EDP-LS/ATS-LS	231			641	700	2 sets 400	1	2	3/0	66			183	200	Panels (1-3)LP-A
		231		641	700	2 sets 400	3	4	3/0		66		183	200	
			231	641	700	2 sets 400	5	6	3/0			66	183	200	
Panel 5DP-K1	107			297	300	350	7	8	1	45			125	125	Panels (4-5)LP-A
		107		297	300	350	9	10	1		45		125	125	
			107	297	300	350	11	12	1			45	125	125	
Panel 3LP-DIM-1	57			159	175	2/0	13	14	2/0	57			158	175	Panel 3LP-DIM-2
		57		159	175	2/0	15	16	2/0		57		158	175	
			57	159	175	2/0	17	18	2/0			57	158	175	
Panels (1-2)AP-B	42			117	125	1	19	20	4/0	75			208	225	Inverter
		42		117	125	1	21	22	4/0		75		208	225	
			42	117	125	1	23	24	4/0			75	208	225	
Panels (3-4)AP-B	70			194	200	3/0	25	26							
		70		194	200	3/0	27	28							
			70	194	200	3/0	29	30							
Panels (3-5)AP-A	53			147	150	1/0	31	32							
		53		147	150	1/0	33	34							
			53	147	150	1/0	35	36							
Panels (1-2)AP-A	63			175	175	2/0	37	38							
		63		175	175	2/0	39	40							
			63	175	175	2/0	41	42							
	623	623	623							243	243	243			

Total Load on Phase A: 866 KVA
Total Load on Phase B: 866 KVA
Total Load on Phase C: 866 KVA

Total Load on Panel: 866 kVA
2403 A

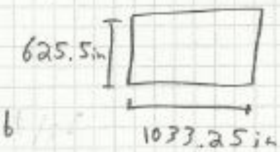
Demand Factor: 0.8
(applied to everything but Inverter)

Feeder Demand Amp: 1963 A
(Size main breaker off demand amps.)

Appendix AI – Structural Calculations

Structural Breadth

Solar Array – assume it is a distributed load



Ballast weight $= \dfrac{\text{perimeter (inches)}}{8} \times 33 \text{ lb} = \text{lb}$

$= \dfrac{3317.5 \text{ inches}}{8} \times 33 \text{ lb} = 13{,}684.7 \text{ lb}$

Ballast lb/sf = weight ÷ area $= 13{,}684.7 \text{ lb} / \left(\dfrac{625.5}{12}\text{in} \times \dfrac{1033.25}{12}\text{in}\right)$ ← convert to feet

$= 3.05 \text{ lb/sf}$

dead load weight of panels, Power Guard, and ballasts $= 3.05 \text{ lb/sf}$ (ballast) $+ 4 \text{ lb/sf}$ (panels and Power Guard) $= 7.05 \text{ lb/sf}$

Check to see if deck is strong enough.

Use combination #3: $w = 1.2D + 1.6(L_r \text{ or } S) \rightarrow 1.2D + 1.6S$

* $L_r = 20$ psf and $S = 30$ psf so snow controls.

Unfactored Loads:

Snow = 30 psf

solar array = 7.05 psf

concrete pavers (2" thick) $= 154 \frac{\text{lb}}{\text{cf}} \times \frac{2 \text{ ft}}{12} = 24$ psf

4" rigid insulation = 2 psf

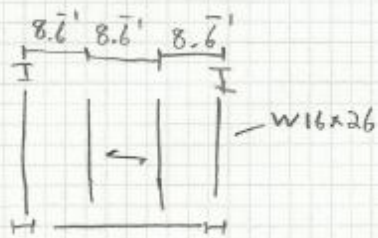
slab (3 1/4" lightweight concrete over 3" deep–18 gage metal deck) = 39 psf (noncomposite; from Vulcraft p. 26 non-composite)

$DL_{total} = 7.05 + 24 + 2 + 39 = 72.05$ psf

(solar, pavers, insulation, slab)

$w_{total} = 1.2(72.05) + 1.6(30) = 134.5$ psf

typical layout



3 spans of 8'-8" each

Need 1.5C18 deck type 4 1/2" slab (t=3") p. 26

8'9" > 8'8" ∴ good

(allowable span) (span)

deflection: $\Delta_{snow} \le l/240$ $\Delta_{TL} \le l/180$

30 < 55 psf ∴ good

134.5 > 70 psf ∴ no good

total load for stress:

134.5 psf > 70 psf ∴ no good

Must make deck thicker.

Try 2C16, 5" (t = 3") page 28 Vulcraft

w_{total} = 134.5 + 1 psf × 1.2 (dead load) = 135.7 psf

span: 12'-5" (allowed) > 8'-8" (span) ∴ good

total load for stress: 142.5 psf (allowed) > 135.7 psf (have) ∴ good

deflection:

$\Delta_{snow} \leq \ell/240$

30 psf (have) < 130.5 psf (allowed) ∴ good

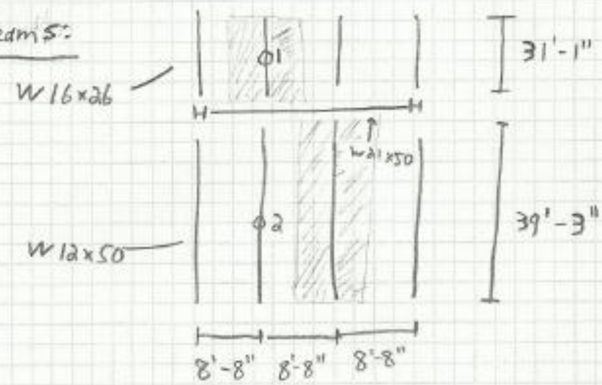
$\Delta_{TL} \leq \ell/180$

135.7 psf (have) < 142.5 psf (allowed) ∴ good

so increase deck in this area from 3 1/4" (t = 3")

to **2C16 5" (t = 3")**

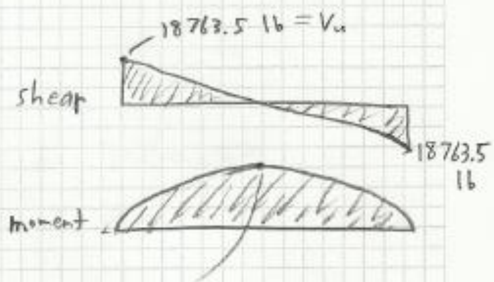
Check beams:



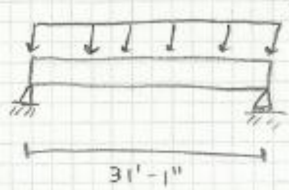
beam 1: W16x26

factored: $w_{total} = (135.7\text{ psf} \cdot 8.\bar{6}\text{ ft}) + \text{self weight} \times 1.2$ (26 plf — it's dead load)

$w_{total} = 1207.3\text{ plf}$



$V_u = (31 + \frac{1}{12}\text{ ft})(1207.3\text{ plf}) \div 2 = 18763.5\text{ lb}$



$M_u = \frac{w\ell^2}{8} = 145807.7\text{ lb}\cdot\text{ft}$

$= 145.8\text{ kip}\cdot\text{ft}$

w_{total} (unfactored) $= 26 + 30 + 7.05 + 24 + 2 + 40 = 129.05\text{ psf} \times 8.\bar{6}\text{ ft} = 1118.4\text{ plf}$

(beam, snow, solar, pavers, insulation, slab)

w_{LL} (unfactored) $= 20\text{ psf} \cdot 8.\bar{6}' = 173.3\text{ plf}$

Strength criteria check:

(factored moment)

$M_u \le \phi M_n = 0.9 F_y Z_x = 166$ kip·ft

p.11 of W-shapes in binder

145.8 kip·ft < 166 kip·ft ∴ good

$V_u \le \phi V_n = 106$ kips

18.7635 kips < 106 kips ∴ good

deflection check:

$\Delta_{LL} \le L/360$ (L: span length in inches)

$$\frac{5 w_{LL} L^4}{384 E I} \times 1728 \le \frac{(31\cdot 12 + 1)}{360}$$

w_{LL}: live load only (psf); L: span in feet; E: $29000\cdot 10^3$ psi; I: 301 in^4 (p. 5 in W-shapes) for $I_{x\text{-}x\ axis}$

$$\frac{5\cdot 20\cdot (31+\frac{1}{12})^4}{384\cdot 29000\cdot 10^3\cdot 301} \times 1728 < 1.0361$$

0.0481 < 1.0361 ∴ good

$\Delta_{TL} \le L/240$

$$1728 \times \frac{5\cdot(129.05)(31+\frac{1}{12})^4}{384\cdot 29000\cdot 10^3\cdot 301} < \frac{(31\cdot 12+1)}{240}$$

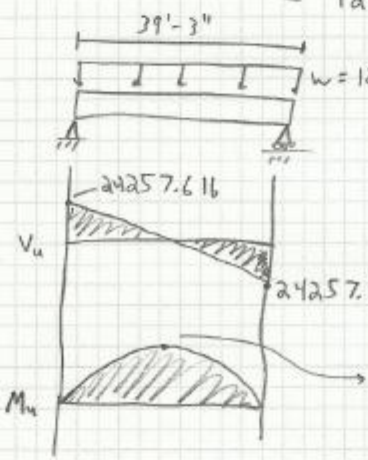
0.3105 > 1.55 ∴ good

Beam 1 works.

