Final Report

Father O'Connell Hall Renovation

The Catholic University of America
Washington, D.C

Kevin Andreone | Mechanical | Laura Miller | 4/16/2014

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Executive Summary

Father O’Connell Hall is a four story office administrative building located on the campus of Catholic University in Washington, DC. The current mechanical system uses natural gas that feeds into two 500 MBH condensing boilers to heat the building in the winter months and a 97.7 ton air cooled scroll chiller for cooling in the winter months. In addition, all electrical power is generated off-site and distributed to the building. This report will focus on redesigning the separate heating and power system into a combined heat and power system. Also, absorption cooling will be added to reduce the air cooled chiller load in the summer months. Furthermore, an electrical breadth will analyze how on-site electricity production will affect the current power distribution and an acoustical analysis will be done on the current indoor air handling units located adjacent to office spaces.

A 30 KW microturbine is added to the basement of Father O’Connell Hall to produce 30 KW of power every day from the hours of 8am to 6pm. This arrangement was analyzed to be most cost effective solution, saving $7,300 dollars a year with a payback period of 14 years. With the addition of the microturbine and the useful exhaust heat, the two boilers were able to be replaced with one 600 MBH condensing boiler. Absorption cooling in the summer was proven to be unsuccessful because of low COP and low useful waste thermal exhaust. They were not able to reduce the electrical load as hoped. Father O’Connell Hall is not the most ideal building for a CHP system, but emissions were cut significantly. From an energy and environmental standpoint the CHP system was successful, but as an economic standpoint it is not recommended.

With the addition of on-site power generation, it is important to consider connecting the microturbine to the current electrical distribution system. A parallel switchgear needs to replace the current switchgear to appropriately sync the grid power and the microturbine power to be used in the building. This also requires appropriately sizing all wire and breaker sizes to ensure safety.

An acoustical analysis involves the study of indoor air handling units meeting appropriate sound emission codes. It was determined that AHU-4 located in the basement meets all standards, but the OAHU-1 on the fourth floor does not meet standards and the background noise is too loud in the adjacent executive office. The addition of duct lining or duct silencer can reduce the sound levels enough to comply with code.

Acknowledgements

SmithGroupJJR

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AE Class of 2014

Friends and Family

Thank you to everyone who helped me make it a special and memorable five years in the Penn State Architectural Engineering Program.

Renovations to Father O'Connell Hall

Catholic University of America

Washington, DC

General Building Data
- Location: Washington, DC
- Size: 54,000 GSF
- Height: 4 Stories above grade, 1 below
- Construction Dates: July 2013-may 2014
- Cost: 15 million
- Delivery Method: Design-Bid-Build

Design & Construction Team
- Owner: Catholic University of America
- Architect: SmithGroupJJR
- MEP/FP Engineer: SmithGroupJJR
- Structural Engineer: McMullan & Associates, Inc.
- Civil Engineer: ADTEK
- Project Management: Mark G Anderson Consultants, Inc.

Architecture
- 3 conjoined structures: 4 story main building, 3 story east wing, and 2 story west wing
-Administrative/Enrollment, admissions, financial aid, and banquet hall
- Granite stone façade with Indiana Limestone accents resembles a historic collegiate gothic style

Structural
- Concrete structure with concrete columns in west and main wings
- Drop panels are used to support concrete slab
- Existing steel beams and columns are used in the east wing.
- Existing roof construction is concrete, slab on concrete joists.

Electrical
- 750kVA medium voltage transformer
- Existing main switchboard 208/120V 3 –phase 3000A
- New 150kW emergency generator

Mechanical
- VAV and Fan powered boxes provide recirculation
- Fan Coil Units for perimeter heating and cooling
- 1 97.7 ton electric air-cooled chiller
- 2 Chilled water pumps with VFD's
- 2 500 MBH condensing pulse combustion boilers

Kevin Andreone | Mechanical

http://www.engr.psu.edu/ae/thesis/portfolios/2014/kpa5028/index.html

Building Overview

Father O'Connell Hall is a 54,000 SF, 15 million dollar exterior and interior renovation on the campus of The Catholic University of America in Washington, DC. Father O'Connell Hall has three conjoined structures: the four story main building constructed in 1914, the three story east wing constructed in 1958, and the west wing constructed in 1962. Refer to figure 1 below. The Hall is the third oldest building on campus; the renovation will preserve the historical Catholic culture which The Catholic University of America reflects in our nation's capital. Father O'Connell Hall will be used for administrative/Enrollment services, admissions, financial aid, and a banquet hall which will be used to hold special events. Undergraduate Admissions is important because it generates revenue for the school. The design sells the school while still reflection the rich historical tradition of The Catholic University of America and of the surrounding buildings.

The façade is primarly granite stone with Indiana limstone. The façade is broken up with a series of two story arched windows along the main building of the banquet hall, while the east and west wings use large rectangular on story windows. This closley represents a historic collegiate gothic style.

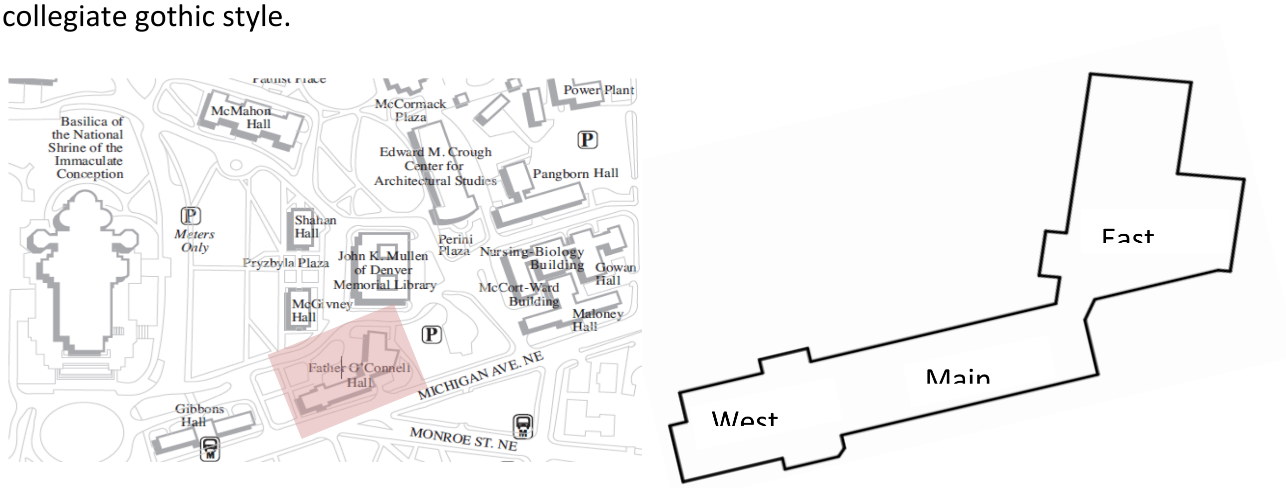

Figure 1: Father O'Connell Hall located on The Catholic University Campus.

Electrical

The building is being served by a 750kVA medium voltage transformer. An existing 208/120, 3-phase 3000A main switchboard serves the entire building. The total connection load is 1956A. A 150KW emergency power generator is used for emergency power lighting panels. The renovation includes the reuse and relocation of some existing panels as well as additional panels, which mostly serve the new mechanical equipment.

Lighting

The lighting system runs on 120 volts. The system utilizes many LED lights as well as electronic dimmable ballasts. A range of lighting fixtures are used in Father O’Connell Hall including ceiling recessed, cove, wall, and pendant fixtures. In addition, occupancy sensors are located in all offices and conference rooms.

Structural

Father O’Connell Hall is a concrete structure with concrete columns in the main building and the west wing. The East wing, the newest addition of the building, utilizes steel beams and steel columns to support the building. Drop panels are used to support the concrete slab. The existing roof construction is concrete with slab on concrete joists.

Construction

The Construction for renovation of Father O’Connell Hall is to be started in June 2013 and a completion date of May 21, 2014. The project will use a traditional design-bid-build delivery method. The estimated MEP cost is 8 million.

Mechanical System Overview

Father O'Connell Hall is ventilated using seven air handling units, with one being 100% outdoor air (OAHU-1). Figure 2 below shows the zoning for each air handling units throughout the building. All New AHU's will be equipped with economizer cycle to maximize ventilation and reduce energy. The 100% outdoor air unit will also have an air-to-air plate exchanger as well as a wraparound heat pipe heat recovery exchanger to pre-condition supply air temperatures and further reduce energy consumption. Recirculation of this air is provided by fan powered boxes, VAV's, and air transfer ducts located in the plenum above the ceiling on the basement and first floors.

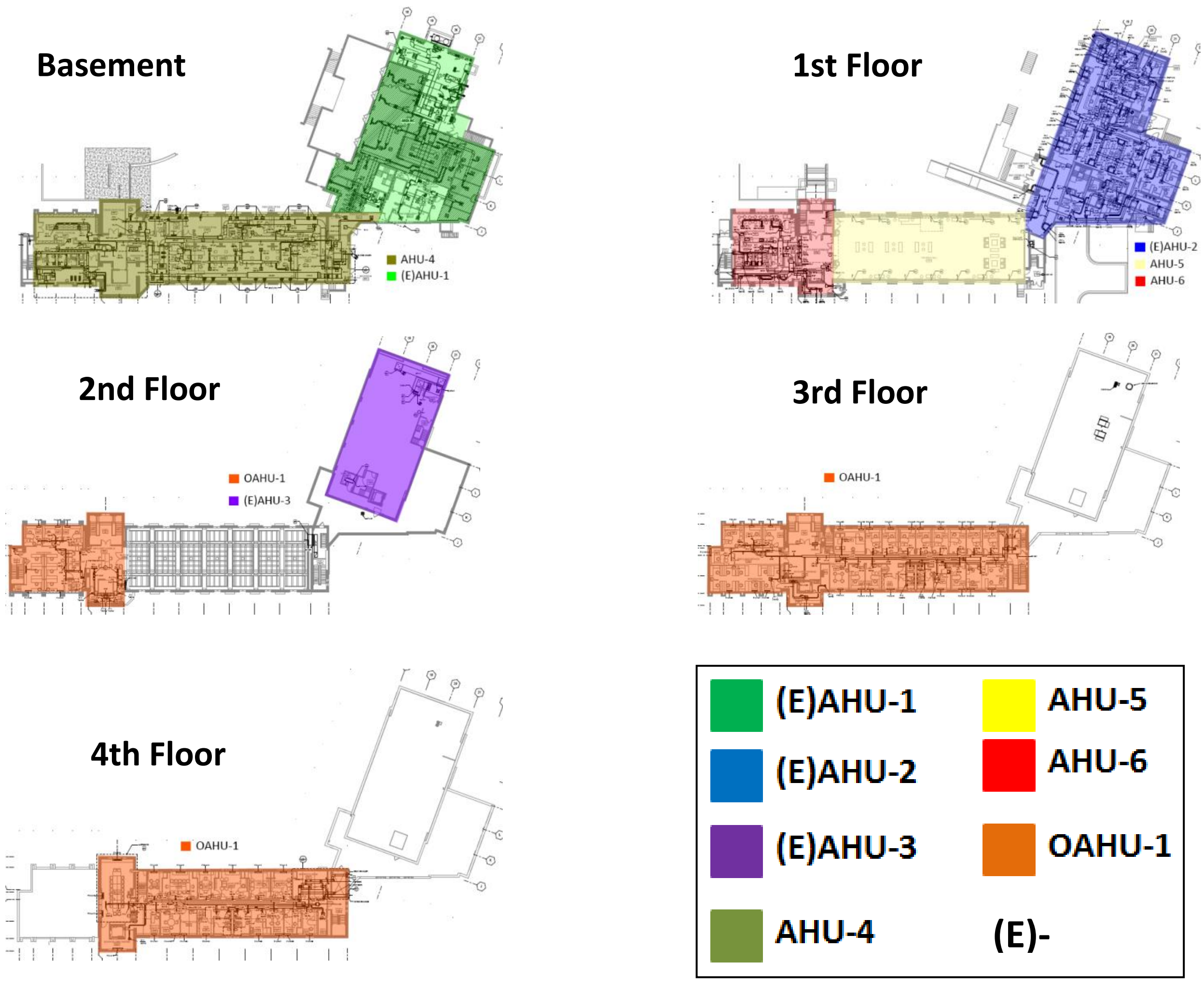

Figure 2: Air Handling Unit Zoning

Chilled Water System

Chilled water is provided from one 97.7 ton electric air-cooled chiller located on grade on the south side of east wing. Chilled water is provided directly to all air handling units (AHU's) and all fan coil units (FCU's) located on floors 2 to 4. Chilled water flow delivered to all AHU's and FCU's is controlled by a proportional integral controller (PIC) control valve regulated by two chilled water pumps with VFD's. Additional cooling for two telecom rooms is provided by two ductless split system units.

Heating Hot Water System

Washington Gas Company provides a low pressure (2 psi), 2 inch gas pipe to two 500 MBH condensing pulse combustion boilers located on the basement level of the west wing. These boilers provide all hot water to the AHU's, FCU's, and reheat coils for the VAV's and Fan powered boxes. The hot water flow is controlled the same way as the chilled water system using three heat water pumps with VFD's. There are two additional existing boilers located in the east wing of the basement floor. These boilers provide heating to the small portion of the building that is not in the scope of this renovation. Information for this portion of the building is not available at this time.

Mechanical System Design Requirements

Father O’Connell Hall previously served as the history department building as well as student housing. The renovation will relocate both of these and will house the new Catholic University of America’s financial aid, admissions, and administration offices. The building will also have a 200 person events/banquet hall. Father O’Connell Hall is the third oldest building on campus dating back to 1916. Strict historic preservation codes must be taken into account during the renovation. There are no current plans for future expansion.

Due to the requirements stated above the new mechanical system must take into account the new occupation of the building as well as obey all historical preservation codes. The design objectives clearly state that individually controlled spaces are desired to maximize occupant comfort. This may cause some challenges due to very tight existing structural conditions. In addition, the building has very poor insulation which creates extremely large heating and cooling loads in perimeter spaces. All systems will be designed in accordance to IBC 2006, as amended by the DC construction codes supplement of 2008 and ASHRAE Standards. Additional mechanical considerations include noise control, simple controls, and easy maintenance checks.

Design Conditions

Father O’Connell Hall is located in Washington, D.C which is in weather region 5A found in ASHRAE. ASHRAE Standard design conditions for Washington, D.C can be seen in Table 1 below.

Outdoor Design Temperature		
	Winter (°F)	Summer (°F)
Outdoor Design Conditions	14 db/11 wb	93 db/76 wb

Table 1: Outdoor Design Temperature

To provide a comfortable indoor environment the mechanical engineers require the following interior design conditions. The temperatures and relative humidity can be seen in Table 2 and Table 3 below.

Indoor Design Temperature		
	Winter (°F)	Summer (°F)
Occupied	72	76
Unoccupied	55	85

Table 2: Indoor Design Temperature

Humidity		
	Winter (%RG)	Summer (%RH)
	25 ± (5)	50 ± 5

Table 3: Relative Humidity

Ventilation

Ventilation rates were calculated using the procedure from ASHRAE Standard 62.1-2010 Section 6. Air handling units 2,4,5,6 and 100% outside AHU (OAHU-1) were analyzed to estimate minimum outside air requirements for all spaces. Existing air handling units 1 and 3 were not able to be analyzed due to lack of information in the project documentation. AHU 1 and 3 only provide ventilation for a small portion of the building which was not in the scope of this renovation. Table 4 below is a summary of all five air handlers that were analyzed. Design CFM and Minimum OA CFM were taken from the project documentation and compared to ASHRAE 62.1 Min. OA CFM calculated values. Detailed spreadsheets used for these calculations are available in Appendix A.

Minimum Ventilation Rates				
Unit	Design CFM	Minimum OA CFM	ASHRAE 62.1 Min. OA CFM	Compliant (Y/N)
OAHU-1	1800	1800	1400	Y
(E)AHU-2	7790	1861	1171	Y
AHU-4	4100	1480	613	Y
AHU-5	8000	1480	1479	Y
AHU-6	3500	500	381	Y

Table 4: Minimum Ventilation Rates

Heating and Cooling Loads

Father O'Connell Hall Renovation building load and energy modal was done using Trane Trace 700. This is an accepted program by many building industry professionals for load and energy consumption calculations. Trane was utilized to calculate ventilation loads, heating and cooling loads, and annual energy and operating costs at Father O'Connell Hall. Block loading was done since time was a sensitive issue. Restrooms and stairwells were neglected since these would not contribute to any cooling loads. Also existing zones that were not renovated were also neglected for these calculations. These block zones can be seen in the Figures 3-7 on the following page. Specific parameters for Father O'Connell Hall were taken into account to calculate accurate loads. Some of the parameters include lighting, occupancy schedules, construction, and building orientation. Tables 5 and 6 below show the calculated data compared to the designed data. As you can see reasonably accurate loads were calculated compared with design documents.

Unit	Design (CFM)	Calculated (CFM)	Error (%)
AHU-2	7790	7446	4.4
AHU-4	4100	3537	13.7
AHU-5	8000	9090	-13.6
AHU-6	3500	3302	5.7
OAHU-1	1800	1697	5.7

Table 5: Ventilation Error

Design vs Calculated Energy Capacities			
Cooling		Heating	
Design (Tons)	97.7	Design (MBh)	1000
Calculated (Tons)	105.1	Calculated (MBh)	1122
Error (%)	7.6	Error (%)	12.2