beam 2: W 12×50

$w_{total} = (135.7\,psf \cdot 8.\overline{6}') + \text{self weight} \cdot 1.2$ (self weight → 50 plf)

$= 1236.1\ plf$



$V_u = (39 + \frac{3}{12})\,1236.1/2 = 24257.6\ lb$

$M_u = \frac{w\ell^2}{8} = \frac{(1236.1)(39+\frac{3}{12})^2}{8} = 238.04\ kip \cdot ft$

$w_{LL\ unfactored} = 20\ psf$

$w_{TL\ unfactored} = 129.05\ psf$

Strength criteria check:

$M_u \le \phi M_n$

$238.04\ kip \cdot ft < 270\ kip \cdot ft \quad \therefore$ good

p. 11 of W-shapes in binder

$V_u \le \phi V_n$

$24.3\ kips < 135\ kip \quad \therefore$ good deflection check:

$\Delta_{LL} \leq L/360$

$$\frac{5 w_{LL} L^4}{384 EI} \times 1728 < \frac{L}{360}$$

$$\frac{5(20)(39 + \frac{3}{12})^4}{384 \cdot 29000 \cdot 10^3 \cdot 391} \times 1728 < \frac{(39 \cdot 12 + 3)}{360}$$

p. 7 of w-shapes

$0.0942 < 1.3083 \therefore$ good

$\Delta_{TL} \leq L/240$

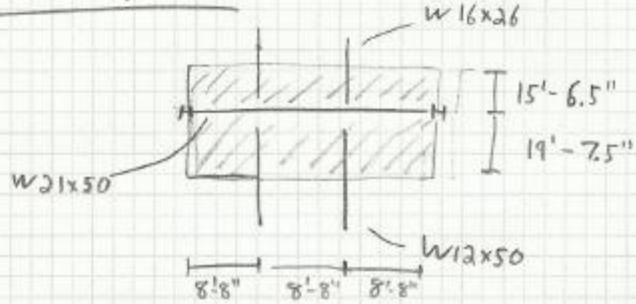
$$\frac{5 \cdot w_{TL} \cdot L^4}{384 EI} \times 1728 \leq L/240$$

$$\frac{5 \cdot 129.05(39 + \frac{3}{12})^4}{384(29000 \cdot 10^3) 391} \times (1728) \leq \frac{(39 \cdot 12 + 3)}{240}$$

$0.6077 < 1.9625 \therefore$ good

Beam 2 works

Check girder: W21x50



factored

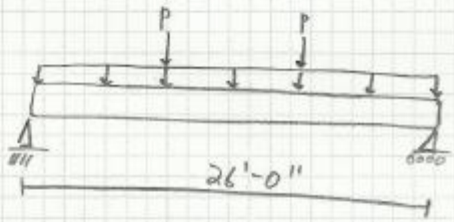
$P = 1207.3 \text{ plf} \left(15' + \frac{6.5}{12} \text{ ft}\right) + 1207.3 \text{ plf} \left(19' + \frac{7.5}{12} \text{ ft}\right)$

$P = 42456.7 \text{ lb}$

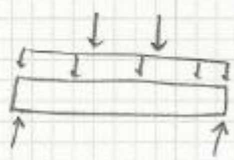
$w = 50 \text{ plf} \cdot 1.2 = 60 \text{ plf}$

due to self weight (factored)

girder:



V_u @ end:

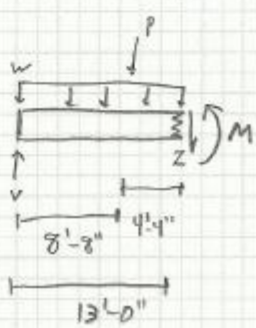


$2V_u = 2P + w \cdot \text{span}$

$2V_u = 2(42456.7 \text{ lb}) + 60 \text{ plf} \cdot 26'$

$V_u = 43236.7 \text{ lb} = 43.24 \text{ kips}$

M_u @ center:



$\circlearrowleft + \Sigma M_{cut} = 0 = M + P\left(4 + \frac{4}{12}\right) + w(13)(6.5) - V(13)$

$M_u = 373.03 \text{ kips} \cdot \text{ft}$

Strength criteria check:

$$M_u \le \phi M_n$$

373.03 kips·ft < 413 kips·ft ∴ good

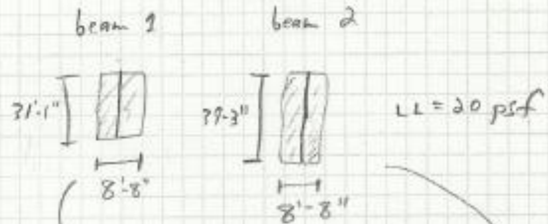
$$V_u \le \phi V_n$$

43.2 kips < 237 kips ∴ good

deflection check:

$$\Delta_{LL} \le L/360$$

live load unfactored ← $\dfrac{P_{LL} L^3}{28EI} \le L/360$



$LL = 20\,psf\left(8+\frac{8}{12}\right)\left(31+\frac{1}{12}\right) = 5388$ lb

$LL = 20\,psf\left(8+\frac{8}{12}\right)\left(39+\frac{3}{12}\right) = 6803.\overline{3}$ lb

$$P_{LL} = \frac{5388 + 6803.\overline{3}}{2} = 6096 \text{ lb}$$

$$\frac{(6096\text{ lb})(26\cdot 12\text{ in})^3}{28(29000\cdot 10^3\text{ psi})(984\text{ in}^4)} < \frac{(26\cdot 12\text{ in})}{360}$$

page 4 in W-shapes

$$0.2317\ \frac{\text{lb}\cdot\text{in}^3}{\frac{\text{lb}}{\text{in}^2}\cdot\text{in}^4} < 0.8\overline{66}\text{ in}$$

0.2317 in $< 0.8\overline{6}$ in ∴ good

$$\Delta_{TL} \leq L/240$$

total load unfactored

$$\frac{P_{TL} L^3}{28EI} \leq L/240$$

$$P_{TL} = \frac{1118.4\,plf \cdot (31 + \frac{1}{12}\,ft)}{2} + \frac{129.05\,psf \cdot (8 + \frac{8}{12}\,ft)(39 + \frac{3}{12}\,ft)}{2} + \frac{50\,plf \cdot 26'}{2}$$

(beam 1 TL; beam 2 TL; self weight)

$$P_{TL} = 39981.05\ lb$$

$$\frac{(39981.05\ lb)(26 \cdot 12\,in)^3}{28(29000 \cdot 10^3\,psi)(984\,in^4)} < \frac{26 \cdot 12\,in}{240}$$

$$1.519\,in > 1.3\,in \quad \therefore \text{ no good}$$

solve for I:

$$\frac{(39981.05\ lb)(26 \cdot 12\,in)^3}{28(29000 \cdot 10^3\,psi)\,I} = \frac{26 \cdot 12\,in}{240}$$

$$I \geq 1150.3\,in^4$$

try W24x55

$$\Delta_{TL} \leq \frac{L}{240}$$

$$P_{TL} = 39981 + \frac{5\,plf \cdot 26}{2} = 40046\ lb$$

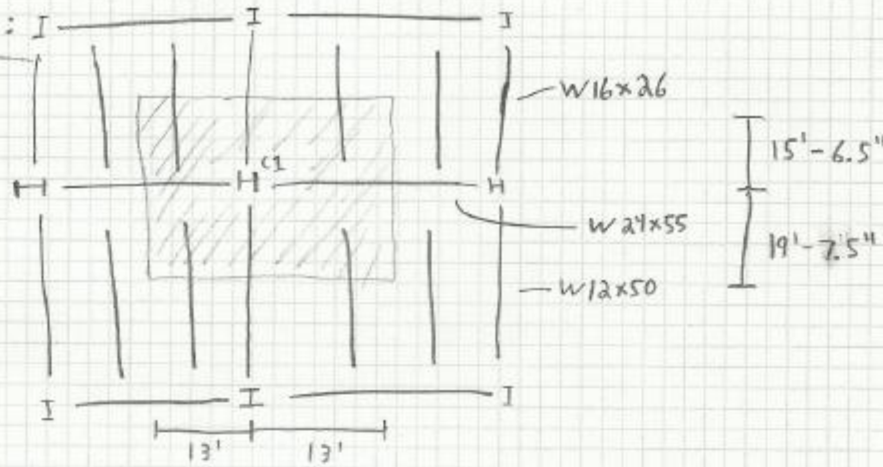
$$\frac{(40046\ lb)(26 \cdot 12\,in)^3}{28(29000 \cdot 10^3\,psi)(1350\,in^4)} < \frac{26 \cdot 12\,in}{240}$$

$$1.1096\,in < 1.3\,in \quad \therefore \text{ works}$$

Use a W24x55 girder instead.

check column:

check typical column C1



column C1 is

W12x40

16'-4" tall

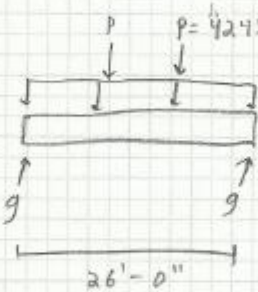
need to check axial: $P_u \leq \phi P_n$ (factored) → also accounts for buckling

P_u is comprised of: (1) girder

(0.5) beam 1

(0.5) beam 2

girder:



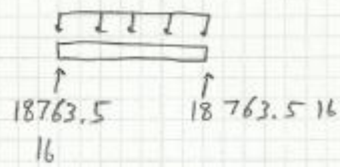
$w_u = 1.2 \cdot 55 \text{ plf} = 66 \text{ plf}$

$2g = 2P + 66 \text{ plf} (26')$

$2g = \underline{86629.4 \text{ lb}}$

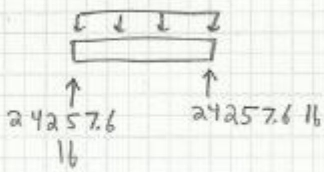
↑ 1 girder

(0.5) beam 1:



18763.5 lb

(0.5) beam 2:



24257.6 lb

$P_u = 86629.4 \text{ lb} + 18763.5 \text{ lb} + 24257.6 \text{ lb} = 129.65 \text{ kips}$

$KL = 1(16.3') = 16.3'$ (assume braced same in both directions)

$K = 1$ (no moments supported)

p. 20 in column section

for $KL = 16.3'$ W12x40 → $\phi P_n = 249.3$ kips

$P_u \leq \phi P_n$

$129.65 \text{ kips} < 249.3 \text{ kips}$ ∴ good

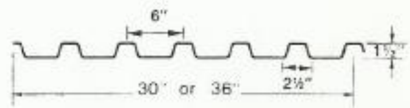
Column is fine.

Appendix AJ – Vulcraft Non-Composite Deck

VULCRAFT

NON-COMPOSITE

1.5 C CONFORM



MAXIMUM CONSTRUCTION CLEAR SPANS (S.D.I. CRITERIA)

Total Slab Depth	Deck Type	Weight PSF	NW Concrete N=9 145 PCF			Weight PSF	LW Concrete N=14 110 PCF		
			1 Span	2 Span	3 Span		1 Span	2 Span	3 Span
3 1/2" (t=2")	1.5C24	37	5- 4	7- 1	7- 2	28	5- 9	7- 8	7- 9
	1.5C22	37	4- 7	6- 1	6- 2	29	5- 0	6- 7	6- 8
	1.5C20	38	5- 5	7- 3	7- 4	29	5- 11	7- 10	7- 11
	1.5C18	38	6- 6	8- 6	8- 10	30	7- 1	9- 3	9- 7
4" (t=2 1/2")	1.5C24	43	5- 1	6- 9	6- 10	33	5- 6	7- 4	7- 5
	1.5C22	43	4- 5	5- 10	5- 11	33	4- 9	6- 4	6- 5
	1.5C20	44	5- 2	6- 11	7- 0	34	5- 8	7- 6	7- 7
	1.5C18	44	6- 2	8- 1	8- 5	34	6- 9	8- 10	9- 2
4 1/2" (t=3")	1.5C24	49	4- 10	6- 5	6- 7	38	5- 3	7- 1	7- 2
	1.5C22	49	4- 2	5- 7	5- 8	38	4- 7	6- 1	6- 2
	1.5C20	50	4- 11	6- 8	6- 8	38	5- 5	7- 3	7- 4
	1.5C18	50	5- 10	7- 9	8- 0	39	6- 5	8- 6	8- 9
5" (t=3 1/2")	1.5C24	55	4- 8	6- 2	6- 4	42	5- 1	6- 10	6- 11
	1.5C22	55	4- 0	5- 5	5- 6	42	4- 5	5- 11	5- 11
	1.5C20	56	4- 9	6- 4	6- 5	43	5- 2	7- 0	7- 1
	1.5C18	56	5- 7	7- 5	7- 8	43	6- 2	8- 2	8- 5
5 1/2" (t=4")	1.5C24	61	4- 6	5- 11	6- 1	47	4- 11	6- 7	6- 8
	1.5C22	61	3- 11	5- 3	5- 3	47	4- 3	5- 8	5- 9
	1.5C20	62	4- 7	6- 2	6- 3	47	5- 0	6- 9	6- 10
	1.5C18	63	5- 5	7- 2	7- 5	48	6- 0	7- 11	8- 2
6" (t=4 1/2")	1.5C24	67	4- 4	5- 9	5- 11	51	4- 9	6- 4	6- 6
	1.5C22	68	3- 9	5- 1	5- 1	52	4- 2	5- 6	5- 7
	1.5C20	68	4- 5	5- 11	6- 0	52	4- 10	6- 6	6- 7
	1.5C18	69	5- 3	6- 11	7- 2	53	5- 9	7- 8	7- 11
6 1/2" (t=5")	1.5C24	73	4- 2	5- 7	5- 9	56	4- 7	6- 2	6- 3
	1.5C22	74	3- 8	4- 11	5- 0	56	4- 0	5- 5	5- 5
	1.5C20	74	4- 3	5- 9	5- 10	57	4- 8	6- 4	6- 5
	1.5C18	75	5- 1	6- 8	6- 11	57	5- 7	7- 5	7- 8

REINFORCED CONCRETE SLAB ALLOWABLE LOADS

Total Slab Depth	Reinforcement		Superimposed Uniform Load (psf) — 3 Span Condition, Clear Span (ft.-in.)										
	W.W.F.	As	4- 0	4- 6	5- 0	5- 6	6- 0	6- 6	7- 0	7- 6	8- 0	8- 6	9- 0
3 1/2" (t=2")	6X6-W2.1XW2.1	0.042*	108	86									
	6X6-W2.9XW2.9	0.058	147	116									
	4X4-W2.9XW2.9	0.087	214	169									
4" (t=2 1/2")	6X6-W2.1XW2.1	0.042*	136	108	87	72							
	6X6-W2.9XW2.9	0.058	185	147	119	98							
	4X4-W2.9XW2.9	0.087	272	215	174	144							
4 1/2" (t=3")	6X6-W2.1XW2.1	0.042*	164	129	160	132	111	95	82				
	6X6-W2.9XW2.9	0.058*	224	177	215	177	149	127	110				
	4X4-W2.9XW2.9	0.087	329	260	318	263	221	188	162				
5" (t=3 1/2")	6X6-W2.9XW2.9	0.058*	262	207	264	218	183	156	135	117			
	4X4-W2.9XW2.9	0.087	387	306	392	324	272	232	200	174			
	4X4-W4.0XW4.0	0.120	400	400	400	400	363	310	267	233			
5 1/2" (t=4")	6X6-W2.9XW2.9	0.058*	301	238	313	259	217	185	160				
	4X4-W2.9XW2.9	0.087	400	351	400	385	323	275	237				
	4X4-W4.0XW4.0	0.120	400	400	400	400	400	370	319				
6" (t=4 1/2")	6X6-W2.9XW2.9	0.058*	330	268	358	298	249	212	183				
	4X4-W2.9XW2.9	0.087*	400	397	400	400	370	315	272				
	4X4-W4.0XW4.0	0.120	400	400	400	400	400	400	366				
6 1/2" (t=5")	4X4-W2.9XW2.9	0.087*	400	400	400	400	400	348					
	4X4-W4.0XW4.0	0.120	400	400	400	400	400	400					
	4X4-W5.0XW5.0	0.150	400	400	400	400	400	400					
			1.5C24				1.5C18						

NOTES:
1. * As does not meet A.C.I. criterion for temperature and shrinkage.
2. Recommended conform types are based upon S.D.I. criteria and normal weight concrete.
3. Superimposed loads are based upon three span conditions and A.C.I. moment coefficients.
4. Load values for single span and double spans are to be reduced.
5. Superimposed load values in bold type require that mesh be draped. See page 19.
6. Vulcraft's painted or galvanized form deck can be considered as permanent support in most building applications. See page 19. If uncoated form deck is used, deduct the weight of the slab from the allowable superimposed uniform loads.

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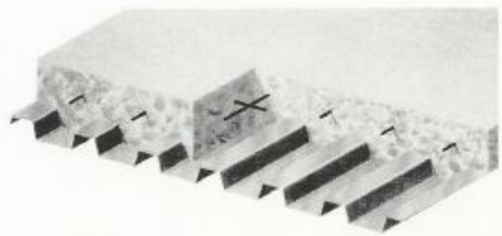
VULCRAFT

NON-COMPOSITE

SECTION PROPERTIES

Deck Type	Design Thick.	Weight PSF	Ip in^4/ft	In in^4/ft	Sp in^3/ft	Sn in^3/ft	Fy ksi
1.5C24	0.0239	1.44	0.136	0.108	0.132	0.120	60
1.5C22	0.0295	1.68	0.183	0.155	0.192	0.186	33
1.5C20	0.0358	2.04	0.222	0.201	0.247	0.234	33
1.5C18	0.0474	2.72	0.295	0.289	0.327	0.318	33



ALLOWABLE UNIFORM LOAD (PSF)

Deck Type	No. of Spans	Design Criteria	Clear Span (ft.-in.) 4-0	4-6	5-0	5-6	6-0	6-6	7-0	7-6	8-0	8-6	9-0	9-6	10-0
1.5C24	1	Fb = 36,000	198	156	127	105	88	75	65	56	50	44	39	35	32
		DEFL. = l/240	139	98	71	54	41	32	26	21	17	15	12	10	9
		DEFL. = l/180	186	130	95	71	55	43	35	28	23	19	16	14	12
		W1[1]	82	60	44	33	25	19	15	11	8	6	4		
	2	Fb = 36,000	180	142	115	95	80	68	59	51	45	40	36	32	29
		DEFL. = l/240	180	142	115	95	80	68	56	46	38	31	26	22	19
		DEFL. = l/180	180	142	115	95	80	68	59	51	45	40	35	30	26
		W1[1]	160	122	95	75	60	48	39	31	25	20	16	12	9
	3	Fb = 36,000	225	178	144	119	100	85	73	64	56	50	44	40	36
		DEFL. = l/240	225	166	121	91	70	55	44	36	29	25	21	18	15
		DEFL. = l/180	225	178	144	119	93	73	59	48	39	33	28	23	20
		W1[1]	172	132	103	81	64	51	40	32	26	21	17	13	10
1.5C22	1	Fb = 20,000	160	126	102	85	71	61	52	46	40	35	32	28	26
		DEFL. = l/240	160	126	96	72	56	44	35	28	23	20	16	14	12
		DEFL. = l/180	160	126	102	85	71	58	47	38	31	26	22	19	16
		W1[1]	57	40	28	20	14	10	6	4					
	2	Fb = 20,000	155	122	99	82	69	59	51	44	39	34	31	27	25
		DEFL. = l/240	155	122	99	82	69	59	51	44	39	34	31	27	25
		DEFL. = l/180	155	122	99	82	69	59	51	44	39	34	31	27	25
		W1[1]	129	94	70	53	40	30	23	17	12	9	6	4	
	3	Fb = 20,000	194	153	124	102	86	73	63	55	48	43	38	34	31
		DEFL. = l/240	194	153	124	102	86	73	61	50	41	34	29	24	21
		DEFL. = l/180	194	153	124	102	86	73	63	55	48	43	38	33	28
		W1[1]	133	97	72	55	41	31	24	18	13	10	7	4	
1.5C20	1	Fb = 20,000	206	163	132	109	91	78	67	59	51	46	41	36	33
		DEFL. = l/240	206	160	116	87	67	53	42	34	28	24	20	17	15
		DEFL. = l/180	206	163	132	109	90	71	57	46	38	32	27	23	19
		W1[1]	87	64	48	36	28	21	16	12	9	7	5	3	
	2	Fb = 20,000	195	154	125	103	87	74	64	55	49	43	39	35	31
		DEFL. = l/240	195	154	125	103	87	74	64	55	49	43	39	35	31
		DEFL. = l/180	195	154	125	103	87	74	64	55	49	43	39	35	31
		W1[1]	175	134	105	83	66	53	42	34	27	22	18	14	11
	3	Fb = 20,000	244	193	156	129	108	92	80	69	61	54	48	43	39
		DEFL. = l/240	244	193	156	129	108	92	76	62	51	43	36	31	26
		DEFL. = l/180	244	193	156	129	108	92	80	69	61	54	48	41	35
		W1[1]	188	145	111	87	68	55	44	35	29	23	19	15	12
1.5C18	1	Fb = 20,000	273	215	174	144	121	103	89	78	68	60	54	48	44
		DEFL. = l/240	273	212	155	116	90	70	56	46	38	31	27	23	19
		DEFL. = l/180	273	215	174	144	119	94	75	61	50	42	35	30	26
		W1[1]	132	99	76	60	47	38	31	25	20	17	14	11	9
	2	Fb = 20,000	265	209	170	140	118	100	87	75	66	59	52	47	42
		DEFL. = l/240	265	209	170	140	118	100	87	75	66	59	52	47	42
		DEFL. = l/180	265	209	170	140	118	100	87	75	66	59	52	47	42
		W1[1]	245	189	150	120	98	80	67	55	46	39	32	27	22
	3	Fb = 20,000	331	262	212	175	147	125	108	94	83	73	65	59	53
		DEFL. = l/240	331	262	212	175	147	125	105	86	71	59	50	42	36
		DEFL. = l/180	331	262	212	175	147	125	108	94	83	73	65	56	48
		W1[1]	263	204	161	130	106	87	72	61	51	43	36	30	25

[1] W1 is the maximum weight of concrete and deck (W1 in Figure 1 of the SDI Loading Diagrams).
Minimum exterior bearing length required is 1.5 inches. Minimum interior bearing length required is 3 inches.

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VULCRAFT

NON-COMPOSITE

2 C CONFORM

MAXIMUM CONSTRUCTION CLEAR SPANS (S.D.I. CRITERIA)

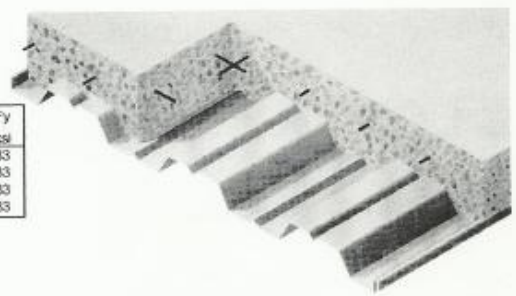
Total Slab Depth	Deck Type	Weight PSF	NW Concrete N=9 145 PCF			Weight PSF	LW Concrete N=14 110 PCF		
			1 Span	2 Span	3 Span		1 Span	2 Span	3 Span
4 1/2" (t=2 1/2")	2C22	44	5- 7	7- 4	7- 8	34	6- 2	8- 3	8- 4
	2C20	45	6- 7	8- 9	9- 0	34	7- 3	9- 7	9- 11
	2C18	45	8- 2	10- 4	10- 8	35	9- 0	11- 3	11- 7
	2C16	46	9- 3	11- 6	11- 11	36	10- 3	12- 6	12- 11
5" (t=3")	2C22	50	5- 4	6- 9	7- 1	39	5- 11	7- 11	8- 0
	2C20	51	6- 3	8- 5	8- 7	39	6- 11	9- 2	9- 6
	2C18	51	7- 9	9- 10	10- 2	40	8- 7	10- 9	11- 2
	2C16	52	8- 10	11- 0	11- 4	40	9- 9	12- 0	12- 5
5 1/2" (t=3 1/2")	2C22	56	5- 2	6- 2	6- 6	43	5- 8	7- 6	7- 8
	2C20	57	6- 0	8- 1	8- 3	43	6- 8	8- 10	9- 1
	2C18	57	7- 5	9- 6	9- 9	44	8- 3	10- 5	10- 9
	2C16	58	8- 5	10- 7	10- 11	45	9- 4	11- 7	12- 0
6" (t=4")	2C22	62	4- 10	5- 9	6- 1	48	5- 6	7- 0	7- 4
	2C20	63	5- 9	7- 9	7- 11	48	6- 5	8- 7	8- 9
	2C18	63	7- 1	9- 1	9- 5	49	7- 11	10- 1	10- 5
	2C16	64	8- 1	10- 2	10- 6	49	9- 0	11- 2	11- 7
6 1/2" (t=4 1/2")	2C22	68	4- 6	5- 4	5- 8	52	5- 3	6- 7	6- 11
	2C20	69	5- 7	7- 6	7- 8	53	6- 2	8- 3	8- 6
	2C18	69	6- 10	8- 10	9- 1	53	7- 7	9- 9	10- 1
	2C16	70	7- 9	9- 10	10- 2	54	8- 8	10- 10	11- 3
7" (t=5")	2C22	74	4- 3	5- 0	5- 3	57	5- 1	6- 2	6- 6
	2C20	75	5- 5	7- 2	7- 2	57	6- 0	8- 0	8- 3
	2C18	75	6- 7	8- 6	8- 10	58	7- 4	9- 5	9- 9
	2C16	76	7- 6	9- 6	9- 10	59	8- 5	10- 6	10- 11

REINFORCED CONCRETE SLAB ALLOWABLE LOADS

Total Slab Depth	Reinforcement		Superimposed Uniform Load (psf) — 3 Span Condition, Clear Span (ft.-in.)										
	W.W.F.	As	5- 0	5- 6	6- 0	6- 6	7- 0	7- 6	8- 0	8- 6	9- 0	9- 6	10- 0
4 1/2" (t=2 1/2")	6X6-W2.1XW2.1	0.042*	84	69									
	6X6-W2.9XW2.9	0.058	114	94									
	4X4-W2.9XW2.9	0.087	167	138									
5" (t=3")	6X6-W2.1XW2.1	0.042*	**153**	**127**	**107**	**91**	**78**						
	6X6-W2.9XW2.9	0.058*	**206**	**170**	**143**	**122**	**105**						
	4X4-W2.9XW2.9	0.087	**305**	**252**	**212**	**180**	**155**						
5 1/2" (t=3 1/2")	6X6-W2.9XW2.9	0.058*	**255**	**211**	**177**	**151**	**130**	**113**	**100**				
	4X4-W2.9XW2.9	0.087	**378**	**313**	**263**	**224**	**193**	**168**	**148**				
	4X4-W4.0XW4.0	0.120	**400**	**400**	**351**	**299**	**258**	**224**	**197**				
6" (t=4")	6X6-W2.9XW2.9	0.058*	**304**	**251**	**211**	**180**	**155**	**135**	**119**	**105**	**94**		
	4X4-W2.9XW2.9	0.087	**400**	**374**	**314**	**267**	**231**	**201**	**177**	**156**	**140**		
	4X4-W4.0XW4.0	0.120	**400**	**400**	**400**	**359**	**309**	**270**	**237**	**210**	**187**		
6 1/2" (t=4 1/2")	6X6-W2.9XW2.9	0.058*	**353**	**292**	**245**	**209**	**180**	**157**	**138**	**122**	**109**	**98**	**88**
	4X4-W2.9XW2.9	0.087*	**400**	**400**	**365**	**311**	**268**	**234**	**205**	**182**	**162**	**146**	**131**
	4X4-W4.0XW4.0	0.120	**400**	**400**	**400**	**400**	**361**	**315**	**277**	**245**	**219**	**196**	**177**
7" (t=5")	4X4-W2.9XW2.9	0.087*	**400**	**400**	**400**	**355**	**306**	**266**	**234**	**207**	**185**	**168**	**150**
	4X4-W4.0XW4.0	0.120	**400**	**400**	**400**	**400**	**400**	**360**	**316**	**280**	**250**	**224**	**202**
	4X4-W5.0XW5.0	0.150	**400**	**400**	**400**	**400**	**400**	**400**	**389**	**344**	**307**	**276**	**249**
			2C22	2C20				2C18			2C16		