Table 6: Design vs. Calculated Energy Capacities

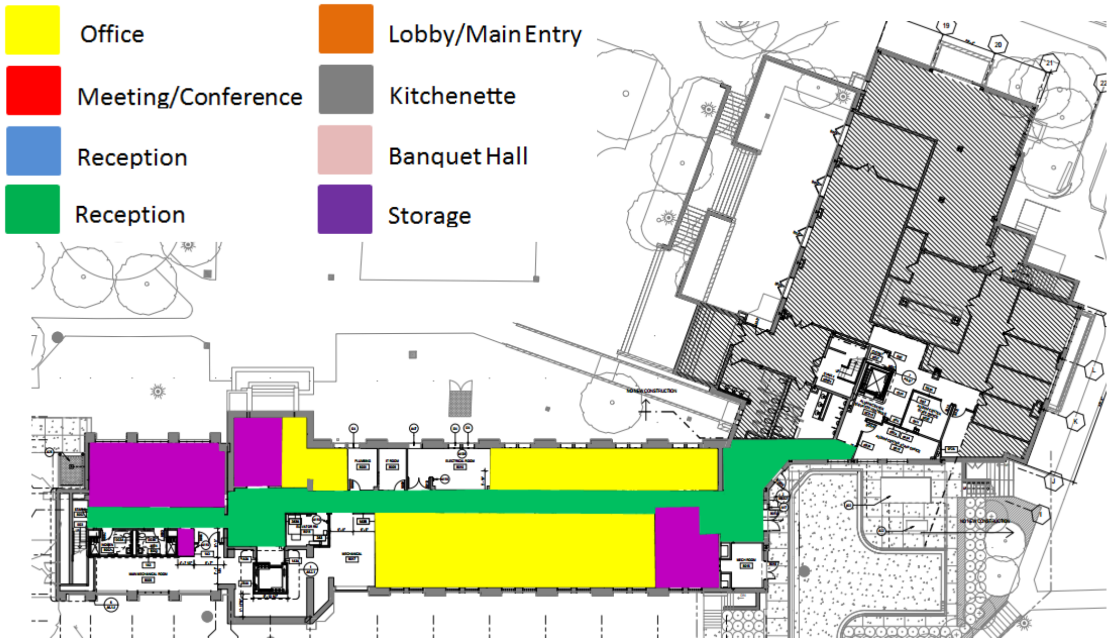

Figure 3: Basement Level Block Load

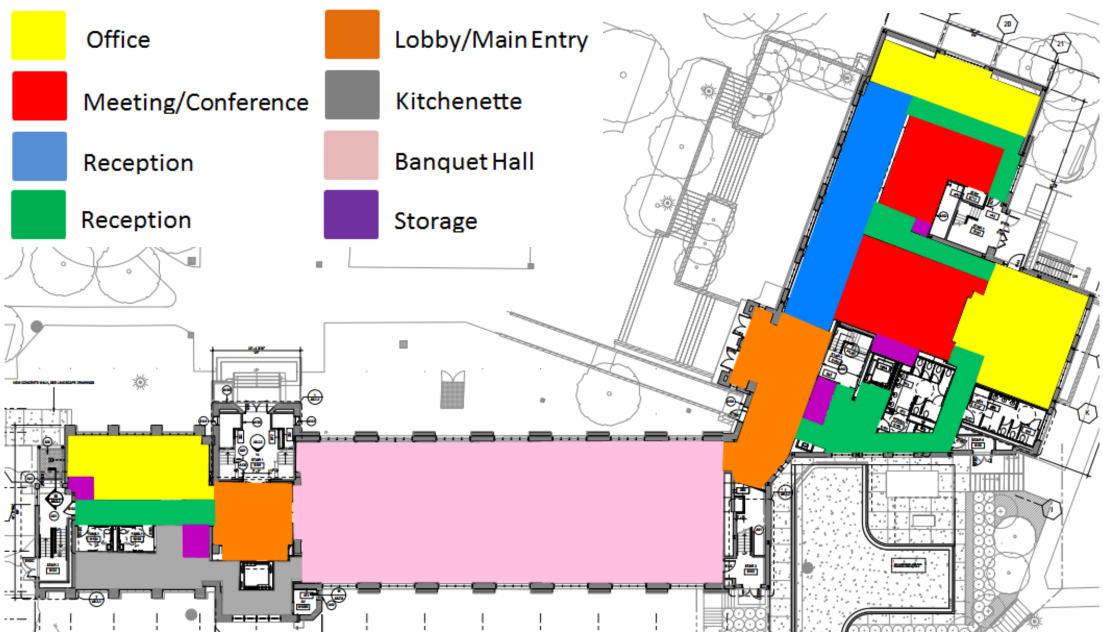

Figure 4: First Floor Block Loads

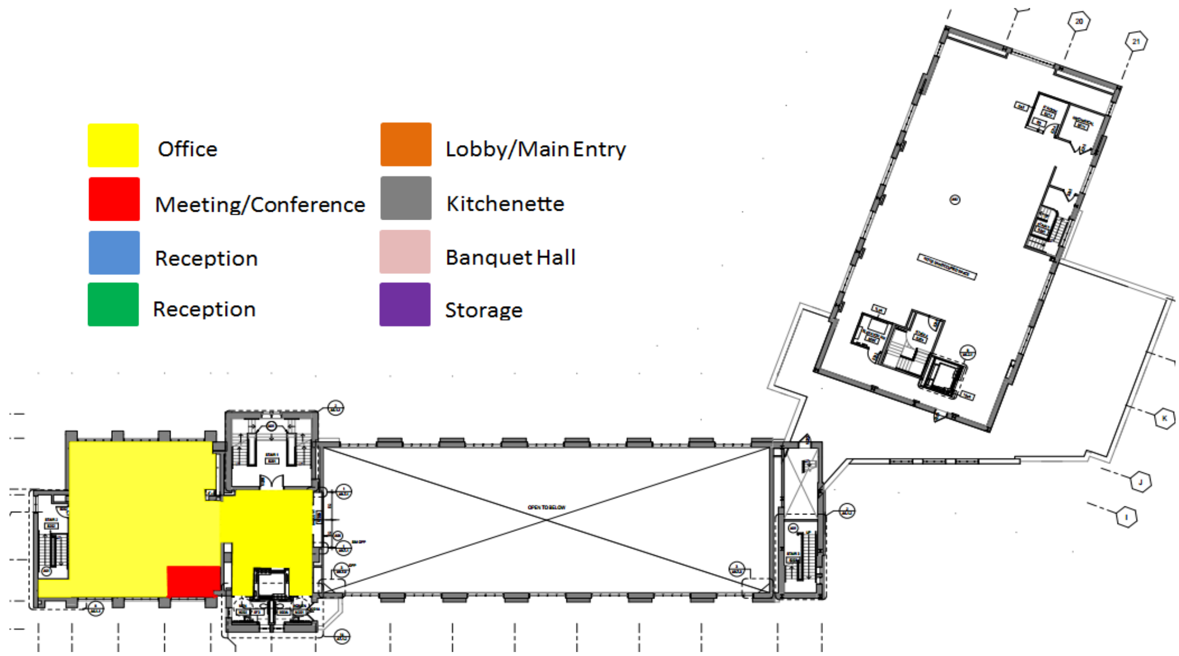

Figure 5: Second Floor Block Loads

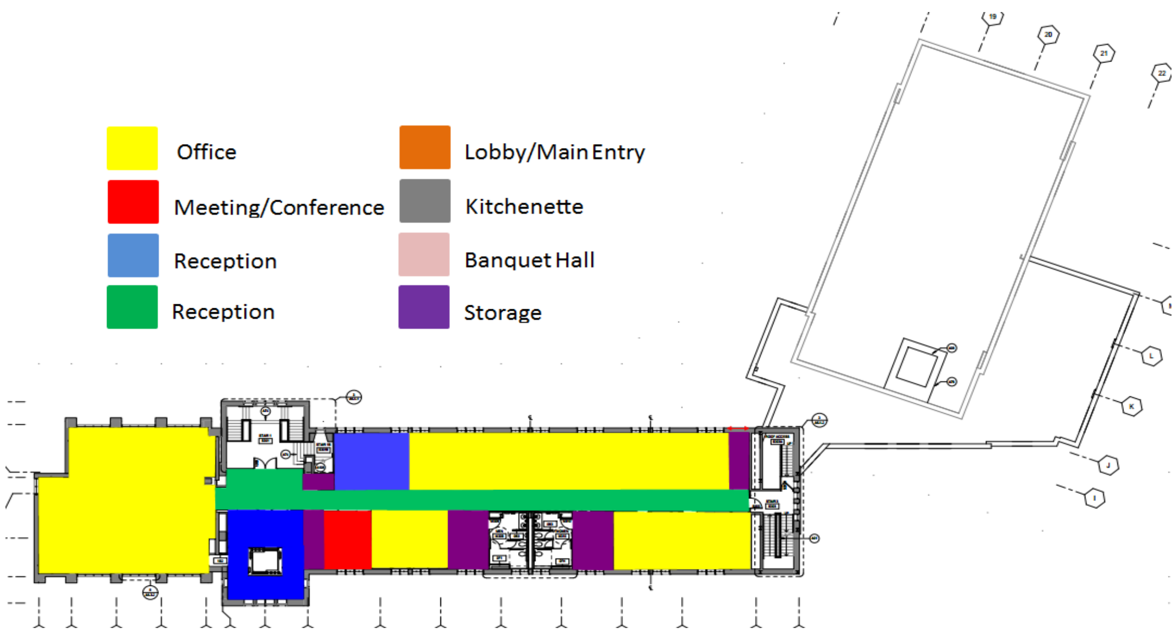

Figure 6: Third Floor Block Loads

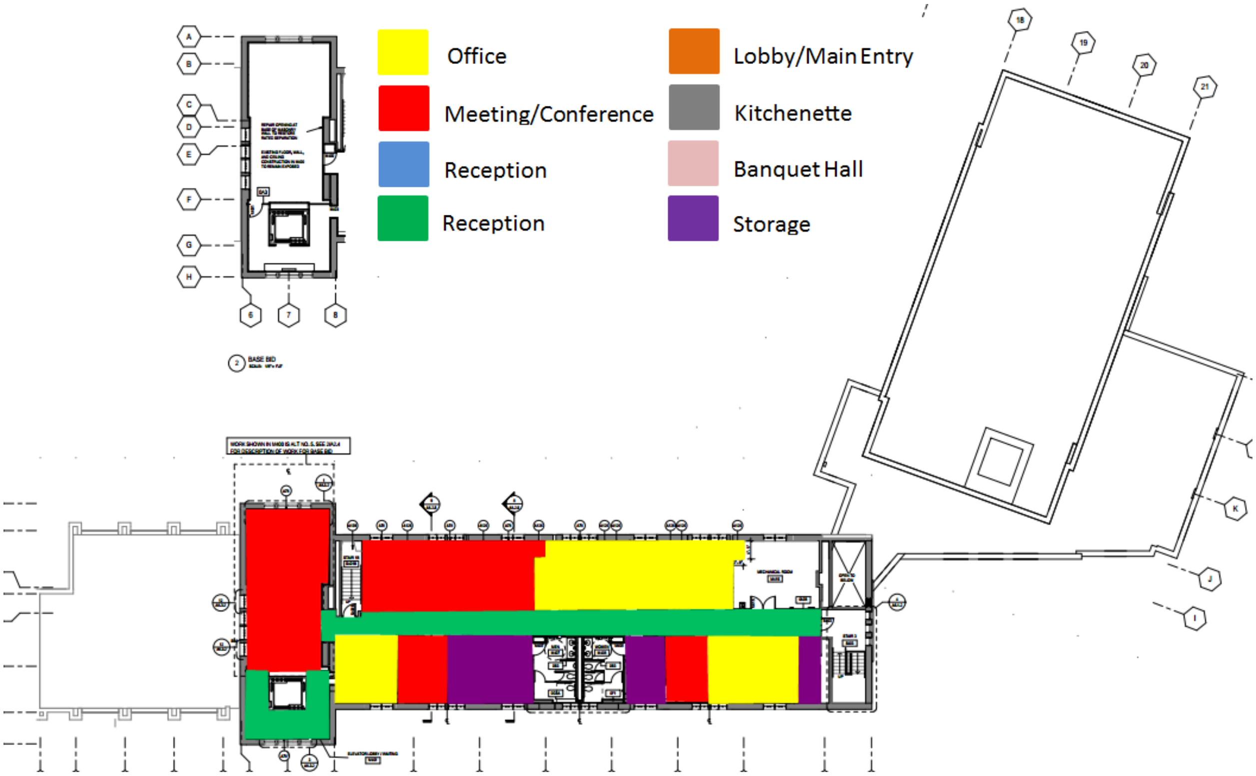

Figure 7: Fourth Floor Block Loads

Annual Energy Consumption and Cost

Trace was also used to calculate Father O'Connell's energy usage and cost. The Annual energy consumption and cost can be seen below in Table 7. No measured data is available for comparison.

Annual Energy Consumption and Cost				
Electricity (KWh)	Electricity Cost Per Year	Natural Gas (Therms)	Natural Gas Cost Per Year	Total Cost Per Year
270,655	$40,402.65	2,010	$3,096.00	$43,499

Table 7: Annual Energy Consumption and Cost

Mechanical Equipment Summary

Father O'Connell Hall is ventilated using seven air handling units, with one being 100% outdoor air. Figure 8 on the following page shows the zoning for each air handling units throughout the building. All New AHU's will be equipped with economizer cycle to maximize ventilation and reduce energy. The 100% outdoor air unit will also have an air-to-air heat plate exchanger as well as a wraparound pipe heat recovery exchanger to pre-condition supply air temperatures and further reduce energy consumption. Recirculation of this air is provided by fan powered boxes, VAV's, and air transfer ducts located in the plenum above the ceiling on the basement and first floors.

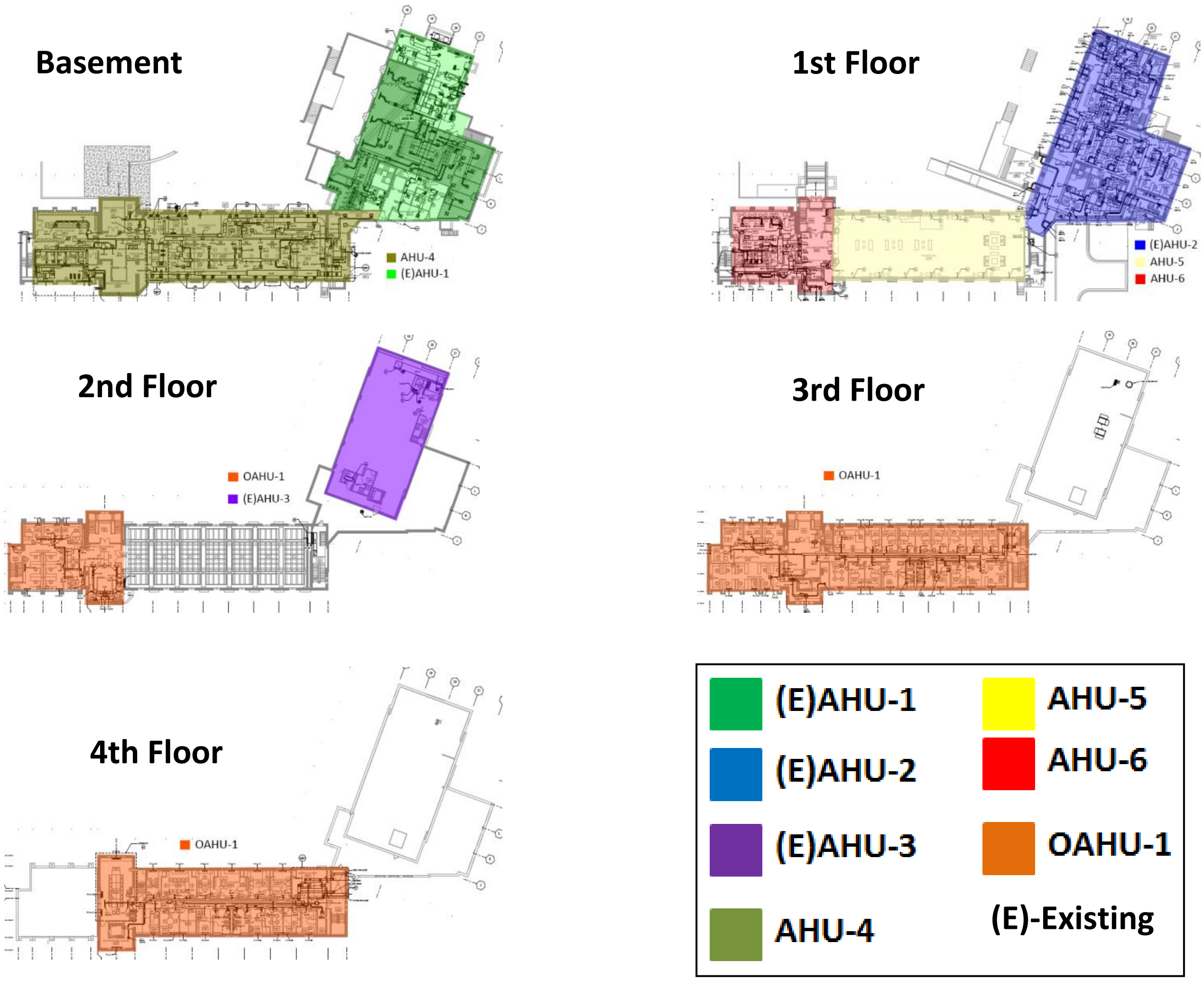

Figure 8: Air Handling Unit Zoning

Tables 8 to 12 below breakdown the major mechanical equipment used. In addition to the equipment listed
below, 62 fan coil units, 12 fan powered boxes, and 11 variable air volume boxes are used.

Air Handling Unit Schedule						
Tag	Supply Airflow (CFM)	Outside Airflow (CFM)	Cooling Coil LAT DB (°F)	Heating Coil LAT DB (°F)	Total Capacity (MBH)	VFD
AHU-4	4100	745	54	85	150	Y
AHU-5	8000	1480	54	85	274	Y
AHU-6	3500	500	54	85	113	Y
OAHU-1	1800	1800	55	70	88.5	Y

Table 8: Air Handling Unit Schedule

Chiller Schedule (Electric Air-Cooled)					
Tag	Tons	Electrical Volts	Evaporator		Condenser
			GPM	LWT (°F)	Ambient Temp (°F)
CH-1	97.7	208	195.3	42	95

Table 9: Chiller Schedule

Boiler Schedule (Hot Water)						
Tag	Type	Input (MBH)	Flowrate (GPM)	EWT (°F)	LWT (°F)	Electrical Volts
B-1	Condensing-Pulse Combustion	500	45	140	160	120
B-2	Condensing-Pulse Combustion	500	45	140	160	120

Table 10: Boiler Schedule

Pump Schedule							
Tag	Flowrate (GPM)	Discharge Head (FT WG)	Minimum Efficiency	Motor Data			VFD
				HP	LWT (°F)	Electrical Volts	
CHWP-1	180	85	72	7.5	1750	208	Yes
CHWP-2	180	85	72	7.5	1750	208	Yes
HHWP-1	45	50	57	1.5	1750	120	Yes
HHWP-2	45	50	57	1.5	1750	120	Yes
HHWP-3	45	50	57	1.5	1750	120	Yes

Table 11: Pump Schedule

Fan Schedule						
Tag	Design (CFM)	Type	External SP (In wg)	HP	Electrical Volts	VFD
EF-1-01	300	Centrifugal	0.25	0.167	120	Yes
EF-1-02	300	Centrifugal	0.25	0.167	120	Yes
EF-1-03	300	Centrifugal	0.25	0.167	120	Yes
EF-2-01	820	Centrifugal	0.3	0.25	120	Yes
EF-B-01	100	Centrifugal	0.25	0.167	120	Yes
EF-B-02	520	Centrifugal	0.4	0.25	120	Yes

Table 12: Fan Schedule

Mechanical First Costs

The mechanical system at Father O'Connell Hall has a first cost estimate of about 1.6 million dollars or $44.67 per square foot. Table 13 below shows all service first cost estimates. Figure 9 above breaks up the mechanical costs for detail estimates. Major miscellaneous costs in Graph 1 include sheet metal, piping, and insulation.

Service Costs	Cost
Mechanical	1,593,323
Demo	12,850
Central Plant	253,708
Distribution	949,165
Controls and BAS	256,875
Testing and Balancing	20,625
Miscellaneous	100,100
Electrical	1,091,650
Plumbing	447,595
Fireprotection	262,770
Elevators	348,015
Total	**3,743,353**

Table 13: Service Cost

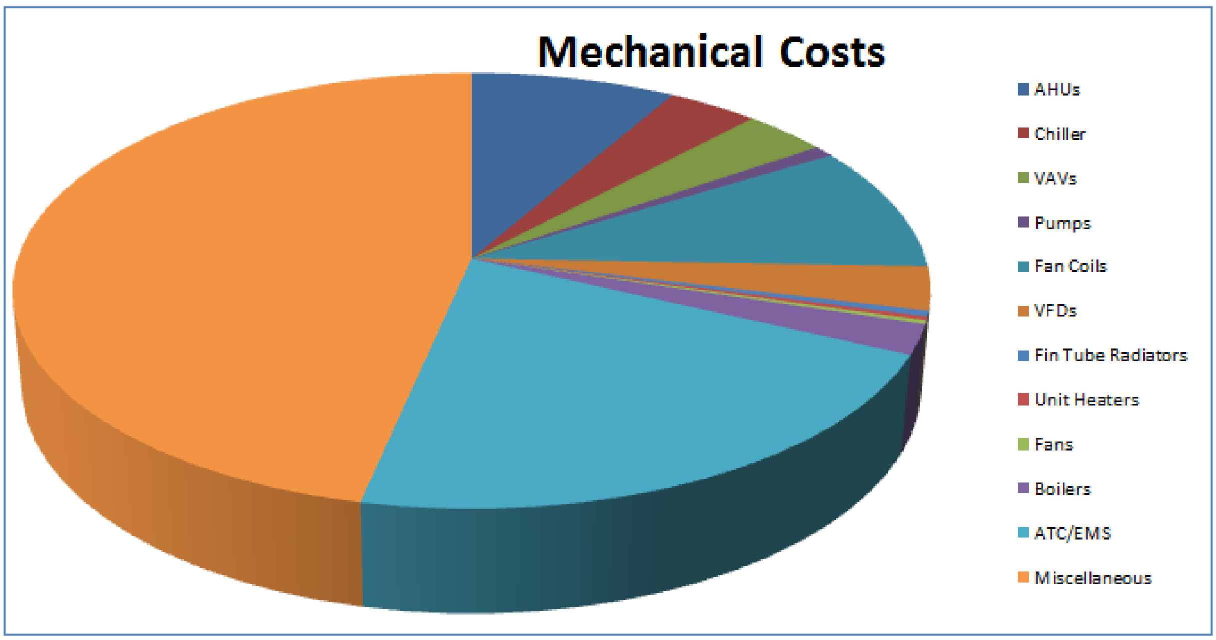

Figure 9: Mechanical Costs

Mechanical Operation and Schematics

Air-Side Operations

Air Handling Units 4, 5, and 6

Air handling units 4, 5, and 6 are controlled identically since they serve similar spaces in Father O'Connell Hall. These units serve floors one and two, while AHU-5 strictly serves the banquet hall. The air handling unit is initialized when the automatic outdoor damper is open. The supply fan is equipped with a VFD that is controlled by pressure sensors. The return air is controlled by an exhaust fan, also equipped with a VFD. A mixing box is placed in the plenum above the air handling unit and dampers control how much return air mixes with outdoor air. Most of the spaces are office spaces so the recirculation of air does not violate any of ASHRAE standards. The air handling units contain an economizer cycle and utilize free cooling when the outdoor weather conditions permit. Air handling unit schematics can be seen in figure 10.

Outdoor Air Handling Unit OAHU-1

Floors two, three, and four are ventilated from the 100% outdoor air handling unit (OAHU) located on the fourth floor. OAHU can be very beneficial and significant energy savers since it uses much less fan energy during peak and part loads. The OAHU only delivers the minimum amount of ventilation to each space. The supply fan and return fan are both equipped with VFDs. Both the fans speed is controlled by the BMS. In addition, and Air-To-Plate heat exchanger is used between the exhaust air and the supply outdoor air. This is used to preheat the outdoor air before the coils during the heating season. Furthermore, a wraparound heat pipe recovery exchanger is also used. These heat exchangers are important to preheat the outside air and used for humidity control during the cooling season. An economizer cycle is also used. This is dependent on the outdoor air wet bulb temperature. An optimal start is utilized to provide a comfortable environment when employees arrive in the morning. A sound silencer is used to isolate sound from the supply fan because it is adjacent to the mechanical room on the fourth floor is office space. OAHU-1 schematic can be seen in figure 11.

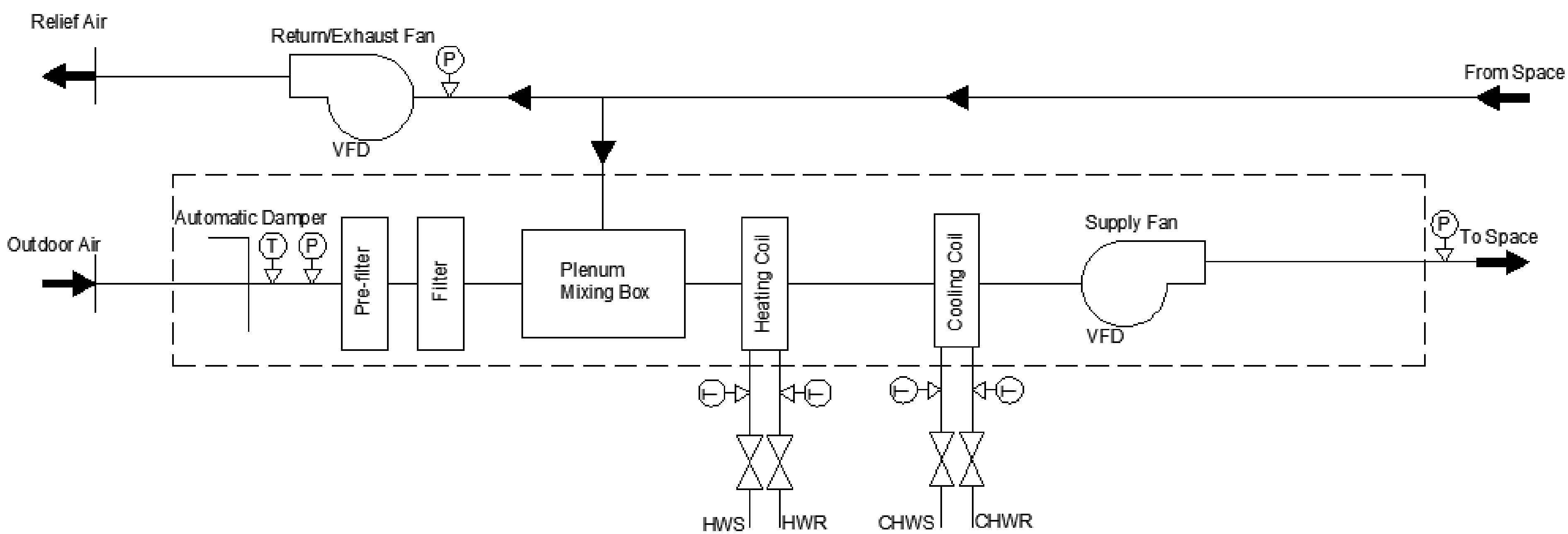

Figure 10: Typical Air Handling Unit Schematic

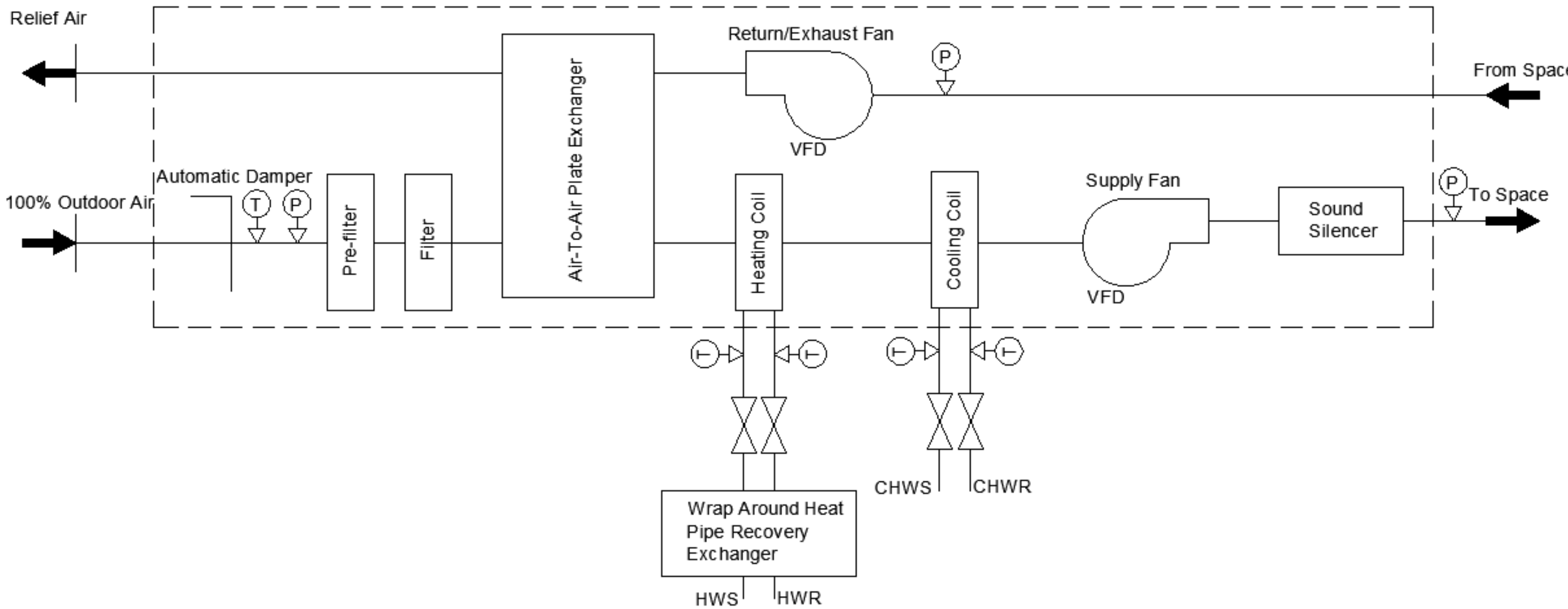

Figure 11: Outdoor Air Handling Unit Schematic

Water-Side Operations

Hot Water System

The hot water system consists of two lead/lag condensing boilers. Once the building management system (BMS) enables the heating hot water system controlled by the time and season schedules, the ModSync controller starts the lead boiler at the same time that it starts the lead primary hearing hot water pump. When the ModSync controller senses that the single boiler cannot meet heating loads a signal is sent to the BMS indicating the need for the lad primary hot water pump. Once the lag heating hot water pump is started the lag boiler is started. An additional heating hot water pump with a bypass valve is in the loop intended for backup. If a hot water pump shall fail, an alarm will set and the backup pump will automatically start. The boilers have been sized for an entering water temperature of 140 $^{\circ}$F and leaving water temperature of 160 $^{\circ}$F.

All three heating hot water pumps are equipped with Variable frequency Drive's (VFD's). The BMS monitors the differential pressure between the hot water supply and the hot water return piping in the building. If the differential pressure drops below an initial set point pressure of 15psi, the pump speed will increase. If the differential pressure exceeds the initial set point the pump speed will decrease. The initial set point is set at 15psi, but the actual set point will be set in the field. If both pumps are operating at the same time, they will be operating at the same speed. In addition, the pumps speed will be controlled to meet the minimum flow of 45 GPM to the boilers. Refer below to Figure 12 for a detailed heating hot water schematic.

Chilled Water System

The chilled water system consists of a single air cooled chiller, two primary chilled water pumps, and a bypass valve for building cooling. The two pumps are controlled using staging with a lead/lag system. Chilled water is distributed throughout the building to all air handling units and fan coil units. When the cooling load cannot be met with one pump, the BMS sends a signal to start the second pump. Like the heating hot water pumps, both chilled water pumps are equipped with VFD's and controlled the same way. Water is supplied from the chiller at a constant 42 $^{\circ}$F.

The speed of the pumps are controlled by a differential pressure sensor between the chilled water supply and chilled water return piping. If the differential pressure drops below the initial set point of 20 psi, the pump speed will increase. If the differential pressure exceeds the set point the pump speed will decrease. The differential pressure is initially set at 20psi, but the actual pressure will be determined in the field. Refer below to Figure 13 for a detailed heating hot water schematic.

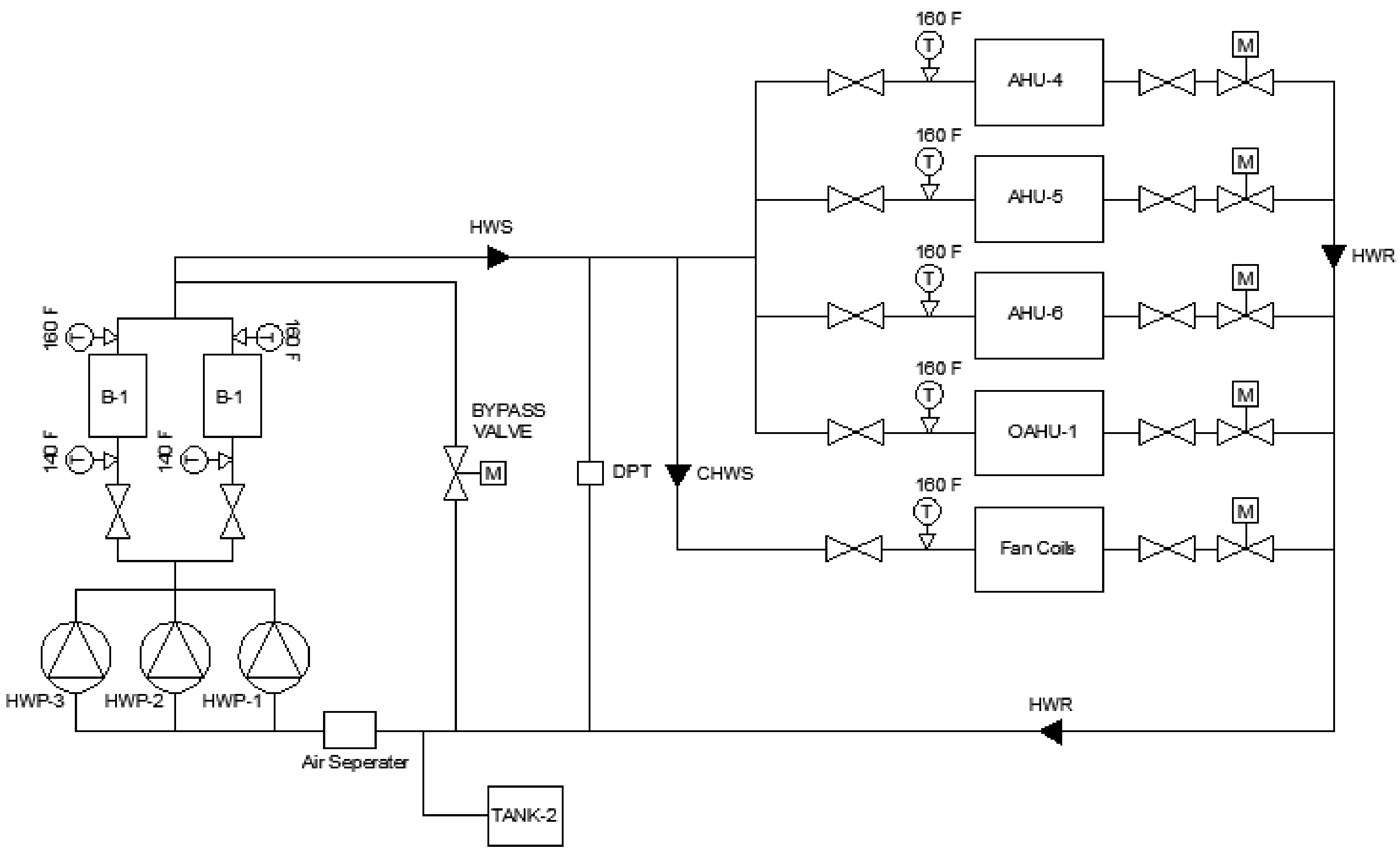

Figure 12: Heating Hot Water Schematic

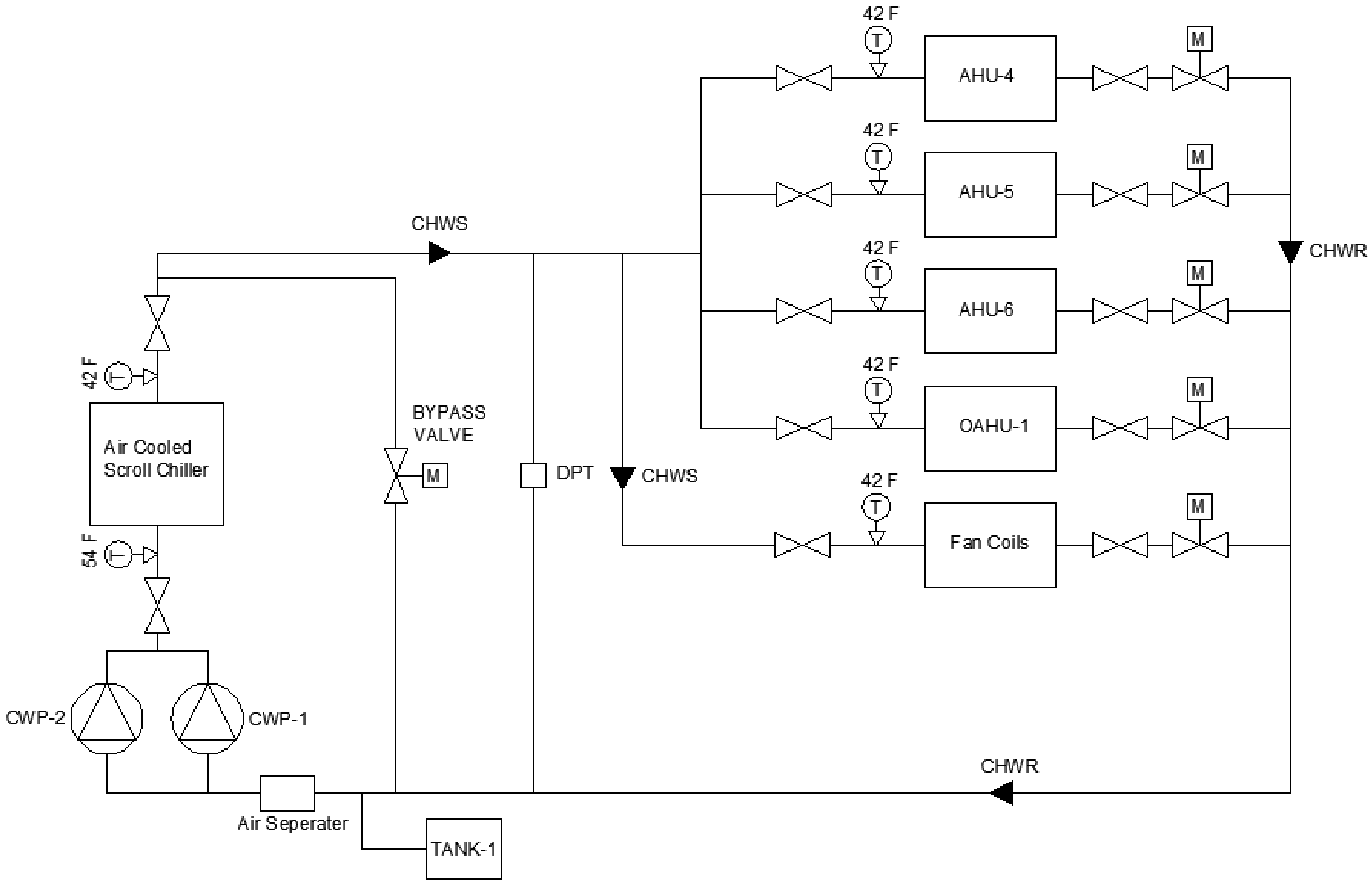

Figure 13: Chilled Water Schematic

Usable Space

Mechanical rooms and shafts take up valuable usable space in buildings. This space could be used to gain profit through tenants, however, mechanical equipment is extremely important for the building to function properly. Father O'Connell does a pretty good job limiting mechanical space throughout the building. Father O'Connell utilizes a dedicated outdoor air handling unit. This is important because it can significantly reduce duct sizes. Not only would that increase usable space from smaller shafts, but also could increase ceiling heights. Table 14 below shows the breakdown of usable space on each floor, however, this usable space does not include elevator rooms, electrical rooms, or piping shafts so the usable space is actually much lower. Although, compared with only mechanical systems it was found 94 % of the floor area is usable space.

Mechanical Space Requirements				
Level	**Floor Area**	**Mechanical Area**	**Usable Area**	**% Usable**
Basement	16,000	2,815	13,185	82
First	16,000	136	15,864	99
Second	12,913	123	12,790	99
Third	8,357	10	8,347	100
Fourth	6,245	546	5,699	91
Total	**59,515**	**3,630**	**55,885**	**94**

Table 14: Mechanical Space Requirements

ASHRAE Standard 62.1-2010 Analysis

Section 5: System and Equipment

5.1 Ventilation Air Distribution

Father O'Connell Hall meets design ventilation requirements by section 6 of Standard 62.1. AHU-4, AHU-5, and AHU-6 provide ventilation to the basement and first floor areas. Air transfer ducts, fan powered boxes, and variable air volume boxes are used to help ventilate these floors. Floors 2-4 are ventilated using a 100% outside air handling unit. Detailed calculations can be seen in appendix A.

5.2 Exhaust Duct Location

All exhaust ducts carrying potentially harmful contaminates from toilet or janitor rooms have a SMACNA seal class of C and a minimum negative pressurization of 2-inch wg. All exhaust is discharged at a safe distance above roof.

5.3 Ventilation System Controls

Father O'Connell Hall will be equipped with a Building Automated System (BAS). This system has occupied, unoccupied, and hand-off-auto operation modes that will control outside air dampers to ensure minimum ventilation requirements are met. All air handling units have a supply fan VFD that is controlled by the BAS.

5.4 Airstream Surfaces

Mold growth and erosion is avoided by using galvanized steel sheet metal that is in accordance of UL 181 ASTMC 1338 Standards.

5.5 Outdoor Air Intakes

Outside air louver intake for the 100% outside air handling unit is located on the fourth floor west wall of the main building. Outside air intake for AHU-6 and AHU-4 are located on the south wall of the basement level. AHU-5 has an air intake on the west wall of the main building on the basement level. All outside air intakes are located at least 15 feet from all exhaust outlets which exhaust class 3 air from toilet and janitor rooms. All intakes comply with ASHRAE Standard 62.1 Table 5-1 seen below in Table 15. Details of louvers or louver shop drawings could not be located but specification requires bird screens and storm-proof to prevent entry of rain and snow.

TABLE 5-1 Air Intake Minimum Separation Distance

Object	Minimum Distance, ft (m)
Class 2 air exhaust/relief outlet (Note 1)	10 (3)
Class 3 air exhaust/relief outlet (Note 1)	15 (5)
Class 4 air exhaust/relief outlet (Note 2)	30 (10)
Plumbing vents terminating less than 3 ft (1 m) above the level of the outdoor air intake	10 (3)
Plumbing vents terminating at least 3 ft (1 m) above the level of the outdoor air intake	3 (1)
Vents, chimneys, and flues from combustion appliances and equipment (Note 3)	15 (5)
Garage entry, automobile loading area, or drive-in queue (Note 4)	15 (5)
Truck loading area or dock, bus parking/idling area (Note 4)	25 (7.5)
Driveway, street, or parking place (Note 4)	5 (1.5)
Thoroughfare with high traffic volume	25 (7.5)
Roof, landscaped grade, or other surface directly below intake (Notes 5 and 6)	1 (0.30)
Garbage storage/pick-up area, dumpsters	15 (5)
Cooling tower intake or basin	15 (5)
Cooling tower exhaust	25 (7.5)

Note 1: This requirements applies to the distance from the outdoor air intakes for one ventilation system to the exhaust/relief outlets for any other ventilation system.
Note 2: Minimum distance listed does not apply to laboratory fume hood exhaust air outlets. Separation criteria for fume hood exhaust shall be in compliance with NFPA 45[5] and ANSI/AIHA Z9.5.[6] Information on separation criteria for industrial environments can be found in the *ACGIH Industrial Ventilation Manual*[7] and in the *ASHRAE Handbook—HVAC Applications*.[8]
Note 3: Shorter separation distances shall be permitted when determined in accordance with (a) ANSI Z223.1/NFPA 54[9] for fuel gas burning appliances and equipment, (b) NFPA 31[10] for oil burning appliances and equipment, or (c) NFPA 211[11] for other combustion appliances and equipment.
Note 4: Distance measured to closest place that vehicle exhaust is likely to be located.
Note 5: Shorter separation distance shall be permitted where outdoor surfaces are sloped more than 45 degrees from horizontal or that are less than 1 in. (3 cm) wide.
Note 6: Where snow accumulation is expected, the surface of the snow at the expected average snow depth constitutes the “other surface directly below intake.”

Table 15: Table 5-1 ASHRAE Standard 62.1 Section 5

5.6 Local Capture of Contaminants

All contaminants that are generated by equipment are properly exhausted directly outside to avoid mixing into occupied spaces.

5.7 Combustion Air

Father O’Connell Hall has two condensing boilers located on the basement level. Both Boilers are vented directly to the outdoors. See Figure 14 below.

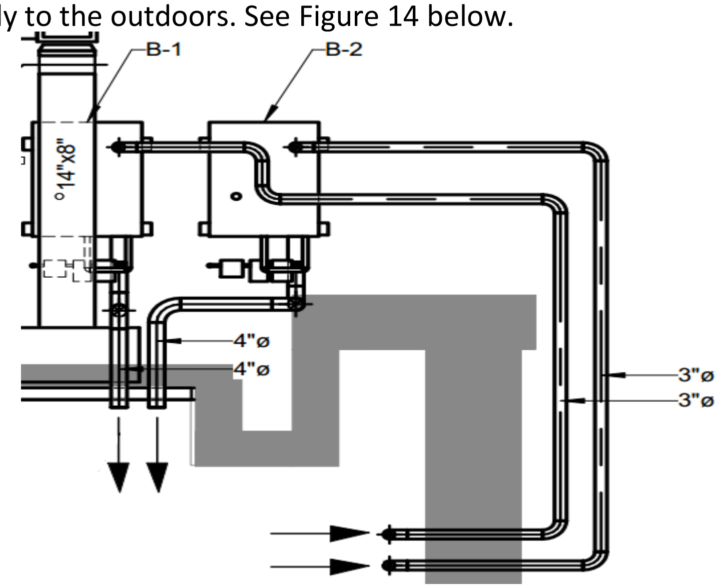

Figure 14: Boiler intake and exhaust vent from project

5.8 Particulate Matter Removal

All AHU's will use pre-filters with a MERV 7 rating and a final filter with a MERV 13 rating upstream of the cooling coil. This complies with ASHRAE Standard 52.2 which requires a minimum filtration rating of MERV 6.

5.9 Dehumidification Systems

Father O'Connell Hall is specified to maintain a relative humidity of 50% throughout the building. Minimum supply air is greater than the maximum exhaust air, maintaining a positive pressure for the building as a whole. The building meets exfiltration requirements.

5.10 Drain Pans

Condensate drain pans have at least a 2 percent slope in the direction toward the drain connection. All sizes are large enough to collect from all cooling coils with a minimum depth of 2 inches deep. All other drain pans are to be designed and manufactured to according to ASHRAE Standard 62.1. See Figure 15 below for a complete detail of a typical drain pan.

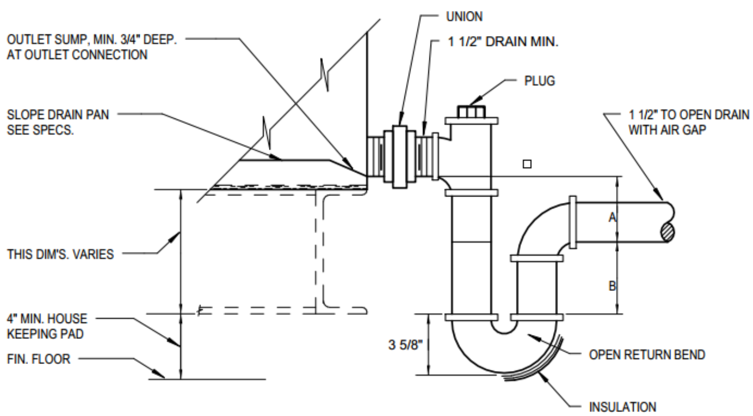

Figure 15: Drain Pan Detail

5.11 Finned-Tube Coils and Heat Exchangers

All finned-tube coils and heat exchangers have drain pans according to ASHRAE section 5.1. All Heat exchangers will have access doors at least 18 inches wide and are provided on both sides of coils. A pressure drop of less than 0.75 in. w.c. due to the access doors is not mentioned.

5.12 Humidifiers and Water-Spray Systems

Water used for humidity control originates directly from a potable source. Drip pans are located under the humidifier and there are no obstructions downstream. Therefore, Father O'Connell Hall complies with ASHRAE Standard 62.1 section 5.12.

5.13 Access for Inspection, Cleaning, and Maintenance

The following will be provided access doors for inspection, cleaning, and maintenance:

-Duct Filters

-Outdoor-air intakes and mixed-air plenums

-Control devices

-Volume dampers

-Duct silencers

-Turning vanes

-Drain pans

-Fire dampers

5.14 Building Envelope and Interior Surfaces

All exterior roofing and exterior walls will have appropriate waterproofing. Figure 16 to the right shows a typical wall section indicating a fluid applied waterproofing membrane. Pipes will have a 125-mil-thick vapor barrier and waterproofing membrane to prevent condensation. All pipe and duct penetration will also have sufficient insulation and waterproof membrane.

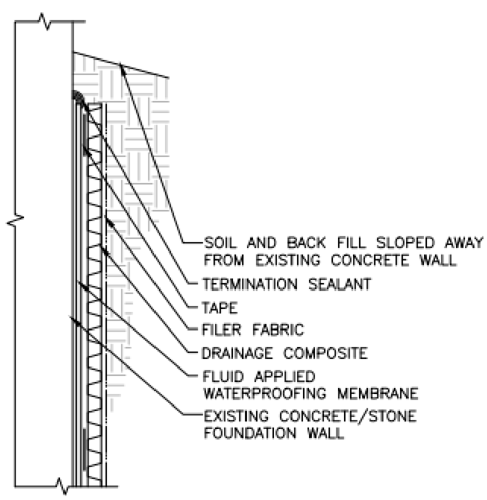

Figure 16: Typical Wall Section

5.15 Building Attached Parking Garages

This section does not apply because there are no parking garages. Vehicular exhaust is not a concern for this project.

5.16 Air Classification and Recirculation

Fan powered boxes are used to re-circulate plenum air on the basement level and the 2nd level on the east building. Office space, storage rooms for dry materials and corridors make up these spaces which all have class 1 air; therefore, it meets ASHRAE Standard 62.1 because class 1 air is permitted to be re-circulated. All toilet and janitor closets have class 3 air and are directly exhausted to the outside. Some air transfer ducts are used to re-circulate corridor air on floors 2-4.

5.17 Requirements for Buildings Containing ETS Areas

Father O'Connell Hall is a smoke free building; therefore, this section does not apply.

Section 6: Ventilation Rate Procedure Analysis

Air handling units 2,4,5,6 and 100% outside AHU (OAHU-1) were analyzed to estimate minimum outside air requirements for all spaces. Existing air handling units 1 and 3 were not able to be analyzed due to lack of information in the project documentation. AHU's 1 and 3 only provide ventilation for a small portion of the building which was not in the scope of this renovation.

Equation 6-1 in section 6.2.2.1 in ASHRAE Standard 62.1 was used to calculate breathing zone outdoor airflow (V_{bz}).

$$V_{bz} = (R_p \times P_z) + (R_a \times A_z)$$

Where: A_z = zone floor area: the net occupiable floor area of the ventilation zone ft^2

P_z = zone population: the number of people in the ventilation zone during typical usage. (this was determined from counting seats from furniture plans)

R_p = outdoor airflow rate required per person as determined from Table 6-1

R_a = outdoor airflow rate required per unit area as determined from Table 6-1

The zone outdoor airflow (Voz) is the outdoor air that must be provided to ventilate the zone.

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

Where E_z = zone distribution effectiveness which is found from table 6-2. E_z varied between 0.8,1, and 1.2 depending on how the air is distributed into the zone.