NOTES:
1. * As does not meet A.C.I. criterion for temperature and shrinkage.
2. Recommended conform types are based upon S.D.I. criteria and normal weight concrete.
3. Superimposed loads are based upon three span conditions and A.C.I. moment coefficients.
4. Load values for single span and double spans are to be reduced.
5. Superimposed load values in bold type require that mesh be draped. See page 19.
6. Vulcraft's painted or galvanized form deck can be considered as permanent support in most building applications. See page 19. If uncoated form deck is used, deduct the weight of the slab from the allowable superimposed uniform loads.

VULCRAFT



NON-COMPOSITE

SECTION PROPERTIES

Deck Type	Design Thick.	Weight PSF	Ip in^4/ft	In in^4/ft	Sp in^3/ft	Sn in^3/ft	Fy ksi
2C22	0.0295	1.62	0.338	0.336	0.283	0.287	33
2C20	0.0358	1.97	0.423	0.420	0.367	0.373	33
2C18	0.0474	2.61	0.557	0.557	0.520	0.520	33
2C16	0.0598	3.29	0.704	0.704	0.653	0.653	33

ALLOWABLE UNIFORM LOAD (PSF)

Deck Type	No. of Spans	Design Criteria	Clear Span (ft.-in.)												
			5-0	5-6	6-0	6-6	7-0	7-6	8-0	8-6	9-0	9-6	10-0	10-6	11-0
2C22	1	Fb = 20,000	151	125	106	89	77	67	59	52	47	42	38	34	31
		DEFL. = l/240	151	125	103	81	65	53	43	36	30	26	22	19	17
		DEFL. = l/180	151	125	106	89	77	67	58	48	41	34	30	26	22
		W1[1]	60	47	37	29	23	18	14	11	9	7	5	4	3
	2	Fb = 20,000	153	127	106	91	78	68	60	53	47	42	38	35	32
		DEFL. = l/240	153	127	106	91	78	68	60	53	47	42	38	35	32
		DEFL. = l/180	153	127	106	91	78	68	60	53	47	42	38	35	32
		W1[1]	75	66	59	53	48	43	37	31	25	21	17	14	12
	3	Fb = 20,000	191	158	133	113	98	85	75	66	59	53	48	43	40
		DEFL. = l/240	191	158	133	113	98	85	75	66	57	49	42	36	31
		DEFL. = l/180	191	158	133	113	98	85	75	66	59	53	48	43	40
		W1[1]	80	71	63	57	51	46	39	32	26	22	18	15	12
2C20	1	Fb = 20,000	196	162	136	116	100	87	76	68	60	54	49	44	40
		DEFL. = l/240	196	162	128	101	81	66	54	45	38	32	28	24	21
		DEFL. = l/180	196	162	136	116	100	87	72	60	51	43	37	32	28
		W1[1]	89	71	57	46	38	31	26	22	18	15	13	11	9
	2	Fb = 20,000	199	164	138	118	101	88	78	69	61	55	50	45	41
		DEFL. = l/240	199	164	138	118	101	88	78	69	61	55	50	45	41
		DEFL. = l/180	199	164	138	118	101	88	78	69	61	55	50	45	41
		W1[1]	118	105	95	86	78	68	58	49	41	35	30	25	21
	3	Fb = 20,000	249	206	173	147	127	111	97	86	77	69	62	56	51
		DEFL. = l/240	249	206	173	147	127	111	97	85	72	61	52	45	39
		DEFL. = l/180	249	206	173	147	127	111	97	86	77	69	62	56	51
		W1[1]	116	104	93	85	77	71	62	53	45	39	33	28	24
2C18	1	Fb = 20,000	277	229	193	164	141	123	108	96	86	77	69	63	57
		DEFL. = l/240	277	219	169	133	106	87	71	59	50	43	37	32	27
		DEFL. = l/180	277	229	193	164	141	115	95	79	67	57	49	42	37
		W1[1]	145	116	96	79	66	56	47	40	35	30	26	23	20
	2	Fb = 20,000	277	229	193	164	141	123	108	96	86	77	69	63	57
		DEFL. = l/240	277	229	193	164	141	123	108	96	86	77	69	63	57
		DEFL. = l/180	277	229	193	164	141	123	108	96	86	77	69	63	57
		W1[1]	211	190	173	144	121	103	88	76	66	57	49	43	37
	3	Fb = 20,000	347	287	241	205	177	154	135	120	107	96	87	79	72
		DEFL. = l/240	347	287	241	205	177	154	135	112	95	80	69	60	52
		DEFL. = l/180	347	287	241	205	177	154	135	120	107	96	87	79	69
		W1[1]	229	206	186	155	131	112	96	83	71	62	54	47	41
2C16	1	Fb = 20,000	348	288	242	206	178	155	136	121	107	96	87	79	72
		DEFL. = l/240	348	277	214	168	135	109	90	75	63	54	46	40	35
		DEFL. = l/180	348	288	242	206	178	146	120	100	84	72	62	53	46
		W1[1]	192	156	128	107	90	77	66	57	49	43	38	34	30
	2	Fb = 20,000	348	288	242	206	178	155	136	121	107	96	87	79	72
		DEFL. = l/240	348	288	242	206	178	155	136	121	107	96	87	79	72
		DEFL. = l/180	348	288	242	206	178	155	136	121	107	96	87	79	72
		W1[1]	328	268	222	186	158	135	116	101	87	76	67	59	52
	3	Fb = 20,000	435	360	302	258	222	193	170	151	134	121	109	99	90
		DEFL. = l/240	435	360	302	258	222	193	170	142	119	102	87	75	65
		DEFL. = l/180	435	360	302	258	222	193	170	151	134	121	109	99	87
		W1[1]	352	288	238	200	170	145	125	109	95	83	73	64	57

[1] W1 is the maximum weight of concrete and deck (W1 in Figure 1 of the SDI Loading Diagrams).
Minimum exterior bearing length required is 2.0 inches. Minimum interior bearing length required is 4.0 inches.

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Appendix AK – W Shapes Selection