For 100% outside air systems the outdoor air intake flow (V_{ot}) is found by equation 6-4.

$$V_{ot} = \Sigma_{\text{all zones}} \times V_{oz}$$

The primary outdoor air fraction (Z_{pz}) is the minimum percent of ventilation air from the supply air. This is calculated from equation 6.5.

$$Z_{pz} = V_{oz}/V_{pz}$$

Where V_{pz} is the zone primary airflow.

Table 16 below is a summary of all five air handlers that were analyzed. Design CFM and Minimum OA CFM were taken from the project documentation and compared to ASHRAE 62.1 Min. OA CFM calculations based on the above formulas. Detailed spreadsheets used for these calculations are available in Appendix A.

Minimum Ventilation Rates				
Unit	Design CFM	Minimum OA CFM	ASHRAE 62.1 Min. OA CFM	Compliant (Y/N)
OAHU-1	1800	1800	1400	Y
(E)AHU-2	7790	1861	1171	Y
AHU-4	4100	1480	613	Y
AHU-5	8000	1480	1479	Y
AHU-6	3500	500	381	Y

Table 16: Minimum Ventilation Rates

ASHRAE 62.1 – 2010 Summary

After analyzing the ventilation system of Father O'Connell Hall, it has been determined that all spaces have met the minimum ventilation requirements required by ASHRAE 62.1. Seven air handling units, including one 100% outdoor air unit, and air transfer ducts exceed or meet the minimum ventilation requirements. In addition to minimum ventilation requirements, Father O'Connell Hall also complies with Section 5. This includes all materials and HVAC control systems. Father O'Connell Hall is currently undergoing renovation to install new waterproof membrane around the footing and windows to comply with section 5.14 building envelope and interior surfaces.

ASHRAE Standard 90.1-2010 Analysis

Section 5: Building Envelope

5.1.4 Climate

The Catholic University of America located in Washington, DC is in climate zone 4A as you can see from the Figure 17 below. Table B-1 is found in Appendix B of ASHRAE Standard 90.1 and is used to determine building envelope requirements.

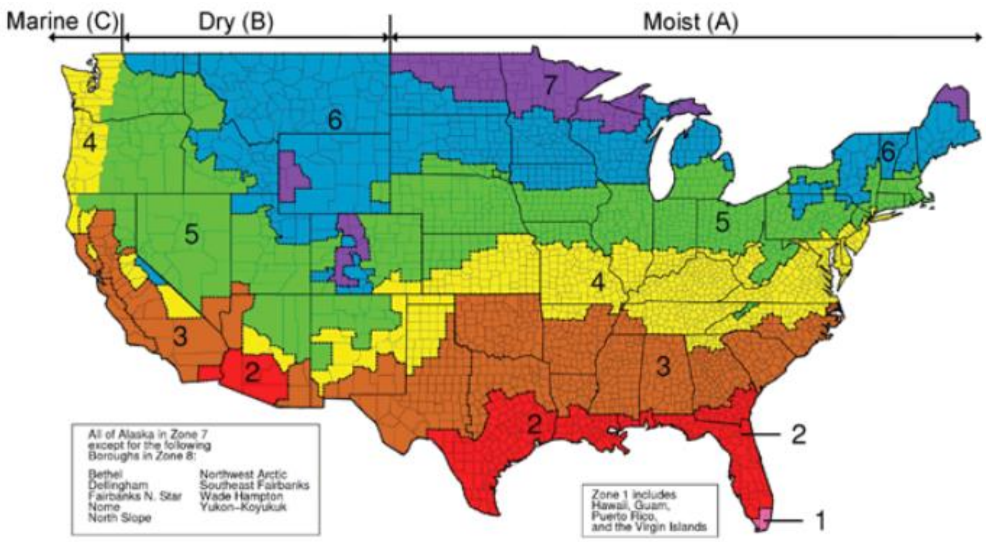

Figure 17: Climate Zones in the US from ASHRAE Table B-1

5.4 Mandatory Provisions

The exterior envelope of Father O'Connell hall is currently being renovated. Exterior limestone and granite joints are to be reappointed. Coping stone is to be removed and reinstalled to install thru wall flashing. In addition, much of the exterior footer is to be excavated to in order to install water proofing. Windows and doors are specified to be sealed. Figure 18 below is a detail of the window sealant. The entire building envelope is constructed with a continuous air barrier.

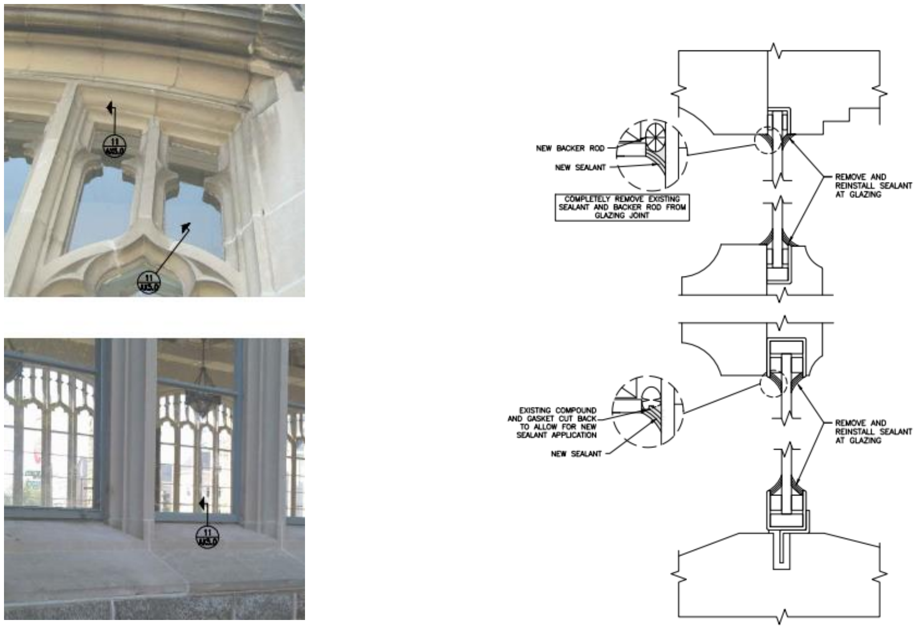

Figure 18: Sealant of existing windows detail from project

5.5 Prescriptive Building Envelope

In order to determine compliance with building envelope requirements of ASHRAE Standard 90.1, the prescriptive building method was used. Table 18 below shows a comparison of Father O'Connell Hall building envelope and requirements for nonresidential zone 4A. It was found that it does not comply with Standard 90.1. This is because the building was built in 1914 and no or very little insulation was used. This shows a potential for design improvements. In addition, the total vertical fenestration area must be less than 40% of the gross wall area. Table 2 below clearly indicates that Father O'Connell Hall complies. Fenestration calculations can be seen in Table 17 below.

Vertical Fenestration Area				
Face	Glazing Area SF	Wall Area SF	Glazing %	Comply
North	2181	15,495	14.07551	Y
South	2201.7425	16,125	13.65422	Y
East	713.49	5,716	12.48233	Y
West	337.4175	3,670	9.193937	Y
Total	5433.65	41,006	13.25087	Y

Table 17: Fenestration Areas

Building Envelope for Nonresidential zone 4A							
Element	R-Value	Insulation Min. R-Value	U-Value	Max U-Value	SHGC	Max SHGC	Comply
Walls, Above Grade Mass	4.6*	9.5	0.217	0.104	-	-	N
Roofs, Built up roof East and West wing	9	20	0.095	0.048	-	-	N
Roofs, Built up roof main building	2.89*	20	0.346	0.048	-	-	N
Glazing, Nonmetal Framing East and West Wing	-	-	0.40	0.40	0.5	0.40	N
Glazing, Nonmetal Framing Main Building	-	-	0.60	0.40	0.5	0.40	N
* No insulation and overall R-Value was used							

Table 18: Building Material R and U-Values

Section 6: Heating, Ventilating, and Air Conditioning

6.2 Compliance Paths

ASHRAE Standard 90.1 has two methods to evaluate equipment efficiency, the simplified approach option for HVAC systems and the mandatory provisions with prescriptive path. Father O'Connell Hall does not meet the height or gross area requirements of fewer than two stories and less than gross area of 25,000 ft^2; therefore, the mandatory provisions with prescriptive path must be used to evaluate equipment efficiency.

6.3 Simplified Approach Option for HVAC Systems

This section does not apply for reasons mentioned in Section 6.2.

6.4 Mandatory Provisions

Specifications indicate that all mechanical equipment must have manufacturer's label that states the requirements of ASHRAE Standard 90.1 is met; Therefore, minimum efficiencies will be must comply with section 6.4.

Each FCU, VAV, and Fan powered box will have its own thermostat for individual zone control. Room sensors have an accuracy of +/- 2 deg F while relative Humidity has an accuracy of +/- 5%. A combination of Direct Digital Control and Proportional Integral Derivative with a BAS system is used to keep the building at the desired set points.

6.5 Prescriptive Path

All AHU's are equipped with a mixed air economizer cycle. Heat recovery is used in the 100% outside air AHU by an air-to-air plate exchanger and a wraparound heat pipe heat recovery exchanger to reheat supply. During cooling season the leaving air temperature is maintained at 54 F dry bulb and 53.7 F wet bulb. During the heating season the leaving air temperature is maintained at 85 F. No motors with 5 or larger horsepower are used in Father O'Connell Hall so fan power limitation does not apply.

6.7 Submittals

Upon completion of the project, each contractor must submit normal cut sheets and shop drawings of all equipment. This includes control drawings, wire diagrams, dimensions, and O&M manual. Submittals must be approved by authorities having jurisdiction prior to submitting them to the Architect.

Section 7: Service Water Heating

Washington Gas Company provides 2 psi gas to heat two 500 MBH condensing boilers for heating spaces. Domestic water heaters are used for heating domestic potable water. Hot-water supply boilers heated by gas that are greater than 4000 (btu/h)/gal are required to have a minimum efficiency of 78%. These boilers are rated at 91% (according to the manufacturer's website). All hot water piping is properly insulated. The heating hot water system is automatically enabled and disabled by the BMS time and season schedules.

Section 8: Power

Father O'Connell Hall complies with the National Electric Code for construction which requires a maximum voltage drop of 2% for feeders and a maximum voltage drop of 3% for branch circuits.

Section 9: Lighting

9.2 Compliance Path

Lighting and equipment can be examined by using the Building Area Method or the Space-by-Space Method. Due to time restraints the simplified building area method will be used to calculate interior lighting power allowance.

9.4 Mandatory Provisions

Father O'Connell Hall utilizes occupancy sensors to reduce the amount of energy consumption. Some types of rooms that have occupancy sensors include restrooms, storage, offices, and conference rooms. The rest of the lights are operated manually or by the building management system. Table 19 below summarizes the allowable power density levels as specified by ASHRAE

Standard 90.1 by using the Building Area Method. Additional and more accurate results could be calculated at a later date using the Space-by-Space Method. Father O'Connell Hall uses many LED lights which use very little energy which could contribute to the low LPD calculated.

Lighting Power Densities					
Area Type	Std. 90.1 LPD (W/SF)	Building Area (SF)	Building (W)	Building LPD (W)	Comply
Office	0.9	60,000	36283	0.60	Y

Table 19: Lighting power densities calculated by using building area method

Table 10.8B from ASHRAE Standard 90.1 states the minimum efficiency for all electric motors manufactured on or after December 19, 2010. According to Table 10.8, efficiency of the pumps does not comply with standard 90.1. A reason for this could be that the project documentation states that this is a minimum efficiency while Table 10.8B specifies efficiency for full load. Since the pumps have a VFD the efficiency might be much higher at full load. Another reason for this non-compliance is that pumps are generally oversized due to safety factors. Table 20 below shows full calculations.

Minimum Pump Efficiency					
Unit	HP	Min. Efficiency	RPM	ASHRAE Std. 90.1 Efficiency	Comply
CHWP-1	7.5	72	1,750	89.5	N
CHWP-2	7.5	72	1,750	89.5	N
HHWP-1	1.5	57	1,750	84	N
HHWP-2	1.5	57	1,750	84	N
HHWP-3	1.5	57	1,750	84	N

Table 20: Minimum pump efficiency requirements for ASHRAE Standard 90.1

ASHRAE 90.1 – 2010 Summary

ASHRAE Standard 90.1 establishes minimum energy efficiency requirements for non-residential buildings. Standard 90.1 looks into building envelope and system equipment heavily to confirm a baseline energy efficient design.

Father O'Connell Hall did not comply with some sections of 90.1, mostly because of the building envelope. Little to none insulation was used causing the overall U-Value to be much higher than required. However, vertical fenestration did very well. Only 13.5% of the total building was found to be glazing. In addition, lighting power density was much lower than the requirements of standard 90.1. This has much to do with the use of LED lighting.

The mechanical equipment selection seemed to be very efficient, especially the gas condensing boilers. The chilled and hot water pumps were not compliant and must be investigated further to why the efficiency was not met. Additional, energy models will be investigated in technical report two to see how adding additional insulation to the walls and roofs will reduce energy usage.

LEED Analysis

Leadership in Energy and Environmental Design (LEED) is an internationally recognized program that rates the design, construction, and operation of high performance buildings. Certifications are achieved based on satisfying credits in 6 different categories. Below is an analysis of Father O'Connell Hall of two categories that deal with the mechanical system: Energy and Atmosphere and Indoor Environmental Quality.

Energy and Atmosphere

It was estimated that Father O'Connell Hall would achieve 5 credits in this category.

Prerequisite 1: Fundamental Commissioning of the Building Energy Systems

Commissioning processes were done by the project team to reduce energy usage and lower operating costs. The system is operating in accordance to the owner's project requirements.

Prerequisite 2: Minimum Energy Performance

Father O'Connell Hall is in complete accordance with ASHRAE Standard 90.1. An energy model could not be obtained from the design team, but my own energy model showed significant savings compared to ASHRAE baseline.

Prerequisite 3: Fundamental Refrigerant Management

Refrigerant R-410a is used in place of CFC refrigerants. R-410a has a lower ozone depletion and global warming potential than CFC's or HCFC's.

Credit 1: Optimize Energy Performance – 2 Points

The purpose of this credit it to further achieve higher levels of energy performance beyond the minimum required in prerequisite 2. It is estimated that Father O'Connell Hall will perform about 14% better.

Credit 2: On-Site Renewable Energy

This credit is awarded to projects that use on site renewable energy rather than burning fossil fuels at an off-site location. Father O'Connell Hall does not use any on site renewable energy.

Credit 3: Enhanced Commissioning – 1 Point

In house commissioning was done from the design team to achieve this credit.

Credit 4: Enhanced Refrigeration Management – 2 Point

This credit looks at refrigerant global warming potential (GWP) and ozone depletion potential (ODP). Table 21 below used from the United State Green Building Council website, shows that Father O'Connell is well below the 100 max of average refrigerant impact.

HVAC&R Equipment Type	N	Q (tons)	Refrig-erant	GWPr	ODPr	Rc (lb/ton)	Life (yrs)	Lr (%)	Mr (%)	LCGWP	LCODP x10^5	Impact per ton	Impact Total
Scroll Compressor	1	100	R-410A	1890	0.000	0.88	20	2	10	42	0	42	4,200
Total		100	Average refrigerant impact per ton (must be less than or equal to 100)									42	4,200

Table 21: Refrigerant Management

Credit 5: Measurement and Verification

The intent of this credit is to provide ongoing accountability of the building energy consumption over time. No know plans were set to measure consumption in the future.

Credit 6: Green Power

To meet the criteria for this credit it is encouraged to develop renewable energy to create a net zero site. No renewable energy is used at Father O'Connell Hall.

Indoor Environmental Quality

It is estimated that 12 credits are obtainable for Father O'Connell Hall in this section.

Prerequisite 1: Minimum IAQ Performance

The purpose of this prerequisite is to establish a minimum indoor air quality. This prerequisite requires the compliance of ASHRAE Standard 62.1. Father O'Connell Hall complies with this standard as seen earlier in this report.

Prerequisite 2: Environmental Tobacco Smoke (ETS)

The purpose of this credit is to prevent the building from being exposed to environmental tobacco smoke. Father O'Connell Hall prohibits smoking inside the building and within 25 feet of all entries and outdoor air intakes.

Credit 1: Outdoor Air Delivery Monitoring – 1 Point

Credit 1 requires the monitoring of ventilation that is being supplied to occupants. The BMS controls ventilation to ensure minimum ventilation rates are being met. In addition, there is a 100% outdoor air handling unit providing ventilation for most of the building.

Credit 2: Increased Ventilation – 1 Point

Credit 2 is intended to improve occupant comfort by providing additional ventilation about the minimum requirements. This credit requires the ventilation to increase 30% above the minimum. Ventilation calculations were done and compared to the design minimum outdoor air rates and it was found that Father O'Connell does provide sufficient ventilation to achieve this credit.

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

Credit 3.1 intent is to reduce indoor air quality problems during construction. The building specifications of the air handling units specifically require compliance with credit 3.1.

Credit 3.2: Construction IAQ Management Plan, Before Occupancy

Credit 3.2 is similar to credit 3.1 in its intent to reduce indoor air quality problems during construction. This credit requires a building flush out before occupancy or using protocols from the EPA to determine the air pollutants indoors. No know tests are scheduled for Father O'Connell Hall.

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

Credit 4.1 intent is to reduce indoor air contaminants that are odorous or harmful to occupants due to adhesives and sealants. Father O'Connell uses low-emitting materials and adhesives and meets this credits requirements.

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

Credit 4.2 is similar to 4.1. Paints and coatings are not to exceed certain volatile organic compound (VOC) levels that can be potentially harmful to occupants. It is specified that materials do not exceed these limits in Father O'Connell Hall.

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

The purpose of credit 4.3 is to reduce indoor air quality problems due to carpet systems. Father O'Connell Hall's carpets have been specified to meet credit 4.3. In addition, the adhesives have been specified to meet credit 4.1.

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

The purpose of credit 4.3 is to improve indoor air quality by using composite wood systems that do not contain urea-formaldehyde resins. Wood floor systems are not used in Father O'Connell Hall so it meets this credits requirements.

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

The purpose of credit 5 is to limit occupant exposure to hazardous chemical pollutants. A minimum filter of MERV 13 is used for all occupied spaces. An entryway system is provided for all spaces. The only space with hazardous gases or chemicals is the kitchen area and the air is directly exhausted outside.

Credit 6.1: Controllability of Systems, Lighting – 1 Point

The purpose of credit 6.1 is to provide high level lighting system with individual control to promote productivity, comfort, and well-being. Individual lighting controls are provided in at least 90% of the building. In addition, many lighting controls are dimmable.

Credit 6.2: Thermal Comfort – 1 Point

The purpose of credit 6.2 is to create comfortable environment with individual controls. At least 50% of the building occupants have individual controls. Most office spaces are controlled by a single fan coil unit with a single programmable thermostat.

Credit 7.1: Thermal Comfort, Design – 1 Point

The purpose of credit 7.1 is to provide a comfortable environment to promote productivity, comfort, and well-being. HVAC systems are design to comply with ASHRAE Standard 55- Thermal Comfort Conditions for Human Occupancy.

Credit 7.2: Thermal Comfort Verification

The purpose of credit 7.2 is to provide an assessment of building occupant thermal comfort over time. One way this credit could be achieved is through the distribution of a survey. No know surveys are planned to be distributed in the future.

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

The purpose of credit 8.1 is to provide building occupants with a connection between indoors and outdoors through the introduction of day lighting for 75% of spaces. A detailed calculation was not done but Father O'Connell Hall is a very long and narrow building with most rooms being exterior rooms. It seems that 75% of spaces will have a direct line of sight to the outdoor environment.

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

The purpose of credit 8.2 is to further encourage a connection between indoors and outdoors for at least 90% of the spaces. This credit could not be achieved.

Mechanical System Evaluation

Father O'Connell Hall mechanical system has been estimated to cost 1.6 million dollars about 13% of total project costs. The mechanical cost on a square foot basis is $44.67 per square foot. The average annual energy cost is $17,000.This annual cost is on the lower end. One reason could be due to the 100% outdoor air handling unit with heat recovery limiting the amount of airflow through much of the building.

Large mechanical rooms in the basement and fourth floor host most of the major equipment. These include the air handling units, boilers, pumps, and fans. Some exhaust fans are located on the rooftop. The chiller is also located outdoors, but everything else is located interior of the building. Even with these large mechanical equipment located indoors, 94% of the building is still usable space when compared with the mechanical equipment.

Father O'Connell Hall does a good job with its mechanical design in terms of LEED. Most points in the Energy and Atmosphere and Indoor Environmental Quality are obtained. Efforts in energy reduction could be looked into improving. On way of improving would be to look into on-site renewable energy. Currently, Father O'Connell Hall has uses no renewable energy sources.

Combined Heat and Power with Absorption Cooling

Introduction

Combined heat and power technologies can increase the overall efficiencies of a building while reducing emissions by simultaneously creating useful thermal and electrical energy. Combined heat and power produces onsite generation which avoids transmission and distribution losses associated with the purchase of electricity from the grid. In addition, CHP systems can provide reliable power in case of a brownout or blackout from the grid. Figure 19 below from the U.S. Environmental Protection Agency shows some potential overall efficiency benefits of combined heat and power (CHP) by comparing it to conventional separate heat and power system (SHP). These efficiencies shown can be misleading. The CHP efficiency shown is the maximum efficiency. The efficiency relies on the thermal to electrical load ratio and this ratio is constantly changing. Therefore, this efficiency can significantly vary as the thermal to electrical load ratio changes. This analysis will compare Father O'Connell Hall's current separate heating and power system with a combined heat and power system. In addition, absorption chillers will replace the current 97.7 ton electric air cooled chiller, further reducing the electric load. Absorption chillers use heat rather than electricity. This will utilize waste heat from the CHP system in the summer months when the heating demand is low. Absorption chillers have a lower coefficient of performance than electric chillers and are often applied when waste heat is available.

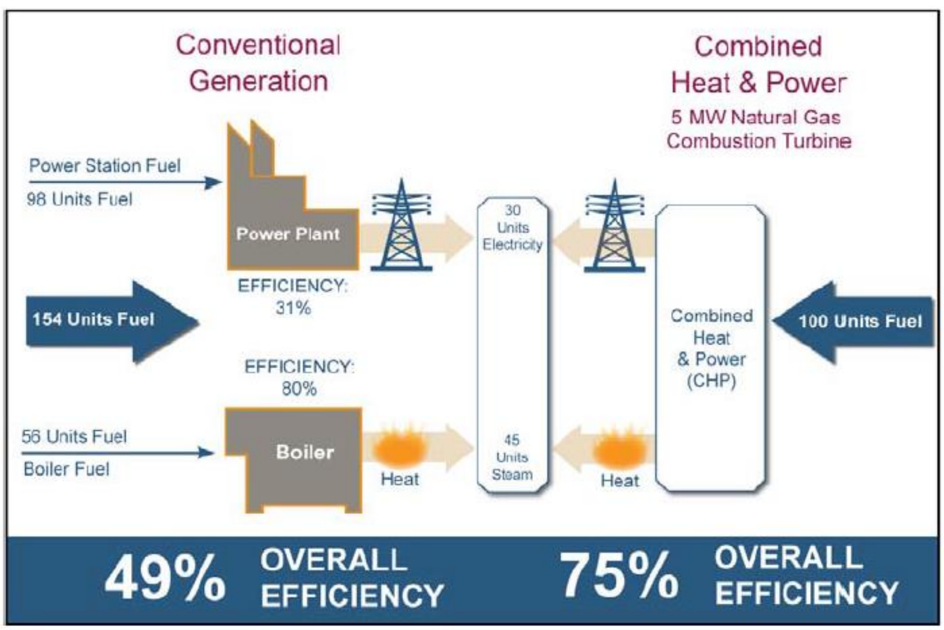

Figure 19: CHP vs SHP efficiencies. Note: Assumes national averages for grid electricity transmission losses

Spark Gap

The spark gap is the difference between the cost of fuel and the cost of purchased electricity. This is an important preliminary consideration for cost savings of a CHP system because a CHP system will replace much of the cost of purchased grid supplied power with the cost of fuel. An engineering rule of thumb to continue with a CHP analysis is that the spark gap must be greater than $12. Below is the calculation for the spark gap for Washington, D.C. 2013 Washington, D.C. average cost for electricity and natural gas were found from the U.S. Department of Labor Statistics. As seen in Table 22, Father O'Connell Hall has a spark gap of $26.84; it has the potential to be a good candidate for a CHP system and further analysis will continue. Natural gas prices are continuing to decrease because of recent technology advancements in recovering underground natural gas, such as fracking, the U.S. could find CHP a viable option in the future to dramatically cut emissions.

Electricity: $0.13/KWh *1 Btuh/3412 KWh *1,000,000 = $38/MMBtu

Natural Gas: $1.117/Therm *10 = $11.17/MMBtu

	Price ($/MMBtu)	Spark Gap
Electricity	$ 38.00	$ 26.84
Natural Gas	$ 11.17	

Table 22: Spark Gap

Building Demand Loads

Thermal and power demands are the driving factors when considering implementing a CHP system. Most CHP systems are not completely disconnected from the grid, but rather produce as much onsite electrical generation as possible and purchase small amounts of electricity as electrical loads vary. In addition, many CHP systems require supplemental means of heating and cooling to satisfy peak demand loads. Thermal and power loads will drive future sizing calculations.

Prime movers are specified by maximum power output and a rate of useful heat output per KW of power produced. Therefore, building thermal loads must be large enough to have a useful purpose as the prime mover produces electricity. This useful thermal energy can be used for domestic water heating, power a boiler, create steam, or as heat input for an absorption chiller. Figure 20 below shows one typical day of heating, cooling, and power loads for each month for Father O'Connell Hall. The new CHP system will incorporate an absorption chiller which will significantly reduce the electrical needs in the summer months, while the heating demands are low. From this chart it is easy to see that during off peak hours the loads are very low.

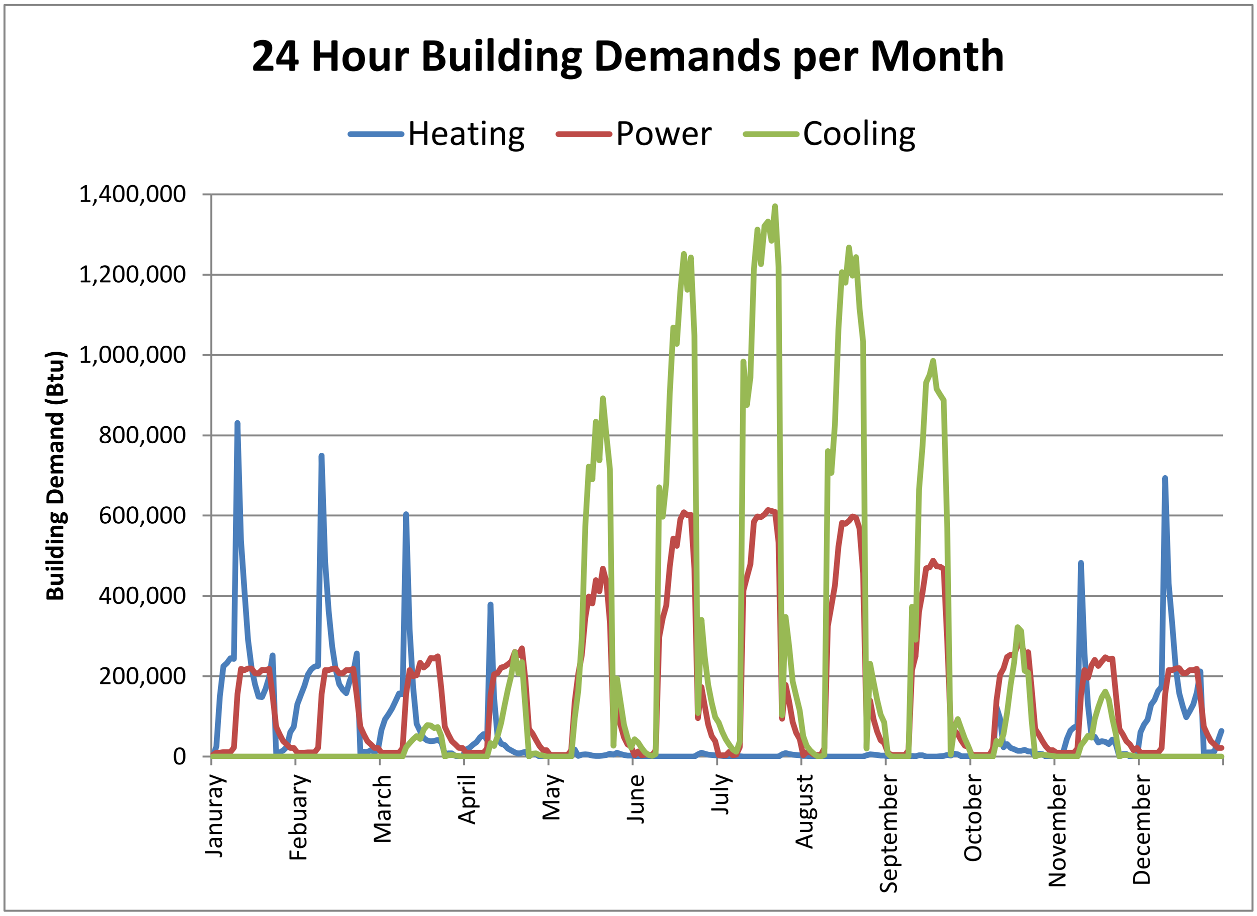

Figure 20: 24 Hour Building Demands per Month

Figure 21 below shows the duration curves for heating, power, and cooling loads. CHP equipment should be selected based on the thermal base load. Select the prime mover by the specified net heat rate (btu's produced per kw). Decide how much thermal load should be met by the CHP system and how much should be met by a supplemental boiler. The electricity produced by the prime mover is a byproduct of the thermal load. By analyzing the load duration curve, it can be determined that to meet the thermal load 90% of the time that a prime mover must exhaust about 220,000 btu of useful heat.

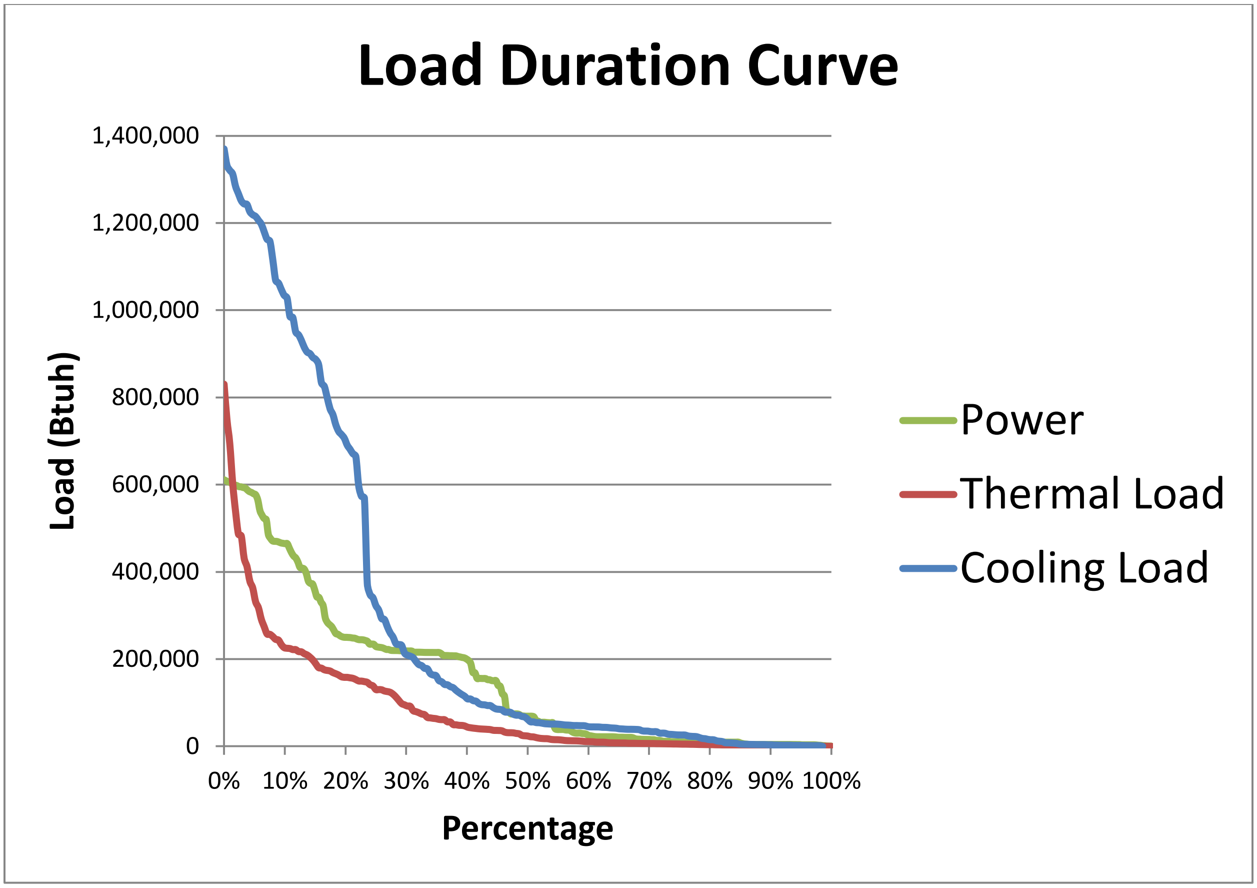

Figure 21: Load duration curves for thermal, heating, and power loads

Prime Mover Selection

The prime mover is the major piece of equipment associated with CHP technologies. There are five types of prime movers, gas turbine, steam turbine, microturbine, IC engine, and fuel cells. Each type of prime mover has its advantages and disadvantages. For example, an IC engine has a very high electrical efficiency but a limited heat recovery capability. A gas turbine has high grade heat available but poor electrical efficiency. Depending what the thermal to power ratio, will determine which prime mover type will work best. A microturbine was selected as the prime mover for Father O'Connell Hall. This was an easy decision because of the limited space available and the low electrical demand. Microturbines are compact with small number of moving parts and low emissions but, have a relatively low electrical efficiency. Microturbines also come equipped with an internal recuperator. A recuperator uses the exhaust of the power turbine to preheat the air from the compressor, thereby reducing the fuel needed to heat the compressed air to the turbine inlet. Recuperators can more than double the efficiency, although it lowers the exhaust temperature reducing the microturbines useful heat output.

Results

Capstone C30 microturbine was chosen as the prime mover. Capstone C30 microturbine full cut sheet can be found in Appendix D. The 30 KW microturbine was chosen to meet 90% of all thermal loads. This resulted in approximately meeting 54% of all electrical loads. This means an additional boiler will need to be used as supplemental heating 10% of the year as well as 46% of electrical needs will be supplied from the grid. The net heat rate of the C30 is 13,100 BTU/kWh. The exhaust is high pressure at 530 ˚F. This is relatively low quality so it is safe to assume a 60% efficient heat recovery unit. Figure 22 below shows the Fuel input and useful exhaust available per KW of power produced. At full load the microturbine is producing 30KW of electricity and 235,800 btu's of useful exhaust.

$$13{,}100\ \frac{BTU}{KW} * 30\ KW * 0.6 = 235{,}800\ BTU's$$

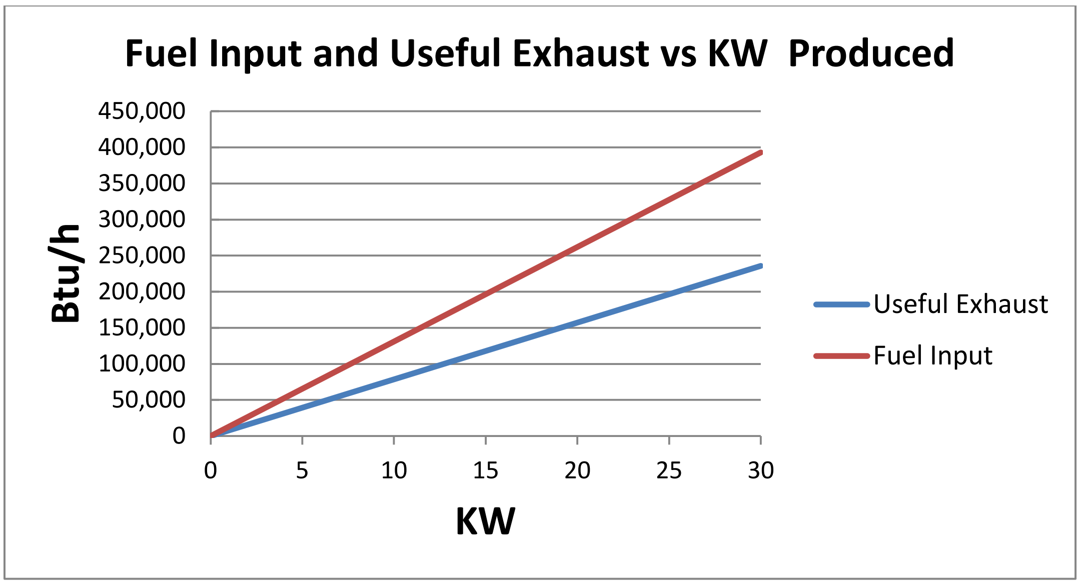

Figure 22: Fuel input and useful exhaust vs KW produced

The following four Figures 23, 24, 25, and 26 shows the distribution of CHP produced electricity and waste heat usage coupled with supplemental boiler, electric chiller, and purchased power. These graphs show 24 hours of typical day of each month. Figure 23 shows that the heating load can be met without a supplemental boiler up to a demand of 235,800 Btu's. When the building thermal demand reaches above this point a boiler must be used to meet the required demand. From Figure 23 it is easy to see that the CHP system is only running from the hours of 8:00 AM to 6:00 PM. Cycling the CHP system on and off each day decreases the over production of electricity. A cost analysis will interpret this more in detail. Figure 25 shows the amount of absorption cooling and electric cooling. Absorption cooling is not as effective as hoped. This is because of the low power demand throughout most of the year which limits the useful exhaust heat used to power the absorption chiller. In addition, a single effect absorption chiller has a COP of about 0.7, requiring even more heat. It was hoped that adding an absorption chiller would reduce the power demand in the summer months. Figure 26 shows 100% of the distribution of the useful exhaust. The green color on the graph, wasted heat, should be avoided at all costs. This occurs when the building loads are too low and thermal heat is wasted. Most of the waste occurs during the intermediate months when economizer cycles can be utilized the most. If the microturbine was turned on 24 hours a day there would be a much greater waste. The electric, thermal, and cooling loads are much less during the off peak hours. Since Father O'Connell is an administrative building, a typical work day will be between 7:00 AM and 6:00 PM. Table 23 below shows the max loads of each piece of supplemental mechanical equipment which will be used for sizing.

Sizing		
Max Electric Chiller Load	100	Tons
Max Absorption Chiller Load	14	Tons
Max Boiler Load	594,603	Btu
Max $e_{D, GTD}$	150	KW

Table 23: Sizing Supplemental mechanical equipment

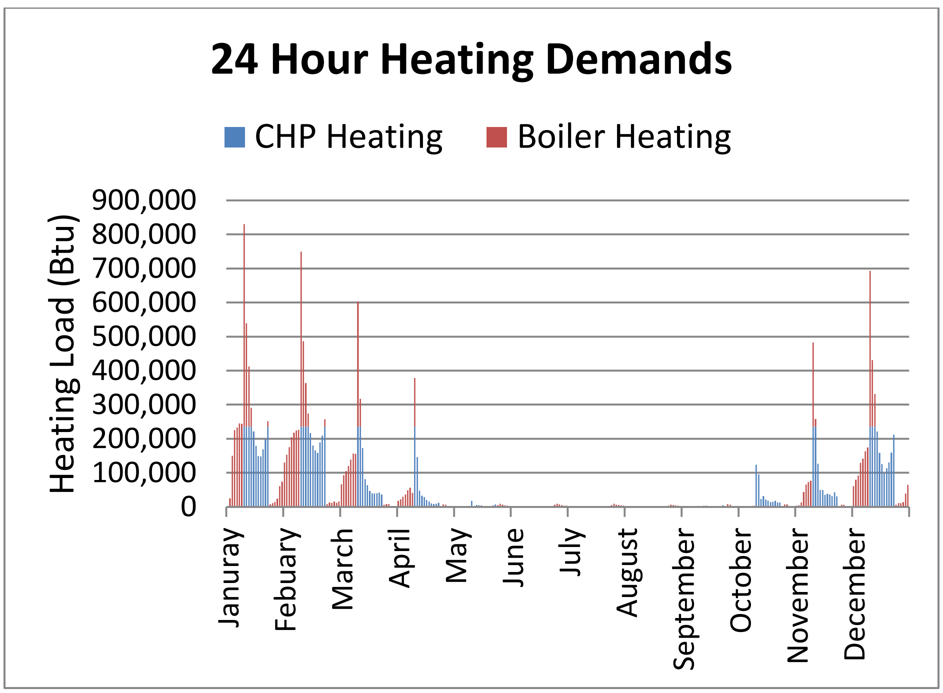

Figure 23: Heating demands met by CHP exhaust and supplemental boilers

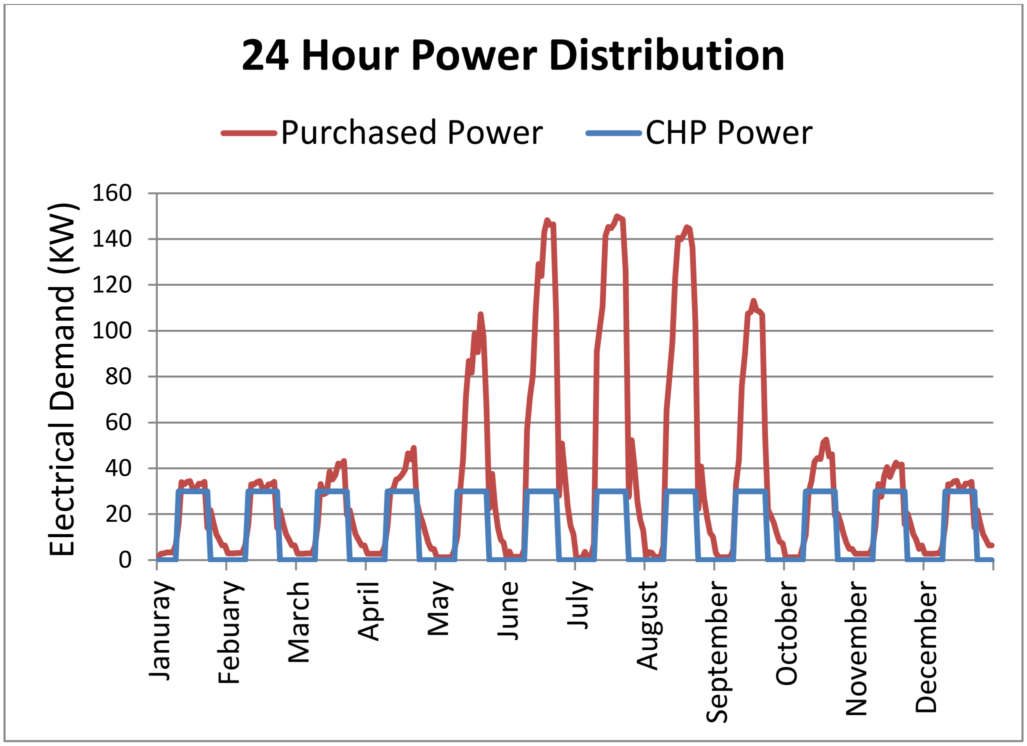

Figure 24: Power distribution from CHP power and purchased power

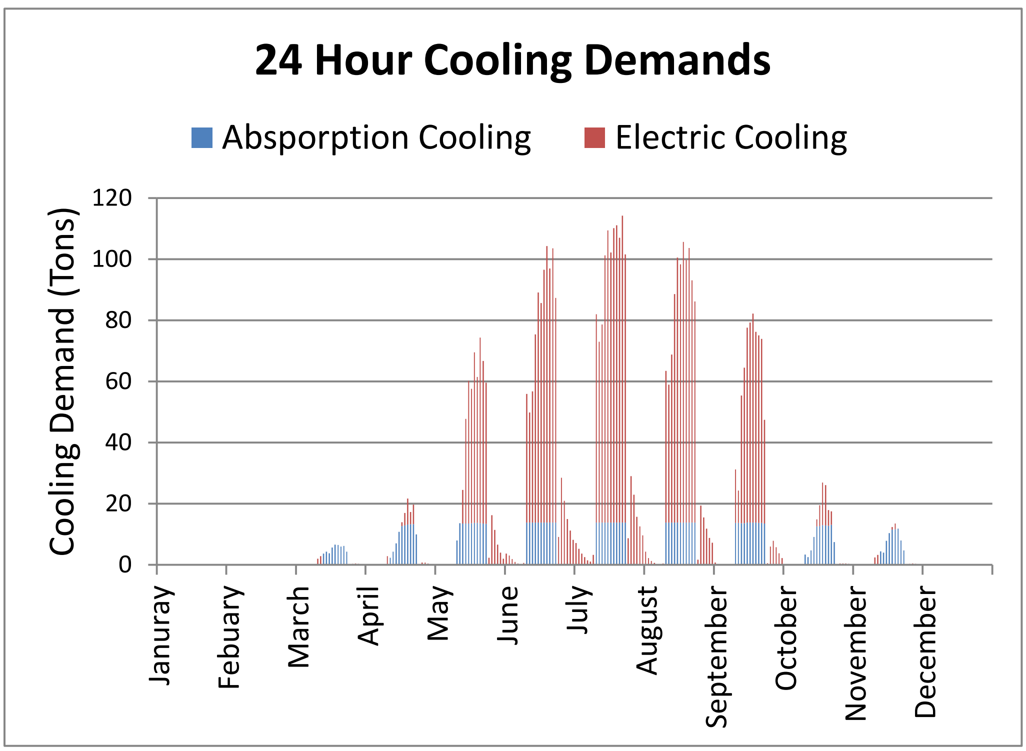

Figure 25: Cooling demands satisfied by absorption and electric power month

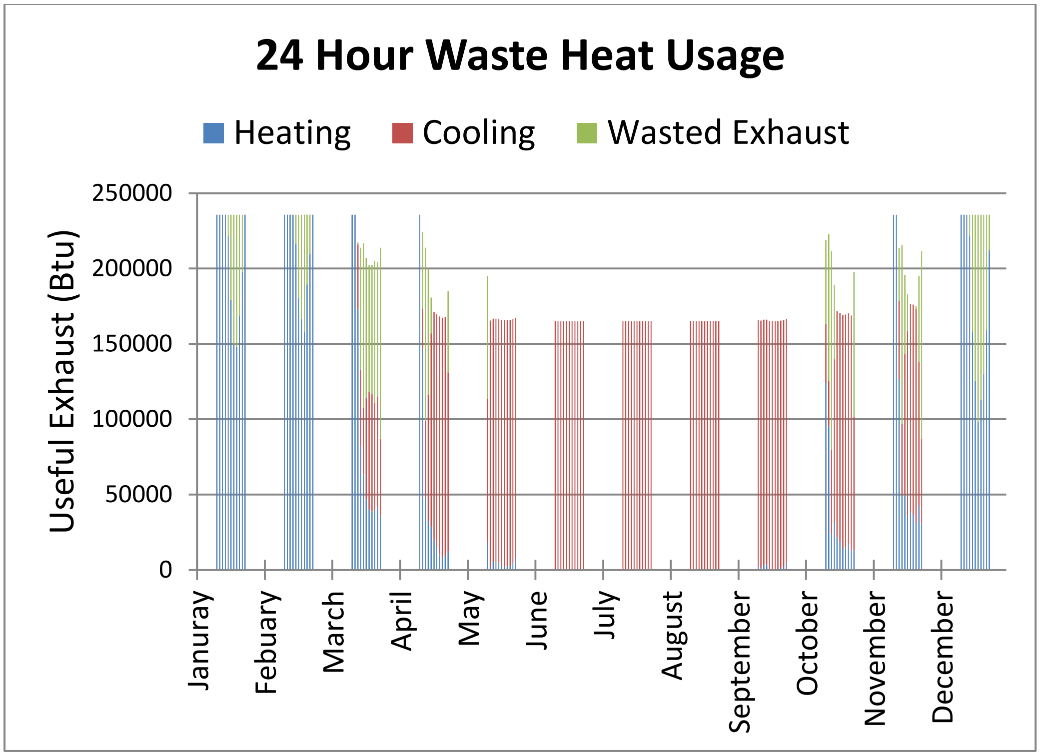

Figure 26: 24 hour waste heat usage

Primary Fuel Utilization Efficiency

Besides economical costs, another reason designers choose CHP systems over SHP systems if the ability to increase overall fuel efficiency. Primary Fuel Utilization Efficiency (PFUE) is the total amount of fuel input compare to the total amount of useful energy output. A microcturbine has a poor electrical efficiency and poor heat recovery unit efficiency, but when you put them together it can be significantly better than a SHP system. Another important term used is percent fuel savings ratio (PFESR). This is the savings ratio from CHP compared to SHP. Figure 27 below shows this particular PUEF for Father O'Connell Hall CHP system compared to the current SHP system, as well as the PFESR, as a function of λ_D. λ_D is the driving factor in these calculations. Analyzing the graph below it is easy to see that when λ_D is smaller than 0.7 that SHP has a higher PUEF. This is because the thermal load is so small that the useful waste heat from the microturbine is being wasted. Maximum PUEF is achieved at $\lambda_D = 2.3$. Between $\lambda_D = 0.7$ and $\lambda_D = 2.3$ the CHP exhaust satisfies the building thermal demand. As gets λ_D grows larger than 2.3 a supplemental boiler is needed to satisfy the buildings thermal demand, but the PFESR is still greater than zero. In addition to thermal load, the resulting electrical load must also be analyzed as a function of λ_D. The graph below shows the fraction of electrical load produced by the CHP system and the fraction of the electrical load purchased from the grid on the secondary axis. As you can see the fraction of FED, GTD becomes negative at $\lambda_D = 1.7$ and FED, CHP =1. This means at $\lambda_D = 1.7$, 100% of the electrical load is met by the CHP system. As λ_D

increases, more electricity is produced than is required by the building and the excess electricity can be sold back to the grid which results in losing money. This further narrows the cost effective operating range of λ_D to 0.7 to 1.7.