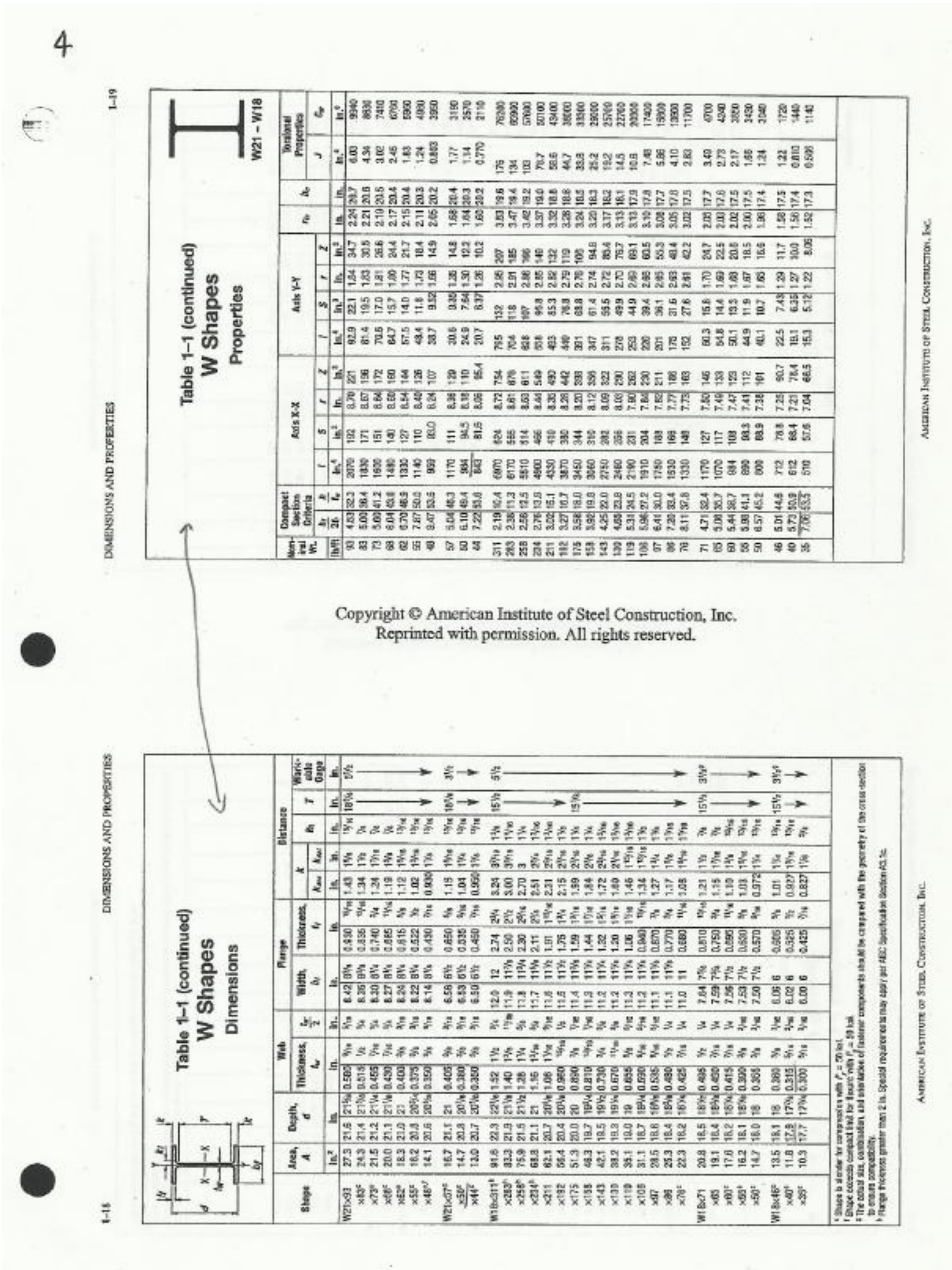

Table 1-1 (continued)
W Shapes
Dimensions

Shape	Area, A	Depth, d		Web Thickness, t_w		$\frac{t_w}{2}$	Flange Width, b_f		Flange Thickness, t_f		k_{des}	k_{det}	k_1	T	Workable Gage
	in.²	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W12×58	17.0	12.2	12 1/4	0.360	3/8	3/16	10.0	10	0.640	5/8	1.24	1 1/2	15/16	9 1/4	5 1/2
×53	15.6	12.1	12	0.345	3/8	3/16	10.0	10	0.575	9/16	1.18	1 3/8	15/16	9 1/4	5 1/2
W12×50	14.6	12.2	12 1/4	0.370	3/8	3/16	8.08	8 1/8	0.640	5/8	1.14	1 1/2	15/16	9 1/4	5 1/2
×45	13.1	12.1	12	0.335	5/16	3/16	8.05	8	0.575	9/16	1.08	1 3/8	15/16	↓	↓
×40	11.7	11.9	12	0.295	5/16	3/16	8.01	8	0.515	1/2	1.02	1 3/8	7/8	↓	↓
W12×35[c]	10.3	12.5	12 1/2	0.300	5/16	3/16	6.56	6 1/2	0.520	1/2	0.820	1 3/16	3/4	10 1/8	3 1/2
×30[c]	8.79	12.3	12 3/8	0.260	1/4	1/8	6.52	6 1/2	0.440	7/16	0.740	1 1/8	3/4	↓	↓
×26[c]	7.65	12.2	12 1/4	0.230	1/4	1/8	6.49	6 1/2	0.380	3/8	0.680	1 1/16	3/4	↓	↓
W12×22[c]	6.48	12.3	12 1/4	0.260	1/4	1/8	4.03	4	0.425	7/16	0.725	15/16	5/8	10 3/8	2 1/4[g]
×19[c]	5.57	12.2	12 1/8	0.235	1/4	1/8	4.01	4	0.350	3/8	0.650	7/8	9/16	↓	↓
×16[c]	4.71	12.0	12	0.220	1/4	1/8	3.99	4	0.265	1/4	0.565	13/16	9/16	↓	↓
×14[c,v]	4.16	11.9	11 7/8	0.200	3/16	1/8	3.97	4	0.225	1/4	0.525	3/4	9/16	↓	↓
W10×112	32.9	11.4	11 3/8	0.755	3/4	3/8	10.4	10 3/8	1.25	1 1/4	1.75	1 15/16	1	7 1/2	5 1/2
×100	29.4	11.1	11 1/8	0.680	11/16	3/8	10.3	10 3/8	1.12	1 1/8	1.62	1 13/16	1	↓	↓
×88	25.9	10.8	10 7/8	0.605	5/8	5/16	10.3	10 1/4	0.990	1	1.49	1 11/16	15/16	↓	↓
×77	22.6	10.6	10 5/8	0.530	1/2	1/4	10.2	10 1/4	0.870	7/8	1.37	1 9/16	7/8	↓	↓
×68	20.0	10.4	10 3/8	0.470	1/2	1/4	10.1	10 1/8	0.770	3/4	1.27	1 7/16	7/8	↓	↓
×60	17.6	10.2	10 1/4	0.420	7/16	1/4	10.1	10 1/8	0.680	11/16	1.18	1 3/8	13/16	↓	↓
×54	15.8	10.1	10 1/8	0.370	3/8	3/16	10.0	10	0.615	5/8	1.12	1 5/16	13/16	↓	↓
×49	14.4	10.0	10	0.340	5/16	3/16	10.0	10	0.560	9/16	1.06	1 1/4	13/16	↓	↓
W10×45	13.3	10.1	10 1/8	0.350	3/8	3/16	8.02	8	0.620	5/8	1.12	1 5/16	13/16	7 1/2	5 1/2
×39	11.5	9.92	9 7/8	0.315	5/16	3/16	7.99	8	0.530	1/2	1.03	1 3/16	13/16	↓	↓
×33	9.71	9.73	9 3/4	0.290	5/16	3/16	7.96	8	0.435	7/16	0.935	1 1/8	3/4	↓	↓
W10×30	8.84	10.5	10 1/2	0.300	5/16	3/16	5.81	5 3/4	0.510	1/2	0.810	1 1/8	11/16	8 1/8	2 3/4[g]
×26	7.61	10.3	10 3/8	0.260	1/4	1/8	5.77	5 3/4	0.440	7/16	0.740	1 1/16	11/16	↓	↓
×22[c]	6.49	10.2	10 1/8	0.240	1/4	1/8	5.75	5 3/4	0.360	3/8	0.660	15/16	5/8	↓	↓
W10×19	5.62	10.2	10 1/4	0.250	1/4	1/8	4.02	4	0.395	3/8	0.695	15/16	5/8	8 3/8	2 1/4[g]
×17[c]	4.99	10.1	10 1/8	0.240	1/4	1/8	4.01	4	0.330	5/16	0.630	7/8	9/16	↓	↓
×15[c]	4.41	10.0	10	0.230	1/4	1/8	4.00	4	0.270	1/4	0.570	13/16	9/16	↓	↓
×12[c,f]	3.54	9.87	9 7/8	0.190	3/16	1/8	3.96	4	0.210	3/16	0.510	3/4	9/16	↓	↓

[c] Shape is slender for compression with F_y = 50 ksi.
[f] Shape exceeds compact limit for flexure with F_y = 50 ksi.
[g] The actual size, combination, and orientation of fastener components should be compared with the geometry of the cross-section to ensure compatibility.
[v] Shape does not meet the h/t_w limit for shear in Specification Section G2.1a with F_y = 50 ksi.

Table 1-1 (continued)
W Shapes
Properties

W12 – W10

Nominal Wt.	$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	X-X: I	X-X: S	X-X: r	X-X: Z	Y-Y: I	Y-Y: S	Y-Y: r	Y-Y: Z	r_{ts}	h_o	J	C_w
lb/ft			in.⁴	in.³	in.	in.³	in.⁴	in.³	in.	in.³	in.	in.	in.⁴	in.⁶
58	7.82	27.0	475	78.0	5.28	86.4	107	21.4	2.51	32.5	2.82	11.6	2.10	3570
53	8.69	28.1	425	70.6	5.23	77.9	95.8	19.2	2.48	29.1	2.79	11.5	1.58	3160
50	6.31	26.8	391	64.2	5.18	71.9	56.3	13.9	1.96	21.3	2.25	11.6	1.71	1880
45	7.00	29.6	348	57.7	5.15	64.2	50.0	12.4	1.95	19.0	2.23	11.5	1.26	1650
40	7.77	33.6	307	51.5	5.13	57.0	44.1	11.0	1.94	16.8	2.21	11.4	0.906	1440
35	6.31	36.2	285	45.6	5.25	51.2	24.5	7.47	1.54	11.5	1.79	12.0	0.741	879
30	7.41	41.8	238	38.6	5.21	43.1	20.3	6.24	1.52	9.56	1.77	11.9	0.457	720
26	8.54	47.2	204	33.4	5.17	37.2	17.3	5.34	1.51	8.17	1.75	11.8	0.300	607
22	4.74	41.8	156	25.4	4.91	29.3	4.66	2.31	0.848	3.66	1.04	11.9	0.293	164
19	5.72	46.2	130	21.3	4.82	24.7	3.76	1.88	0.822	2.98	1.02	11.8	0.180	131
16	7.53	49.4	103	17.1	4.67	20.1	2.82	1.41	0.773	2.26	0.982	11.7	0.103	96.9
14	8.82	54.3	88.6	14.9	4.62	17.4	2.36	1.19	0.753	1.90	0.962	11.7	0.0704	80.4
112	4.17	10.4	716	126	4.66	147	236	45.3	2.68	69.2	3.07	10.1	15.1	6020
100	4.62	11.6	623	112	4.60	130	207	40.0	2.65	61.0	3.03	10.0	10.9	5150
88	5.18	13.0	534	98.5	4.54	113	179	34.8	2.63	53.1	2.99	9.85	7.53	4330
77	5.86	14.8	455	85.9	4.49	97.6	154	30.1	2.60	45.9	2.95	9.73	5.11	3630
68	6.58	16.7	394	75.7	4.44	85.3	134	26.4	2.59	40.1	2.91	9.63	3.56	3100
60	7.41	18.7	341	66.7	4.39	74.6	116	23.0	2.57	35.0	2.88	9.54	2.48	2640
54	8.15	21.2	303	60.0	4.37	66.6	103	20.6	2.56	31.3	2.86	9.48	1.82	2320
49	8.93	23.1	272	54.6	4.35	60.4	93.4	18.7	2.54	28.3	2.84	9.42	1.39	2070
45	6.47	22.5	248	49.1	4.32	54.9	53.4	13.3	2.01	20.3	2.27	9.48	1.51	1200
39	7.53	25.0	209	42.1	4.27	46.8	45.0	11.3	1.98	17.2	2.24	9.39	0.976	992
33	9.15	27.1	171	35.0	4.19	38.8	36.6	9.20	1.94	14.0	2.20	9.30	0.583	791
30	5.70	29.5	170	32.4	4.38	36.6	16.7	5.75	1.37	8.84	1.60	10.0	0.622	414
26	6.56	34.0	144	27.9	4.35	31.3	14.1	4.89	1.36	7.50	1.58	9.89	0.402	345
22	7.99	36.9	118	23.2	4.27	26.0	11.4	3.97	1.33	6.10	1.55	9.81	0.239	275
19	5.09	35.4	96.3	18.8	4.14	21.6	4.29	2.14	0.874	3.35	1.06	9.85	0.233	104
17	6.08	36.9	81.9	16.2	4.05	18.7	3.56	1.78	0.845	2.80	1.04	9.78	0.156	85.1
15	7.41	38.5	68.9	13.8	3.95	16.0	2.89	1.45	0.810	2.30	1.01	9.72	0.104	68.3
12	9.43	46.6	53.8	10.9	3.90	12.6	2.18	1.10	0.785	1.74	0.983	9.66	0.0547	50.9

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Table 3-2 (continued) W Shapes Selection by Z_x

$F_y = 50$ ksi

Z_x

for M_u — for V_u

Shape	Z_x in.^{3}	M_{px}/Ω_b kip-ft ASD	$\phi_b M_{px}$ kip-ft LRFD	M_{rx}/Ω_b kip-ft ASD	$\phi_b M_{rx}$ kip-ft LRFD	BF kips ASD	BF kips LRFD	L_p ft	L_r ft	I_x in.^{4}	V_{nx}/Ω_v kips ASD	$\phi_v V_{nx}$ kips LRFD
W21×55	126	[illegible]	473	[illegible]	289	[illegible]	16.3	6.11	17.4	1140	[illegible]	234
W14×74	126	[illegible]	473	[illegible]	284	[illegible]	8.08	8.76	31.0	795	[illegible]	191
W18×60	123	[illegible]	461	[illegible]	284	[illegible]	14.5	5.93	18.2	984	[illegible]	227
W12×79	119	[illegible]	446	[illegible]	281	[illegible]	5.67	10.8	39.9	662	[illegible]	175
W14×68	115	[illegible]	431	[illegible]	270	[illegible]	7.81	8.69	29.3	722	[illegible]	175
W10×88	113	[illegible]	424	[illegible]	259	[illegible]	3.95	9.29	51.1	534	[illegible]	197
W18×55	112	[illegible]	420	[illegible]	258	[illegible]	13.9	5.90	17.5	890	[illegible]	212
W21×50	110	[illegible]	413	[illegible]	248	[illegible]	18.3	4.59	13.6	984	[illegible]	237
W12×72	108	[illegible]	405	[illegible]	256	[illegible]	5.59	10.7	37.4	597	[illegible]	158
W21×48[f]	107	[illegible]	398	[illegible]	244	[illegible]	14.7	6.09	16.6	959	[illegible]	217
W16×57	105	[illegible]	394	[illegible]	242	[illegible]	12.0	5.65	18.3	758	[illegible]	212
W14×61	102	[illegible]	383	[illegible]	242	[illegible]	7.46	8.65	27.5	640	[illegible]	156
W18×50	101	[illegible]	379	[illegible]	233	[illegible]	13.1	5.83	17.0	800	[illegible]	192
W10×77	97.6	[illegible]	366	[illegible]	225	[illegible]	3.90	9.18	45.2	455	[illegible]	169
W12×65[f]	96.8	[illegible]	356	[illegible]	231	[illegible]	5.41	11.9	35.1	533	[illegible]	142
W21×44	95.4	[illegible]	358	[illegible]	214	[illegible]	16.8	4.45	13.0	843	[illegible]	217
W16×50	92.0	[illegible]	345	[illegible]	213	[illegible]	11.4	5.62	17.2	659	[illegible]	185
W18×46	90.7	[illegible]	340	[illegible]	207	[illegible]	14.6	4.56	13.7	712	[illegible]	195
W14×53	87.1	[illegible]	327	[illegible]	204	[illegible]	7.93	6.78	22.2	541	[illegible]	155
W12×58	86.4	[illegible]	324	[illegible]	205	[illegible]	5.66	8.87	29.9	475	[illegible]	132
W10×68	85.3	[illegible]	320	[illegible]	199	[illegible]	3.86	9.15	40.6	394	[illegible]	147
W16×45	82.3	[illegible]	309	[illegible]	191	[illegible]	10.8	5.55	16.5	586	[illegible]	167
W18×40	78.4	[illegible]	294	[illegible]	180	[illegible]	13.3	4.49	13.1	612	[illegible]	169
W14×48	78.4	[illegible]	294	[illegible]	184	[illegible]	7.66	8.75	21.1	484	[illegible]	141
W12×53	77.9	[illegible]	292	[illegible]	185	[illegible]	5.48	8.76	28.2	425	[illegible]	125
W10×60	74.6	[illegible]	280	[illegible]	175	[illegible]	3.80	9.08	36.6	341	[illegible]	129
W16×40	73.0	[illegible]	274	[illegible]	170	[illegible]	10.1	5.55	15.9	518	[illegible]	146
W12×50	71.9	[illegible]	270	[illegible]	169	[illegible]	5.97	6.92	23.9	391	[illegible]	135
W8×67	70.1	[illegible]	263	[illegible]	159	[illegible]	2.60	7.49	47.7	272	[illegible]	154
W14×43	69.6	[illegible]	261	[illegible]	164	[illegible]	7.24	6.68	20.0	428	[illegible]	125
W10×54	66.6	[illegible]	250	[illegible]	158	[illegible]	3.74	9.04	33.7	303	[illegible]	112

ASD	LRFD
$\Omega_b = 1.67$ $\Omega_v = 1.50$	$\phi_b = 0.90$ $\phi_v = 1.00$

[f] Shape exceeds compact limit for flexure with $F_y = 50$ ksi.