CHP INPUT		
η_{CHP}	0.26	
KW Produced	30	kw
Net Heat Rate	13100	btu/kw
η_{HRU}	0.6	
η_B	0.84	
η_{GTD}	0.33	
Absorption Chiller COP	0.7	

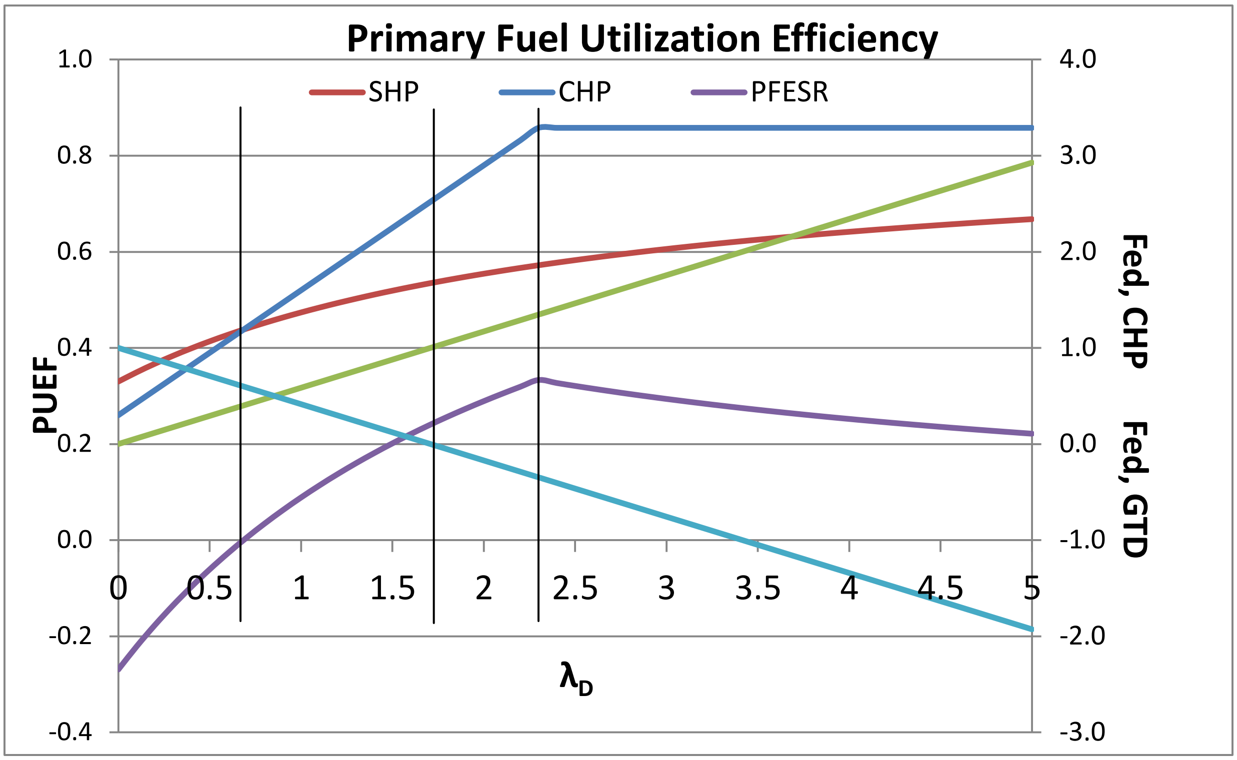

Figure 27: Primary fuel utilization efficiency for CHP and SHP

The following graph shown in Figure 28 shows actual hourly calculated λ_D for Father O'Connell Hall. The hours shown are only from 8:00 AM to 6:00 PM for every month because this will be the only time the microturbine will be running. This is the most cost effective solution. The following cost analysis section will explain in more detail. From Figure 28 it is easy to see the λ_D are not the most ideal, although, many of the points are within the PFESR range. During the summer months, the thermal load is not large enough for the CHP system to be successful. The little thermal load that exists is strictly from the absorption chillers that require the useful waste heat from the microturbine.

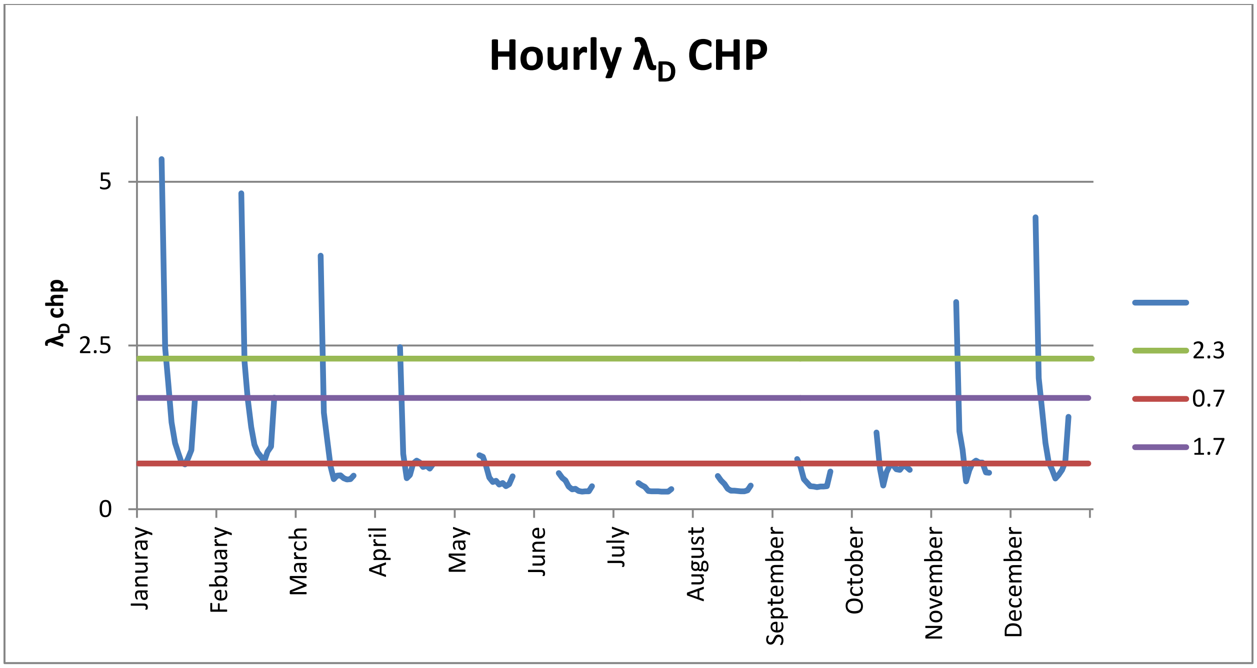

Figure 28: Hourly for λ_D Father O'Connell Hall

Economic Cost Analysis

An economic cost analysis was done to determine how much potential money this particular CHP system has can save. Two main factors determined the savings of the CHP system; size of the microturbine and number of hours of operation per day. Different combinations were analyzed to find the maximum savings per year. Figure 29 below shows the final results. The analysis shows that both the 30 KW and 65 KW microturbines save approximately $7,300 when operating between the hours of 8:00 AM and 6:00 PM. This is when most of the heating and cooling loads occur when the building is occupied. Outside of these hours the building loads are greatly decreased causing an excess amount of heat and power; selling electricity back to the grid. Selling power back to the grid rarely returns a profit since the microturbine produces electricity much less efficiently. Also, utility companies buy power much cheaper than they can sell it as a further incentive not to over produce electricity. All cost analysis tables can be found Appendix C.

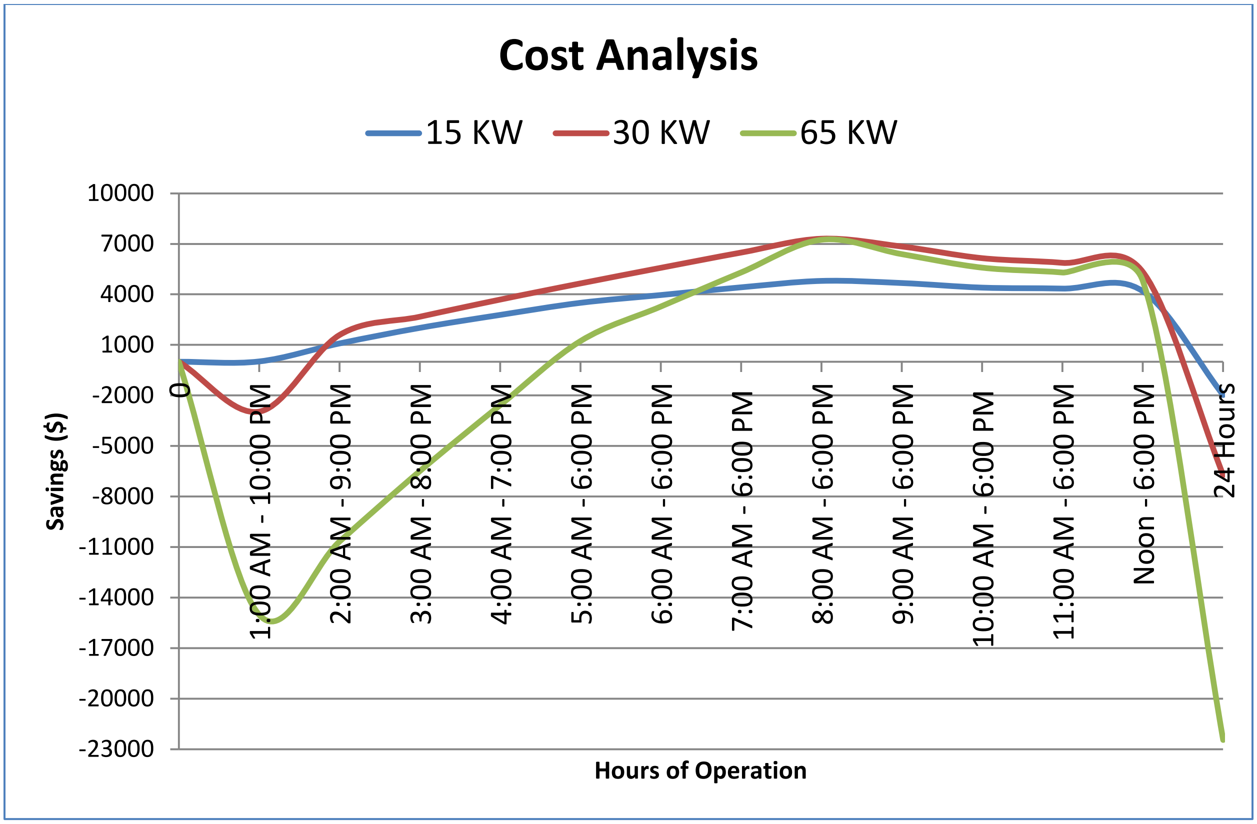

Figure 29: Cost analysis for CHP systems

A simple payback period was calculated to be approximately 14 years. This is a long term investment that most companies will not do. Detailed calculations can be seen in Table 24 below and in Appendix C. EPA was used for microturbine cost while RS Means was used for the other mechanical equipment costs.

Equipment	Installed Cost		
	Cost	CHP	SHP
500 MBH Condensing Boiler	$ 11,206.00	$0.00	$22,412.00
600 MBH Condensing Boiler	$ 14,483.00	$14,483.00	$0.00
20 Ton Absorption Chiller	1250 $/Ton	$25,000.00	$0.00
30 KW Microturbine	2790 $/KW	$83,700.00	$0.00
	Total	$123,183.00	$22,412.00
	Savings	$ 7,304.90	
	Payback Period	13.8	Years

Table 24: Simple payback period

Emissions

Combined heat and power systems should greatly reduce the amount of emissions released into the environment, as well as reduce the overall fuel consumption. With the simultaneous production of heat and power, combined heat and power systems can be as efficient at 75%. Generally, power plants dump the waste heat from producing electricity into the atmosphere reducing the efficiency to around 33%, including transportation and distribution losses.

An emissions analysis was done to see how applying a CHP system to Father O'Connell Hall affected the emissions released into the environment. For these calculations, an educational spreadsheet available on the U.S. Environmental Agency's website was used. This spreadsheet requires specific inputs according to the building. This spreadsheet also accounts for the specific efficiency and emissions caused by off-site power generation. Figure 30 below is the resultant summary of Father O'Connell Hall emissions generated by the EPA spreadsheet. Father O'Connell Hall reduces NO_x by 89%, CO2 by 47%, and total fuel consumption by 27%.

Annual Emissions Analysis					
	CHP System	Displaced Electricity Production	Displaced Thermal Production	Emissions/Fuel Reduction	Percent Reduction
NO_x (tons/year)	0.03	0.29	0.00	0.26	89%
SO_2 (tons/year)	0.00	1.19	0.00	1.19	100%
CO_2 (tons/year)	84	159	0	75	47%
CH_4 (tons/year)	0.00	0.007	0.00	0.005	77%
N_2O (tons/year)	0.00	0.001	0.00	0.001	88%
Total GHGs (CO_2e tons/year)	84	160	0	76	47%
Carbon (metric tons/year)	21	39	0	19	47%
Fuel Consumption (MMBtu/year)	1,437	1,961	1	525	27%
Number of Equivalent Cars Removed				12	
Number of Equivalent Homes Removed				4	

Figure 30: Father O'Connell Hall emissions summary. Spreadsheet generated by U.S. EPA.

Other Contributing Factors

Not all variables and options were explored for CHP systems. One significant factor that could play a role in the CHP design is the ambient air temperature. As shown in Figure 31 below, the power output and efficiency varies with ambient temperature. Colder air temperatures produce higher power outputs and electrical efficiencies than warmer air temperatures. These variations in ambient air temperatures were not taken into account for in the previous calculations.

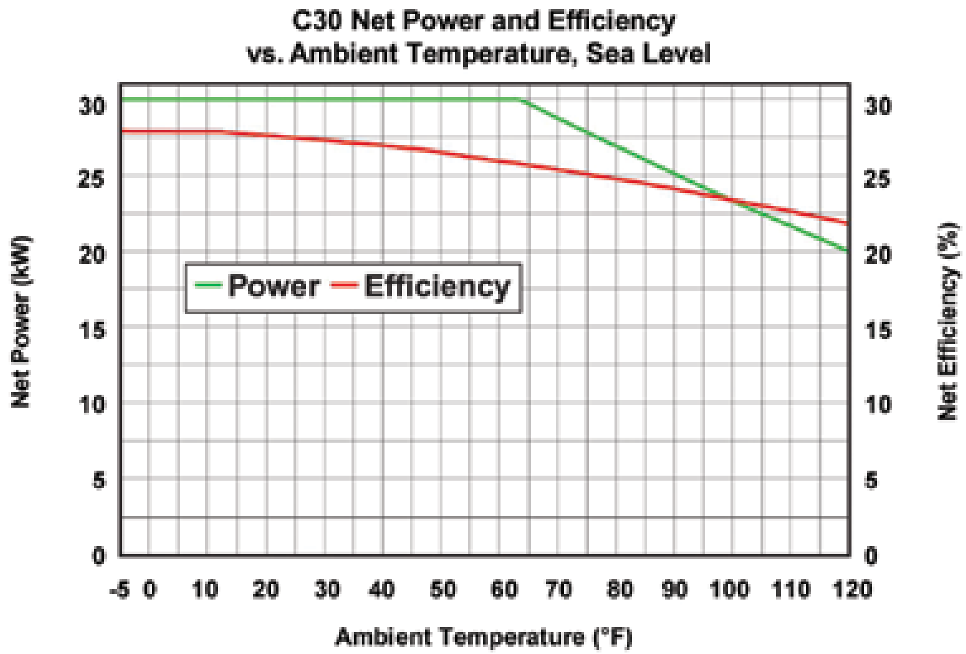

Figure 31: Net power vs ambient air temperatures

Another factor that could improve the CHP design that was not considered is the addition of a duct burner. A duct burner burns additional gas to increase the temperature of the exhaust to provide a greater thermal load capacity. A duct burner is much more efficient than a boiler. This is because the exhaust temperature is already at a higher temperature than the ambient air temperature that a boiler uses for combustion. Furthermore, duct burners have a much higher efficiency for part loading than boilers. One environmental concern when using duct burners is the release of NO_x into the atmosphere. NO_x can occur when the combustion process reaches a temperature over 1450 ^{o}F.

Combined Heat and Power Summary and Recommendations

In conclusion, combined heat and power systems, especially coupled with absorption chillers, can be extremely efficient and cost effective systems given the right building load profiles. CHP systems have the potential to provide reliable power, reduce emissions, and improve overall efficiencies. Unfortunately, Father O'Connell Hall did not meet the typical power to heat ratios that are required for a successful CHP system. Although, the CHP system was not successful on an economic basis, it was also not a complete failure. It did cut a significant amount of emissions and fuel consumption. In addition, it provides a reliable power source in case of a black out or brownout from the grid. Absorption cooling was neither able to decrease significant electrical loads in the summer time nor produce a large portion of the cooling load, which contributes to the unsuccessful system.

Although, implementing a CHP system for Father O'Connell Hall is not recommended, CHP systems could play a big part by cutting emissions and increasing overall efficiencies in the future. CHP systems should be on the rise in this country with the increase in Marcellus shale gas and the continued decrease in natural gas prices and could be a viable option for many building types.

Electrical Breadth

When installing a CHP system tying the system into the original electrical design is important. Father O'Connell Hall emergency power currently runs on a 150KW diesel fuel generator that connects to three automatic transfer switches. These switches connect to the outdoor emergency lighting, indoor emergency lighting, and the elevator. Ideally, this 150 KW emergency generator would be replaced by a duel fuel prime mover which would significantly cut capital costs for the CHP system and reduce the payback period. Unfortunately, because of the low power and thermal loads of Father O'Connell Hall, the 30 KW microturbine does not have enough capacity to power these emergency panels at the same time.

The current electrical distribution at Father O'Connell Hall is one 208/120V, 3000A switchboard with a total connected load of 1956A or 704,757 VA. Capstone C30 microturbine has a maximum output current of 46A. The current switchboard size is large enough to accommodate the extra 46A, but a low voltage paralleling switchgear is needed to supply power from both the grid and microturbine. A low voltage paralleling switchgear syncs power from two or more sources and produces a smooth, constant power output. This increases reliability and adds more redundancy in case the grid goes down. In addition, a step down transformer must be added because the microturbine power is 480V while the switchgear and voltage loads are supplied at 208/120V. With the addition of a microturbine, the emergency loads could be added an extra level of redundancy in case the grid and emergency generator go down. These emergency loads are not critical and the extra level of redundancy is not necessary. Figure 32 below shows an electrical distribution one line diagram for Father O'Connell Hall including all electrical equipment, connections, and wire sizes according to the 2011 National Electrical Code. All wire sizes are based off the original loads of the building.

Part of the electrical breadth also included analyzing optimal hours for the microturbine to maximize economical cost. This included when and how much electricity to produce on-site and how much to purchase from off-site generation, as well as selling electricity back to the grid. Since the utility company in Washington, DC would only buy electricity back at $0.03 per KWh and the microturbine is only 26% efficient, selling electricity back was kept at a minimum. Figure 24 on page 52 shows the power distribution from on-site and off-site generation.