Table 3-2 (continued) W Shapes Selection by Z_x

Z_x

$F_y = 50$ ksi

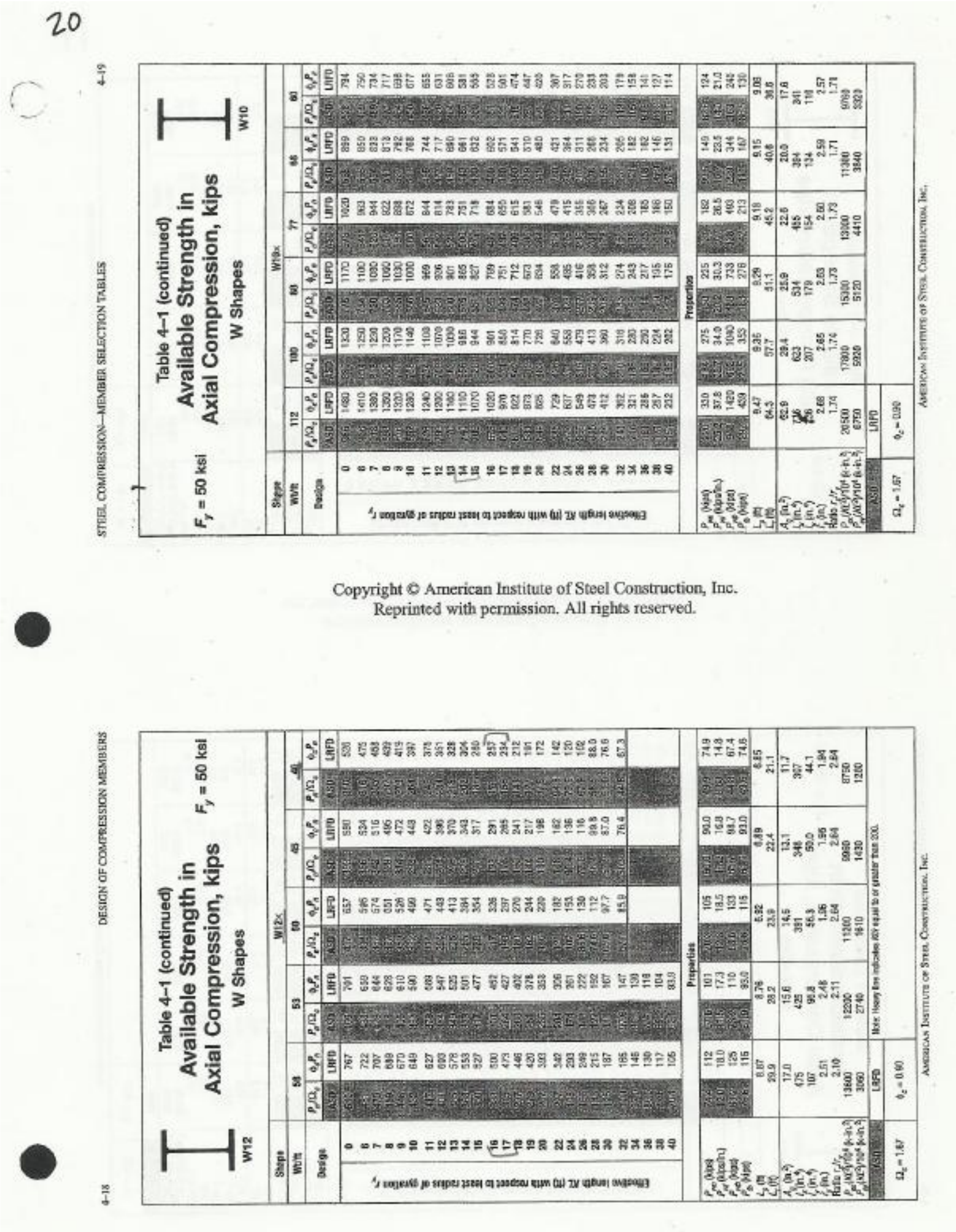
Shape	Z_x in.^{3}	M_{px}/Ω_b kip-ft ASD	$\phi_b M_{px}$ kip-ft LRFD	M_{rx}/Ω_b kip-ft ASD	$\phi_b M_{rx}$ kip-ft LRFD	BF kips ASD	BF kips LRFD	L_p ft	L_r ft	I_x in.^{4}	V_{nx}/Ω_v kips ASD	$\phi_v V_{nx}$ kips LRFD
W18×35	66.5	[illegible]	249	101	151	8.07	12.1	4.31	12.4	510	[illegible]	159
W12×45	64.2	[illegible]	241	[illegible]	151	[illegible]	5.75	6.89	22.4	348	[illegible]	121
W16×36	64.0	[illegible]	240	[illegible]	148	[illegible]	9.31	5.37	15.2	448	[illegible]	140
W14×38	61.5	[illegible]	231	[illegible]	143	[illegible]	8.10	5.47	16.2	385	[illegible]	131
W10×49	60.4	[illegible]	227	[illegible]	143	[illegible]	3.67	8.97	31.6	272	[illegible]	102
W8×58	59.8	[illegible]	224	[illegible]	137	[illegible]	2.56	7.42	41.7	228	[illegible]	134
W12×40	57.0	[illegible]	214	[illegible]	135	[illegible]	5.50	6.85	21.1	307	[illegible]	106
W10×45	54.9	[illegible]	206	[illegible]	129	[illegible]	3.89	7.10	26.9	248	[illegible]	106
W14×34	54.6	[illegible]	205	[illegible]	128	[illegible]	7.59	5.40	15.6	340	[illegible]	120
W16×31	54.0	[illegible]	203	[illegible]	124	[illegible]	10.2	4.13	11.9	375	[illegible]	131
W12×35	51.2	[illegible]	192	[illegible]	120	[illegible]	6.43	5.44	16.7	285	[illegible]	113
W8×48	49.0	[illegible]	184	[illegible]	113	[illegible]	2.53	7.35	35.2	184	[illegible]	102
W14×30	47.3	[illegible]	177	[illegible]	110	[illegible]	6.99	5.26	14.9	291	[illegible]	112
W10×39	46.8	[illegible]	176	[illegible]	111	[illegible]	3.77	6.99	24.2	209	[illegible]	93.7
W16×26[v]	44.2	[illegible]	166	[illegible]	101	[illegible]	8.56	3.96	11.2	301	[illegible]	106
W12×30	43.1	[illegible]	162	[illegible]	101	[illegible]	5.89	5.37	15.6	238	[illegible]	96.3
W14×26	40.2	[illegible]	151	[illegible]	92.7	[illegible]	7.99	3.81	11.1	245	[illegible]	106
W8×40	39.8	[illegible]	149	[illegible]	93.2	[illegible]	2.47	7.21	29.9	146	[illegible]	89.1
W10×33	38.8	[illegible]	146	[illegible]	91.9	[illegible]	3.59	6.85	21.8	171	[illegible]	84.7
W12×26	37.2	[illegible]	140	[illegible]	87.7	[illegible]	5.42	5.33	14.9	204	[illegible]	84.3
W10×30	36.6	[illegible]	137	[illegible]	85.0	[illegible]	4.62	4.84	16.1	170	[illegible]	94.2
W8×35	34.7	[illegible]	130	[illegible]	81.9	[illegible]	2.43	7.17	27.0	127	[illegible]	75.5
W14×22	33.2	[illegible]	125	[illegible]	78.1	[illegible]	7.14	3.67	10.4	199	[illegible]	94.5
W10×26	31.3	[illegible]	117	[illegible]	73.2	[illegible]	4.36	4.80	14.9	144	[illegible]	80.6
W8×31[f]	30.4	[illegible]	114	[illegible]	72.2	[illegible]	2.37	7.18	24.8	110	[illegible]	68.4
W12×22	29.3	[illegible]	110	[illegible]	66.7	[illegible]	6.89	3.00	9.17	156	[illegible]	96.0
W8×28	27.2	[illegible]	102	[illegible]	63.8	[illegible]	2.50	6.72	21.0	98.0	[illegible]	68.9
W10×22	26.0	[illegible]	97.5	[illegible]	60.9	[illegible]	4.82	4.70	13.8	118	[illegible]	73.2
W12×19	24.7	[illegible]	92.6	[illegible]	55.9	[illegible]	6.43	2.90	8.62	130	[illegible]	85.7
W8×24	23.1	[illegible]	86.6	[illegible]	54.9	[illegible]	2.30	5.69	18.0	82.7	[illegible]	58.3
W10×19	21.6	[illegible]	81.0	[illegible]	49.3	[illegible]	4.77	3.09	9.72	96.3	[illegible]	76.8
W8×21	20.4	[illegible]	76.5	[illegible]	47.8	[illegible]	2.79	4.45	14.8	75.3	[illegible]	62.1

ASD	LRFD
$\Omega_b = 1.67$ $\Omega_v = 1.50$	$\phi_b = 0.90$ $\phi_v = 1.00$

[f] Shape exceeds compact limit for flexure with $F_y = 50$ ksi.
[v] Shape does not meet the h/t_w limit for shear in Specification Section G2.1a with $F_y = 50$ ksi, $\Omega_v = 1.67$, $\phi_v = 0.90$.

II

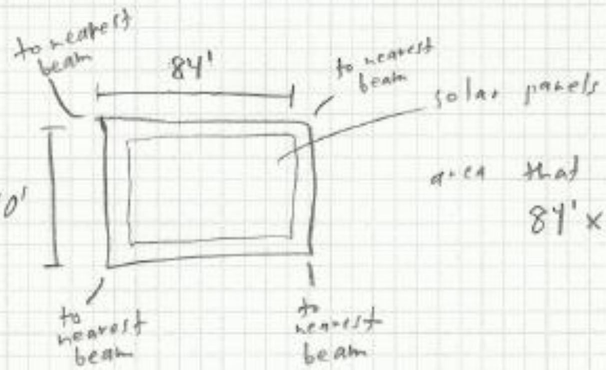
Appendix AL – Column Selection



Appendix AM – Structural Upgrades Cost Calculations

	old	new
concrete:	3.25" lightweight concrete →	5" lightweight concrete
		so 5 − 3.25 = 1.75" more concrete
steel:	3" deep 18 gage	3" deep 16 gage

concrete



area that needs bigger deck:
84' × 70' = 5880 sf

cubic feet = 5880 sf × 1.75 inches × [1 ft / 12 in] = 857.5 cf

cost 1 cubic yard of lightweight concrete = \$205 (RS Means) × 1.289 (location factor) = \$264.245 per cubic yd

857.5 cf × (0.0370 cubic yards / 1 cf) × \$264.245 = **\$8392.23** cost of more concrete

RS Means

\$5.72 − \$4.48 = \$1.24 sf × 1.289 = \$1.59836 per sf

(\$5.72: 3" deep 16 gage per sf; \$4.48: 3" deep 18" gage per sf; 1.289: location factor)

\$1.59836 sf
× 5880 sf
\$9398.36 cost of new steel in deck

16 girders from → W21×50 to W24×55 (weight plf)
(each 35' long)

Steel costs is \$508 net ton
1 net ton = 2000 lb

55 − 50 = 5 plf × 16 × 35' = 2800 lb

2800 lb × (1 net ton / 2000 lb) × \$508 per net ton = **\$711.20** cost of bigger girders