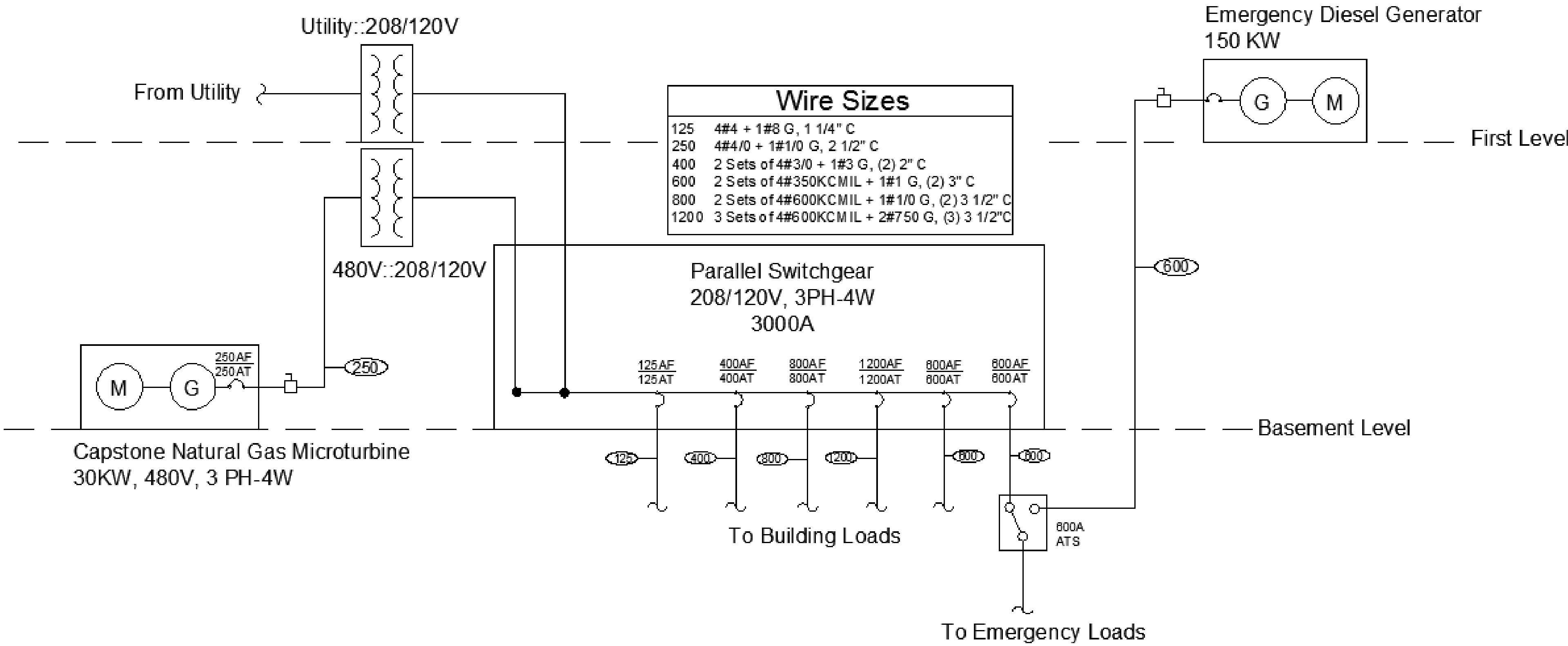

Figure 32: Electrical one line diagram

Acoustical Breadth

Indoor occupant comfort should be a primary concern for any building designer. Acoustic emissions are sometimes overlooked, but are one of the most important factors when considering overall occupant comfort and health. It is important for a University administrative office building to have comfortable employees to improve productivity.

Any mechanical equipment has the potential to cause unwanted background noises and vibrations. Father O'Connell Hall has three indoor air handling units placed adjacent to sound sensitive spaces. Table 25 below shows all sound sensitive spaces with the current wall sound transmission class rating (STC) and the required STC rating as specified by American National Standard Institute S12.60. The STC is a measure of airborne sound blocked from transmitting through a partition. A higher STC rating will allow more background noise into the adjacent space. As seen in Table 25 all wall STC rating comply with ANSI S12.60. There is specific acoustic sealant and insulation that must be installed properly to meet these standards.

Equipment	Adjacent Rooms	Partition Type	Partion Description	STC	Target STC
AHU-4	Open Office	1A3B	1 layer 5/8" GWB each side of 3 5/8" metal Studs 16" OC Acoustic Sealant and 2 12" acoustic insulation	45	45
OAHU-1	Executive Office	0A3A	1 layer 5/8" GWB each side of 3 5/8" metal Studs 16" OC Acoustic Sealant and 2 12" acoustic insulation	45	45
OAHU-1	Corridor	0A3B	2 layer 5/8" GWB each side of 3 5/8" metal Studs 16" OC Acoustic Sealant and 2 12" acoustic insulation	45	45
AHU-6	Restroom	1A3	1 layer 5/8" GWB each side of 3 5/8" metal Studs 16" OC	51	53

Table 25: Wall STC ratings for adjacent rooms to mechanical spaces

Not only can sound travel through walls, but it can also travel through air ducts. To analyze the sound transmitted to adjacent rooms through air ducts Dynasonics free software AIM was used. Two cases were analyzed. The first is OAHU-1 adjacent to an executive office on the fourth floor and the second is on the basement floor where AHU-4 is adjacent to an open office area. Both potential acoustic issues can be seen below in Figures 33 and 34.

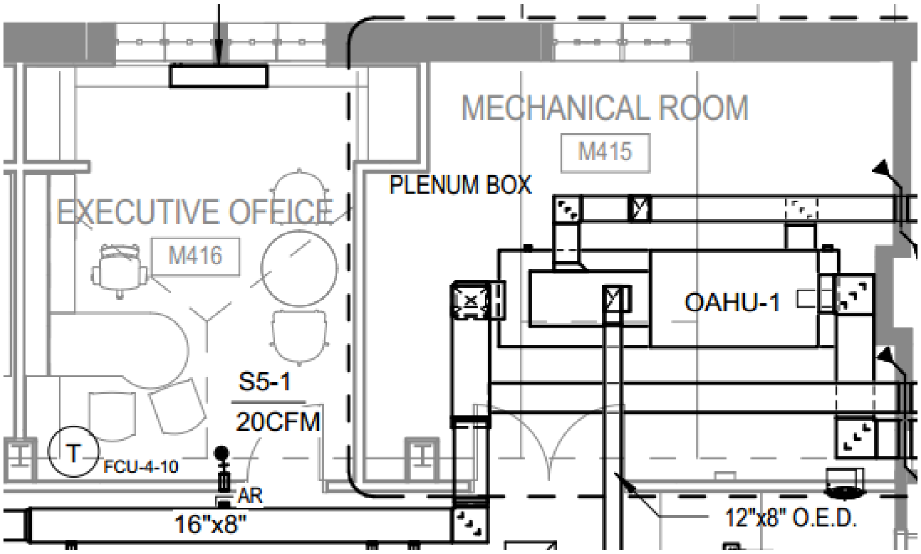

Figure 33: OAHU-1 potential acoustic issue directly adjacent to executive office on fourth floor

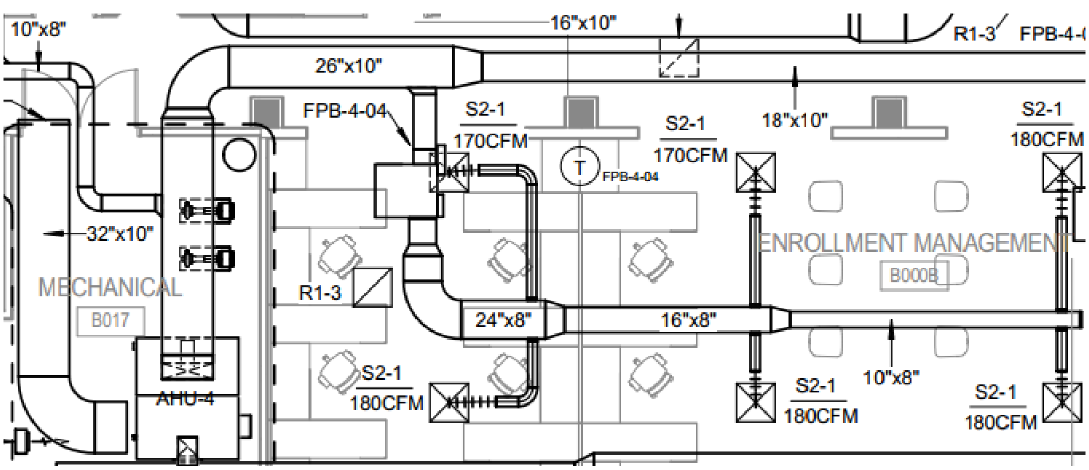

Figure 34: AHU-4 potential acoustic issue directly to open office on basement floor

Figure 35 on the next page shows the results from AIM software for the first case. Figure 35 shows each sound power level at the seven octave midband frequencies. The sound power levels follow the ducts from the air handling units to the diffuser in the room.

OAHU-1 Office

Calculation Summary

	Element	Properties	NC	63	125	250	500	1K	2K	4K	dB(A)
				Octave Midband Frequency, Hz							
11	**OAHU-1 Office**	**Criteria: NC-30**	**48**	**50**	**48**	**50**	**47**	**49**	**46**	**42**	**53**
12	**Supply Path (1)**	**Criteria: NC-30**									
13	OAHU-1			90	80	80	76	74	71	68	
14	Rectangular Duct	16"x8"x10' (0")		-3	-2	-1	-1	-1	-1	-1	
15	Rectangular Elbow Miter	16"x8" (0")		0	-1	-5	-8	-4	-3	-3	
				68	64	59	54	47	39	31	
16	Rectangular Duct	16"x8"x15' (0")		-5	-3	-2	-1	-1	-1	-1	
17	Takeoff (Branch Power Split)	16"x8" / 8"x8"		-5	-5	-5	-5	-5	-5	-5	
				66	63	59	53	47	40	32	
18	Takeoff (Branch Power Split)	16"x8" / 8"x8"		-5	-5	-5	-5	-5	-5	-5	
				45	41	35	29	22	14	5	
19	Takeoff (Branch Power Split)	16"x8" / 18"x8"		-2	-2	-2	-2	-2	-2	-2	
				21	15	9	1	0	0	0	
20	End Reflection Loss	8" (Flush)		-16	-10	-5	-2	-1	0	0	
21	Room Correction (Normally Furnished)	17'x14'x10'		-4	-5	-6	-7	-8	-9	-10	
22	**SUM**		**48**	**50**	**48**	**50**	**47**	**49**	**46**	**42**	**53**

Figure 35: AIM software results for OAHU-1 adjacent to executive office

Figure 36 below shows the resulting NC curve for the office. The resulting NC is 48 which is higher than the ANSI S12.60 NC-30. This NC can be achieved by the addition of duct insulation or a duct silencer. The small executive office and close proximity to the air handling unit and short duct runs to the diffuser contributes to this loud background noise level in the room.

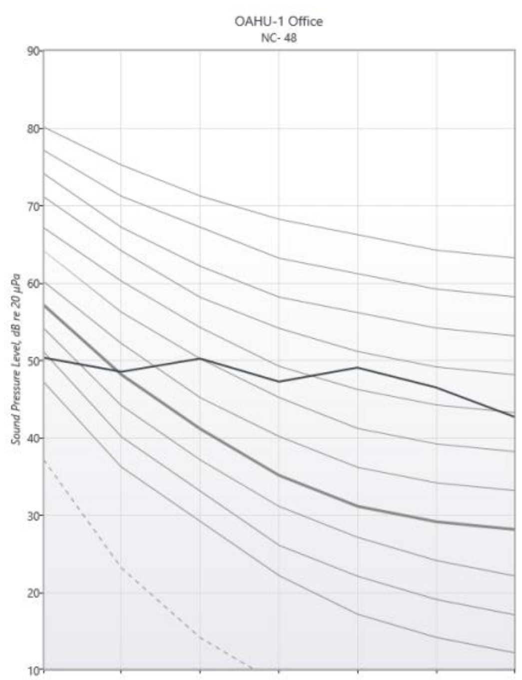

Figure 36: NC Curve for OAHU-1 executive office

Figures 37 and 38 below show the same AIM software results for AHU-4 adjacent to open office case as the OAHU-1 case. The open office does not exceed the NC rating of 40. This is because open offices are allowed less strict background noises than private offices. In addition, the large room correction reduces a large portion of sound power as seen in line 9 in figure 37.

AHU-4 open office

Calculation Summary

				Octave Midband Frequency, Hz							
Element		Properties	NC	63	125	250	500	1K	2K	4K	dB(A)
1	AHU-4 open office	Criteria: NC-40	39	48	55	43	37	35	33	21	43
2	Supply Path (1)	Criteria: NC-40									
3	AHU-4			65	85	66	56	57	58	49	
4	Rectangular Duct	28"x12"x15' (0")		-5	-3	-2	-1	-1	-1	-1	
5	Rectangular Elbow Radius	28"x12" (0")		0	-1	-2	-3	-3	-3	-3	
				13	13	13	11	9	6	2	
6	Rectangular Duct	28"x12"x10' (0")		-3	-2	-1	0	0	0	0	
7	Rectangular Duct	26"x10"x35' (0")		-13	-7	-4	-2	-2	-2	-2	
8	Takeoff (Branch Power Split)	26"x10" / 26"x10"		-4	-4	-4	-3	-3	-3	-3	
				60	57	52	47	41	34	26	
9	Room Correction (Normally Furnished)	75'x25'x10'		-12	-13	-13	-13	-14	-16	-19	
10	SUM		39	48	55	43	37	35	33	21	43

Figure 37: AIM software results for AHU-4 adjacent to open office

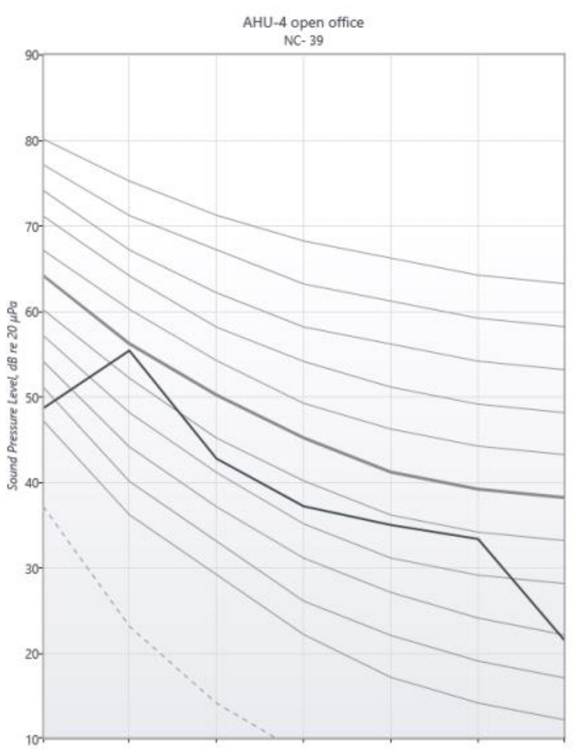

Figure 38: NC Curve for AHU-4 adjacent to open office

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Appendix A: ASHRAE 62.1 Ventilation Spreadsheet

(E)AHU-2

Room No.	Room Description	Az Floor area SF	Pz Zone population	Table 6.1 Space Type	P/100SQFT Occupant Density	Pz Calculate Occupants	Rp Table 6.1 cfm/person	Ra Table 6.1 cfm/sf	Pz*Rp People OA cfm	Az*Ra Area OA cfm	Ez Zone air distribution effectiveness	Voz corrected OA cfm	Vpz Primary airflow to the zone	Max Zp Primary OA air fraction
E120	Office space	155	1	Office Space	5	0.0	5	0.06	5	9	0.8	18	200	0.09
E119	Office space	200	1	Office Space	5	0.0	5	0.06	5	12	0.8	21	410	0.05
EC117	Corridors	261	0	Corridors	0	0.0	0	0.06	0	16	0.8	20	340	0.06
E118	Office space	167	1	Office Space	5	0.0	5	0.06	5	10	0.8	19	210	0.09
E116	Conference/meeting	119	4	Conference/Meeting	50	0.0	5	0.06	20	7	1	27	90	0.30
E115	Conference/meeting	115	4	Conference/Meeting	50	0.0	5	0.06	20	7	1	27	90	0.30
E114	Conference/meeting	113	4	Conference/Meeting	50	0.0	5	0.06	20	7	1	27	90	0.30
E113	Conference/meeting	207	10	Conference/Meeting	50	0.0	5	0.06	50	12	1	62	200	0.31
	Corridors	210	0	Corridors	0	0.0	0	0.06	0	13	0.8	16	100	0.16
E102	Reception areas	933		Reception Areas	30	28.0	5	0.06	140	56	0.8	245	1600	0.15
	Other (storage, telecom closet	20	0	Storage	0	0.0	0	0.00	0	0	0.8	0	10	0.00
E108	Office space	980	11	Office Space	5	0.0	5	0.06	55	59	0.8	142	1050	0.14
E200	Other (storage, telecom closet	33	0	Storage	0	0.0	0	0.00	0	0	1	0	10	0.00
E111	Conference/meeting	800	70	Conference/Meeting	50	0.0	5	0.06	350	48	1	398	1600	0.25
EC102	Corridors	523	0	Corridors	0	0.0	0	0.06	0	31	0.8	39	310	0.13
E105	Other (storage, telecom closet	37	0	Storage	0	0.0	0	0.00	0	0	0.8	0	10	0.00
E104	Janitor closets, trash rooms, re	28	0	Janitor Closet	0	0.0	0	0.00	0	0	0.8	0	10	0.00
E106	Toilets, public	291	0	Toilet	0	0.0	0	0.00	0	0	0.8	0	50	0.00
E107	Toilets, public	222	0	Toilet	0	0.0	0	0.00	0	0	0.8	0	210	0.00
E100	Lobbies/Main entry lobbies (of	802		Main Entry Lobbies	10	8.0	5	0.06	40	48	0.8	110	1200	0.09
		6,216	106						710	335.1		1,171	7,790	0.31

AHU-4

Room No.	Room Description	Az Floor area SF	Pz Zone population	Table 6.1 Space Type	P/100SQFT Occupant Density	Pz Calculate Occupants	Rp Table 6.1 cfm/person	Ra Table 6.1 cfm/sf	Pz*Rp People OA cfm	Az*Ra Area OA cfm	Ez Zone air distribution effectiveness Table 6.2	Voz corrected OA cfm	Vpz Primary airflow to the zone	Max Zp Primary OA air fraction
B000B	Enrollment Management	1697	30	Office Space	5	0.0	5	0.06	150	102	0.8	315	1740	0.18
B000A	Corridor	539	0	Corridors	0	0.0	0	0.06	0	32	0.8	40	200	0.20
B001	Central File	663	0	Office Space	5	0.0	5	0.06	0	40	0.8	50	200	0.25
B002A	Corridor	840	0	Corridors	0	0.0	0	0.06	0	50	0.8	63	310	0.20
B002	Toilet	71	1	Toilet	0	0.0	0	0.00	0	0	0.8	0	0	0.00
B003	Toilet	59	1	Toilet	0	0.0	0	0.00	0	0	0.8	0	0	0.00
B004	Janitor Closet	38	0	Janitor Closet	0	0.0	0	0.00	0	0	0.8	0	0	0.00
B006	Furniture Storage	283	0	Storage	0	0.0	0	0.00	0	0	0.8	0	140	0.00
B007	office	237	2	Office Space	5	0.0	5	0.06	10	14	0.8	30	180	0.17
B0011	Office	160	1	Office Space	5	0.0	5	0.06	5	10	0.8	18	160	0.11
B0012	Executive Office	184	1	Office Space	5	0.0	5	0.06	5	11	0.8	20	180	0.11
B0013	Project Room	384	2	Office Space	5	0.0	5	0.06	10	23	0.8	41	300	0.14
B0014	Corridor	150	0	Corridors	0	0.0	0	0.06	0	9	0.8	11	60	0.19
B0016	Storage	334	0	Storage	0	0.0	0	0.00	0	0	0.8	0	240	0.00
BC018	Corridor	324	0	Corridors	0	0.0	0	0.06	0	19	0.8	24	140	0.17
		5,963	38						180	310.68		613	3,850	0.25

AHU-5

Room No.	Room Description	Az Floor area SF	Pz Zone population	Table 6.1 Space Type	P/100SQFT Occupant Density	Pz Calculate Occupants	Rp Table 6.1 cfm/person	Ra Table 6.1 cfm/sf	Pz*Rp People OA cfm	Az*Ra Area OA cfm	Ez Zone air distribution effectiveness Table 6.2	Voz corrected OA cfm	Vpz Primary airflow to the zone	Max Zp Primary OA air fraction
M101	The Great Hall	4572	200	Multi-Use Assembly (educational)	100	0.0	8	0.06	1500	274	1.2	1479	7750	0.19
		4,572	200						1500	274.32		1,479	7,750	0.19

AHU-6

Room No.	Room Description	Az Floor area SF	Pz Zone population	Table 6.1 Space Type	P/100SQFT Occupant Density	Pz Calculate Occupants	Rp Table 6.1 cfm/person	Ra Table 6.1 cfm/sf	Pz*Rp People OA cfm	Az*Ra Area OA cfm	Ez Zone air distribution effectiveness Table 6.2	Voz corrected OA cfm	Vpz Primary airflow to the zone	Max Zp Primary OA air fraction
WC101	Corridor	272	0	Corridors	0	0.0	0	0.06	0	16	0.8	20	120	0.17
W102	Break Rooms	628	19	Break Rooms (general)	25	0.0	5	0.12	95	75	0.8	213	860	0.25
W103	Janitor closet	27	0	Janitor	0	0.0	0	0.00	0	0	0.8	0	0	0.00
W104	Toilet	57	1	Toilet	0	0.0	0	0.00	0	0	0.8	0	0	0.00
W105	Toilet	57	1	Toilet	0	0.0	0	0.00	0	0	0.8	0	0	0.00
W106	Catering Prep	732	4	Kitchen (cooking, food/bevera	20	0.0	8	0.12	30	88	0.8	147	1630	0.09
W106A	Storage	34	0	Storage	0	0.0	0	0.00	0	0	0.8	0	10	0.00
		1,807	25						125	179.52		381	2,620	0.25

OAHU-1

Room No.	Room Description	Az Floor area SF	Pz Zone population	Table 6.1 Space Type	P/100SQFT Occupant Density	Pz Calculate Occupants	Rp Table 6.1 cfm/person	Ra Table 6.1 cfm/sf	Pz*Rp People OA cfm	Az*Ra Area OA cfm	Ez Zone air distribution effectiveness Table 6.2	Voz corrected OA cfm	Vpz Primary airflow to the zone	Max Zp Primary OA air fraction
W201	Meeting	103	4	Conference/Meeting	50	0.0	5	0.06	20	6	1	26	30	30
W202	Workstations	995	12	Office Space	5	0.0	5	0.06	60	60	1	120	120	120
W204	Office	146	1	Office Space	5	0.0	5	0.06	5	9	1	14	20	20
W205	Office	149	1	Office Space	5	0.0	5	0.06	5	9	1	14	20	20
W206	Office	146	1	Office Space	5	0.0	5	0.06	5	9	1	14	20	20
M200	2nd FL West Vestibule	543	4	Office Space	5	0.0	5	0.06	20	33	1	53	60	70
M201	Womens Toilet	66	1	Toilet	0	0.0	0	0.00	0	0	1	0	0	0
M202	Mens Toilet	66	1	Toilet	0	0.0	0	0.00	0	0	1	0	0	0
W300	Enrollment Services	346	0	Corridors	0	0.0	0	0.06	0	21	1	21	30	30
W301	Office	185	1	Office Space	5	0.0	5	0.06	5	11	1	16	20	20
W302	Office	147	1	Office Space	5	0.0	5	0.06	5	9	1	14	20	20
W303	Executive Office	185	1	Office Space	5	0.0	5	0.06	5	11	1	16	20	20
W304	Office	158	1	Office Space	5	0.0	5	0.06	5	9	1	14	20	20
W305	Workstations	849	10	Office Space	5	0.0	5	0.06	50	51	1	101	110	110
M300	3rd FL vestibule	452		Main Entry Lobbies	10	4.5	5	0.06	23	27	1	50	50	100
M301	IMG Room	162	1	Computer Lab (educational)	25	0.0	10	0.12	10	19	1	29	30	50
M301B	Storage	78	0	Storage	0	0.0	0	0.00	0	0	1	0	0	0
M305	Meeting	129	4	Conference/Meeting	50	0.0	5	0.06	20	8	1	28	30	30
M306	Office	159	1	Office Space	5	0.0	5	0.06	5	10	1	15	20	20
M307	Office	159	1	Office Space	5	0.0	5	0.06	5	10	1	15	20	20
M308	Files	117	0	Storage	0	0.0	0	0.00	0	0	1	0	0	0
M309	Mens Toilet	143	3	Toilet	0	0.0	0	0.00	0	0	1	0	0	0
M310	Womens Toilet	143	3	Toilet	0	0.0	0	0.00	0	0	1	0	0	0
M311	Files	116	0	Storage	0	0.0	0	0.00	0	0	1	0	0	0
M312	Office	153	1	Office Space	5	0.0	5	0.06	5	9	1	14	20	20
M313A	Asst Manager Office	140	2	Office Space	5	0.0	5	0.06	10	8	1	18	20	20
M313B	Work Study	243	4	Office Space	5	0.0	5	0.06	20	15	1	35	40	40
MC302	Corridors	950	0	Corridors	0	0.0	0	0.06	0	57	1	57	60	60
M302A	Files	86	0	Storage	0	0.0	0	0.00	0	0	1	0	0	0
M314	Office	162	1	Office Space	5	0.0	5	0.06	5	10	1	15	20	20
M315	Office	161	1	Office Space	5	0.0	5	0.06	5	10	1	15	20	20
M316	Office	175	1	Office Space	5	0.0	5	0.06	5	11	1	16	20	20
M317	Office	162	1	Office Space	5	0.0	5	0.06	5	10	1	15	20	20
M318	Office	161	1	Office Space	5	0.0	5	0.06	5	10	1	15	20	20
M319	Office	174	1	Office Space	5	0.0	5	0.06	5	10	1	15	20	20
M320	Office	162	1	Office Space	5	0.0	5	0.06	5	10	1	15	20	20
M321	Office	165	1	Office Space	5	0.0	5	0.06	5	10	1	15	20	20
M303	Reception/waiting	322	5	Reception Areas	30	0.0	5	0.06	25	19	1	44	50	70
M400	Events	783	20	Conference/Meeting	50	0.0	5	0.06	100	47	1	147	150	250
M401	Elevator Lobby/Waiting	219	6	Main Entry Lobbies	10	0.0	5	0.06	30	13	1	43	50	50
M402	Executive Assistant	104	1	Office Space	5	0.0	5	0.06	5	6	1	11	20	20
MC403	Corridors	993	0	Corridors	0	0.0	0	0.06	0	60	1	60	60	60
M404	Meeting	155	4	Conference/Meeting	50	0.0	5	0.06	20	9	1	29	30	30
M405	Furniture Storage	159	0	Storage	0	0.0	0	0.00	0	0	1	0	0	0
M406	Files	114	0	Storage	0	0.0	0	0.00	0	0	1	0	0	0
M407	Mens Toilet	143	1	Toilet	0	0.0	0	0.00	0	0	1	0	0	0
M408	Womens Toilet	143	1	Toilet	0	0.0	0	0.00	0	0	1	0	0	0
M409	Files	123	1	Storage	0	0.0	0	0.00	0	0	1	0	0	0
M411	Meeting	153	4	Conference/Meeting	50	0.0	5	0.06	20	9	1	29	30	30
M412	EM Techs	150	2	Office Space	5	0.0	5	0.06	10	9	1	19	20	20
M413	Office	178	1	Office Space	5	0.0	5	0.06	5	11	1	16	20	20
M414	Storage	77	0	Storage	0	0.0	0	0.00	0	0	1	0	0	0
M416	Executive Office	217	1	Office Space	5	0.0	5	0.06	5	13	1	18	20	20
M417	Executive Office	217	1	Office Space	5	0.0	5	0.06	5	13	1	18	20	20
M418	Executive Office	315	1	Office Space	5	0.0	5	0.06	5	19	1	24	30	30
M419	Executive Conference	153	6	Conference/Meeting	50	0.0	5	0.06	30	9	1	39	40	30
M420	Executive Conference	320	12	Conference/Meeting	50	0.0	5	0.06	60	19	1	79	80	80
M421	Meeting	188	4	Conference/Meeting	50	0.0	5	0.06	20	11	1	31	40	50
									663	747		1,410	1,600	1,800

Appendix B: CHP Calculation Spreadsheet

Legend	
λ_D	Power to heat ratio
$Q_{qD, CHP}$	Thermal demand met by CHP system
$Q_{qD, Boiler}$	Thermal demand met by boiler
$e_{D, CHP}$	Power demand met by CHP system
$e_{D, GTD}$	Power demand met by Grid
$f_{eD,CHP}$	Fraction of electric demand met by CHP system
$f_{eD, GTD}$	Fraction of electric demand met by the Grid
$f_{qD, CHP}$	Fraction of thermal demand met by CHP system
$f_{qD, Boiler}$	Fraction of thermal demand met by the boiler
$ή_{CHP}$	CHP electrical efficency
$ή_{HRU}$	Heat recovery unit efficency
$ή_B$	Boiler efficency
$ή_{GTD}$	Grid transportation and distribution efficency

CHP INPUT	
$ή_{CHP}$	0.26
Turbine KW Produced	30 kw
Net Heat Rate	13100 btu/kw
$ή_{HRU}$	0.6
$ή_B$	0.84
$ή_{GTD}$	0.33
Absorption Chiller COP	0.7

Month	Hour	Electric Demand (KW)	Monthly Electric Consumption (KWh)	Heating (Btu)	Cooling (Tons)	Heat to Power Ratio (λ_{pl})	(λ_p) inclduing absorption cooling	Useful Exhaust (Btu)	$Q_{rp,CHP}$ (Btu)	$Q_{rp,Boiler}$ (Btu)	$e_{p,CHP}$ (KW)	$e_{p,GTD}$ (KW)	Absorption Cooling (Tons)	Electric Cooling (Tons)	Wasted Exhaust (Btu)	$f_{rp,CHP}$	$f_{rp,GTD}$	$f_{sp,CHP}$	$f_{sp,Boiler}$	Monthly Electric Consumption From grid	Sell back to Grid (KW)	Monthly Electric Sell back To Grid	Boiler Fuel Consumption (Therms/h)
January	1	1.22	26.93	0	0	0.00	0	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	26.93	0	0.00	0.000
	2	2.79	61.58	25,045	0	2.63	2.63	0	0	25045	0	3	0	0	0	0.000	1.000	0.000	1.000	61.58	0	0.00	0.250
	3	2.89	63.79	149,776	0	15.19	15.19	0	0	149776	0	3	0	0	0	0.000	1.000	0.000	1.000	63.79	0	0.00	1.498
	4	3.32	73.28	224,807	0	19.84	19.84	0	0	224807	0	3	0	0	0	0.000	1.000	0.000	1.000	73.28	0	0.00	2.248
	5	3.32	73.28	233,113	0	20.58	20.58	0	0	233113	0	3	0	0	0	0.000	1.000	0.000	1.000	73.28	0	0.00	2.331
	6	3.37	74.39	245,193	0	21.32	21.32	0	0	245193	0	3	0	0	0	0.000	1.000	0.000	1.000	74.39	0	0.00	2.452
	7	6.53	144.14	243,605	0	10.93	10.93	0	0	243605	0	7	0	0	0	0.000	1.000	0.000	1.000	144.14	0	0.00	2.436
	8	45.55	1005.42	830,403	0	5.34	5.34	235,800	235800	594603	30	16	0	0	0	0.888	0.112	0.284	0.716	105.42	0	0.00	5.946
	9	64.03	1413.33	538,896	0	2.47	2.47	235,800	235800	303096	30	34	0	0	0	0.632	0.368	0.438	0.562	513.33	0	0.00	3.031
	10	63.07	1392.14	412,184	0	1.92	1.92	235,800	235800	176384	30	33	0	0	0	0.642	0.358	0.572	0.428	492.14	0	0.00	1.764
	11	64.19	1416.86	291,334	0	1.33	1.33	235,800	235800	55534	30	34	0	0	0	0.630	0.370	0.809	0.191	516.86	0	0.00	0.555
	12	64.38	1421.05	221,791	0	1.01	1.01	235,800	221791	0	30	34	0	0	14,009	0.591	0.409	1.000	0.000	521.05	0	0.00	0.000
	13	60.89	1344.02	179,292	0	0.86	0.86	235,800	179292	0	30	31	0	0	56,508	0.505	0.495	1.000	0.000	444.02	0	0.00	0.000
	14	60.81	1342.25	149,512	0	0.72	0.72	235,800	149512	0	30	31	0	0	86,288	0.422	0.578	1.000	0.000	442.25	0	0.00	0.000
	15	63.28	1396.77	148,331	0	0.69	0.69	235,800	148331	0	30	33	0	0	87,469	0.402	0.598	1.000	0.000	496.77	0	0.00	0.000
	16	63.11	1393.02	168,958	0	0.78	0.78	235,800	168958	0	30	33	0	0	66,842	0.459	0.541	1.000	0.000	493.02	0	0.00	0.000
	17	64.08	1414.43	197,948	0	0.91	0.91	235,800	197948	0	30	34	0	0	37,852	0.530	0.470	1.000	0.000	514.43	0	0.00	0.000
	18	44.08	972.97	251,764	0	1.67	1.67	235,800	235800	15964	30	14	0	0	0	0.918	0.082	0.937	0.063	72.97	0	0.00	0.160
	19	21.79	480.97	6,995	0	0.09	0.09	0	0	6995	0	22	0	0	0	0.000	1.000	0.000	1.000	480.97	0	0.00	0.070
	20	16.15	356.48	10,771	0	0.20	0.20	0	0	10771	0	16	0	0	0	0.000	1.000	0.000	1.000	356.48	0	0.00	0.108
	21	11.29	249.20	15,158	0	0.39	0.39	0	0	15158	0	11	0	0	0	0.000	1.000	0.000	1.000	249.20	0	0.00	0.152
	22	8.86	195.57	24,148	0	0.80	0.80	0	0	24148	0	9	0	0	0	0.000	1.000	0.000	1.000	195.57	0	0.00	0.241
	23	6.42	141.71	60,965	0	2.78	2.78	0	0	60965	0	6	0	0	0	0.000	1.000	0.000	1.000	141.71	0	0.00	0.610
	24	6.43	141.93	73,999	0	3.37	3.37	0	0	73999.38	0	6.43	0	0	0	0.000	1.000	0	1	141.93	0	0.00	0.7399938
Febuary	1	2.84	56.71	130,062	0	13.42	13.42	0	0	130062	0	3	0	0	0	0.000	1.000	0.000	1.000	56.71	0	0.00	1.301
	2	2.86	57.11	153,087	0	15.69	15.69	0	0	153087	0	3	0	0	0	0.000	1.000	0.000	1.000	57.11	0	0.00	1.531
	3	2.88	57.51	175,473	0	17.86	17.86	0	0	175473	0	3	0	0	0	0.000	1.000	0.000	1.000	57.51	0	0.00	1.755
	4	3.02	60.30	204,290	0	19.83	19.83	0	0	204290	0	3	0	0	0	0.000	1.000	0.000	1.000	60.30	0	0.00	2.043
	5	3.07	61.30	217,256	0	20.74	20.74	0	0	217256	0	3	0	0	0	0.000	1.000	0.000	1.000	61.30	0	0.00	2.173
	6	3.12	62.30	224,202	0	21.06	21.06	0	0	224202	0	3	0	0	0	0.000	1.000	0.000	1.000	62.30	0	0.00	2.242
	7	6.37	127.19	226,122	0	10.40	10.40	0	0	226122	0	6	0	0	0	0.000	1.000	0.000	1.000	127.19	0	0.00	2.261
	8	45.56	909.72	749,551	0	4.82	4.82	235,800	235800	513751	30	16	0	0	0	0.888	0.112	0.315	0.685	9.72	0	0.00	5.138
	9	63.05	1258.95	486,644	0	2.26	2.26	235,800	235800	250844	30	33	0	0	0	0.642	0.358	0.485	0.515	358.95	0	0.00	2.508
	10	63.05	1258.95	363,156	0	1.69	1.69	235,800	235800	127356	30	33	0	0	0	0.642	0.358	0.649	0.351	358.95	0	0.00	1.274
	11	64.07	1279.32	274,316	0	1.25	1.25	235,800	235800	38516	30	34	0	0	0	0.632	0.368	0.860	0.140	379.32	0	0.00	0.385
	12	64.41	1286.11	216,686	0	0.99	0.99	235,800	216686	0	30	34	0	0	19,114	0.577	0.423	1.000	0.000	386.11	0	0.00	0.000
	13	60.87	1215.43	180,374	0	0.87	0.87	235,800	180374	0	30	31	0	0	55,426	0.509	0.491	1.000	0.000	315.43	0	0.00	0.000
	14	60.78	1213.63	166,446	0	0.80	0.80	235,800	166446	0	30	31	0	0	69,354	0.470	0.530	1.000	0.000	313.63	0	0.00	0.000
	15	63.07	1259.35	158,158	0	0.73	0.73	235,800	158158	0	30	33	0	0	77,642	0.430	0.570	1.000	0.000	359.35	0	0.00	0.000
	16	63.03	1258.56	189,374	0	0.88	0.88	235,800	189374	0	30	33	0	0	46,426	0.516	0.484	1.000	0.000	358.56	0	0.00	0.000
	17	64.08	1279.52	209,503	0	0.96	0.96	235,800	209503	0	30	34	0	0	26,297	0.561	0.439	1.000	0.000	379.52	0	0.00	0.000
	18	44.12	880.97	256,820	0	1.71	1.71	235,800	235800	21020	30	14	0	0	0	0.917	0.083	0.918	0.082	0.00	0	19.03	0.210
	19	21.79	435.09	8,355	0	0.11	0.11	0	0	8355	0	22	0	0	0	0.000	1.000	0.000	1.000	435.09	0	0.00	0.084
	20	16.15	322.48	12,597	0	0.23	0.23	0	0	12597	0	16	0	0	0	0.000	1.000	0.000	1.000	322.48	0	0.00	0.126
	21	11.29	225.43	11,666	0	0.30	0.30	0	0	11666	0	11	0	0	0	0.000	1.000	0.000	1.000	225.43	0	0.00	0.117
	22	8.86	176.91	16,019	0	0.53	0.53	0	0	16019	0	9	0	0	0	0.000	1.000	0.000	1.000	176.91	0	0.00	0.160
	23	6.42	128.19	11,666	0	0.53	0.53	0	0	11666	0	6	0	0	0	0.000	1.000	0.000	1.000	128.19	0	0.00	0.117
	24	6.42	128.19	16,019	0	0.73	0.73	0	0	16019	0	6	0	0	0	0.000	1.000	0.000	1.000	128.19	0	0.00	0.160

Month	Hour	Electric Demand (KW)	Monlthy Electric Consumption (KWh)	Heating (Btu)	Cooling (Tons)	Heat to Power Ratio (λH)	(λH) inclduing absorption cooling	Useful Exhaust (Btu)	Q CHP (Btu)	Q Boiler (Btu)	e CHP (KW)	e GTD (KW)	Absorption Cooling (Tons)	Electric Cooling (Tons)	Wasted Exhaust (Btu)	f CHP	f GTD	f CHP	f Boiler	Monlthy Electric Consumption From grid	Sell back to Grid (KW)	Monlthy Electric Sell back To Grid	Boiler Fuel Consumption (Therms/h)
March	1	2.80	63.60	66,157	0	6.92	6.92	0	0	66157	0	3	0	0	0	0.000	1.000	0.000	1.000	63.60	0	0.00	0.662
	2	2.83	64.28	92,306	0	9.56	9.56	0	0	92306	0	3	0	0	0	0.000	1.000	0.000	1.000	64.28	0	0.00	0.923
	3	2.83	64.28	105,338	0	10.91	10.91	0	0	105338	0	3	0	0	0	0.000	1.000	0.000	1.000	64.28	0	0.00	1.053
	4	2.84	64.51	119,483	0	12.33	12.33	0	0	119483	0	3	0	0	0	0.000	1.000	0.000	1.000	64.51	0	0.00	1.195
	5	2.87	65.19	138,474	0	14.14	14.14	0	0	138474	0	3	0	0	0	0.000	1.000	0.000	1.000	65.19	0	0.00	1.385
	6	2.90	65.87	156,996	0	15.87	15.87	0	0	156996	0	3	0	0	0	0.000	1.000	0.000	1.000	65.87	0	0.00	1.570
	7	6.09	138.33	155,894	0	7.50	7.50	0	0	155894	0	6	0	0	0	0.000	1.000	0.000	1.000	138.33	0	0.00	1.559
	8	45.66	1037.12	603,259	2	3.87	3.87	235,800	235800	367459	30	16	0	2	0	0.886	0.114	0.391	0.609	137.12	0	0.00	3.675
	9	63.17	1434.84	317,709	3	1.47	1.47	235,800	235800	81909	30	33	0	3	0	0.641	0.359	0.742	0.258	534.84	0	0.00	0.819
	10	58.65	1332.27	172,801	4	0.86	1.08	235,800	172801	0	30	29	4	0	1,457	0.632	0.368	1.000	0.000	432.27	0	0.00	0.000
	11	59.43	1349.94	81,748	4	0.40	0.65	235,800	81748	0	30	29	4	0	81,195	0.383	0.617	1.000	0.000	449.94	0	0.00	0.000
	12	68.59	1557.97	63,441	4	0.27	0.46	235,800	63441	0	30	39	4	0	109,102	0.270	0.730	1.000	0.000	657.97	0	0.00	0.000
	13	65.09	1478.54	46,747	6	0.21	0.51	235,800	46747	0	30	35	6	0	93,225	0.300	0.700	1.000	0.000	578.54	0	0.00	0.000
	14	67.06	1523.20	40,116	7	0.18	0.52	235,800	40116	0	30	37	7	0	83,912	0.303	0.697	1.000	0.000	623.20	0	0.00	0.000
	15	72.09	1637.38	38,854	6	0.16	0.47	235,800	38854	0	30	42	6	0	85,689	0.278	0.722	1.000	0.000	737.38	0	0.00	0.000
	16	71.52	1624.53	39,630	6	0.16	0.45	235,800	39630	0	30	42	6	0	94,170	0.266	0.734	1.000	0.000	724.53	0	0.00	0.000
	17	73.27	1664.30	41,683	6	0.17	0.46	235,800	41683	0	30	43	6	0	89,202	0.270	0.730	1.000	0.000	764.30	0	0.00	0.000
	18	49.59	1126.44	36,227	4	0.21	0.52	235,800	36227	0	30	20	4	0	126,715	0.302	0.698	1.000	0.000	226.44	0	0.00	0.000
	19	21.79	494.94	6,381	0	0.09	0.09	0	0	6381	0	22	0	0	0	0.000	1.000	0.000	1.000	494.94	0	0.00	0.064
	20	16.16	367.06	7,939	0	0.14	0.14	0	0	7939	0	16	0	0	0	0.000	1.000	0.000	1.000	367.06	0	0.00	0.079
	21	11.30	256.67	8,064	0	0.21	0.21	0	0	8064	0	11	0	0	0	0.000	1.000	0.000	1.000	256.67	0	0.00	0.081
	22	8.86	201.24	1,627	0	0.05	0.05	0	0	1627	0	9	0	0	0	0.000	1.000	0.000	1.000	201.24	0	0.00	0.016
	23	6.42	145.82	0	0	0.00	0.00	0	0	0	0	6	0	0	0	0.000	1.000	0.000	0.000	145.82	0	0.00	0.000
	24	6.42	145.82	105	0	0.00	0.00	0	0	105	0	6	0	0	0	0.000	1.000	0.000	1.000	145.82	0	0.00	0.001
April	1	2.78	54.33	17,565	0	1.85	1.85	0	0	17565	0	3	0	0	0	0.000	1.000	0.000	1.000	54.33	0	0.00	0.176
	2	2.78	54.33	21,943	0	2.31	2.31	0	0	21943	0	3	0	0	0	0.000	1.000	0.000	1.000	54.33	0	0.00	0.219
	3	2.78	54.33	29,530	0	3.11	3.11	0	0	29530	0	3	0	0	0	0.000	1.000	0.000	1.000	54.33	0	0.00	0.295
	4	2.79	54.52	36,431	0	3.83	3.83	0	0	36431	0	3	0	0	0	0.000	1.000	0.000	1.000	54.52	0	0.00	0.364
	5	2.79	54.52	48,134	0	5.06	5.06	0	0	48134	0	3	0	0	0	0.000	1.000	0.000	1.000	54.52	0	0.00	0.481
	6	2.80	54.72	55,828	0	5.84	5.84	0	0	55828	0	3	0	0	0	0.000	1.000	0.000	1.000	54.72	0	0.00	0.558
	7	5.99	117.06	40,908	0	2.00	2.00	0	0	40908	0	6	0	0	0	0.000	1.000	0.000	1.000	117.06	0	0.00	0.409
	8	44.81	875.67	378,603	3	2.48	2.48	235,800	235800	142803	30	15	0	3	0	0.903	0.097	0.623	0.377	0.00	0	24.33	1.428
	9	60.03	1173.19	146,695	2	0.72	0.85	235,800	146695	0	30	30	2	0	50,705	0.496	0.504	1.000	0.000	273.19	0	0.00	0.000
	10	60.99	1191.90	47,878	4	0.23	0.48	235,800	47878	0	30	31	4	0	115,065	0.278	0.722	1.000	0.000	291.90	0	0.00	0.000
	11	65.07	1271.52	32,524	7	0.15	0.52	235,800	32524	0	30	35	7	0	83,790	0.306	0.694	1.000	0.000	371.52	0	0.00	0.000
	12	65.70	1283.92	28,747	11	0.13	0.70	235,800	28747	0	30	36	11	0	23,796	0.410	0.590	1.000	0.000	383.92	0	0.00	0.000
	13	67.29	1315.06	19,977	14	0.09	0.74	235,800	19977	0	30	37	13	1	0	0.436	0.564	1.000	0.000	415.06	0	0.00	0.000
	14	69.51	1358.37	15,327	17	0.06	0.72	235,800	15327	0	30	40	13	4	0	0.419	0.581	1.000	0.000	458.37	0	0.00	0.000
	15	76.56	1496.09	10,274	22	0.04	0.64	235,800	10274	0	30	47	13	9	0	0.377	0.623	1.000	0.000	596.09	0	0.00	0.000
	16	73.86	1443.27	7,727	17	0.03	0.66	235,800	7727	0	30	44	13	4	0	0.389	0.611	1.000	0.000	543.27	0	0.00	0.000
	17	78.95	1542.80	9,444	20	0.04	0.62	235,800	9444	0	30	49	13	6	0	0.365	0.635	1.000	0.000	642.80	0	0.00	0.000
	18	55.70	1088.54	12,223	10	0.06	0.69	235,800	12223	0	30	26	10	0	53,863	0.404	0.596	1.000	0.000	188.54	0	0.00	0.000
	19	20.23	395.33	708	0	0.01	0.01	0	0	708	0	20	0	0	0	0.000	1.000	0.000	1.000	395.33	0	0.00	0.007
	20	16.78	327.91	6,974	1	0.12	0.12	0	0	6974	0	17	0	1	0	0.000	1.000	0.000	1.000	327.91	0	0.00	0.070
	21	12.16	237.63	6,110	1	0.15	0.15	0	0	6110	0	12	0	1	0	0.000	1.000	0.000	1.000	237.63	0	0.00	0.061
	22	7.70	150.47	0	0	0.00	0.00	0	0	0	0	8	0	0	0	0.000	1.000	0.000	0.000	150.47	0	0.00	0.000
	23	4.86	94.97	0	0	0.00	0.00	0	0	0	0	5	0	0	0	0.000	1.000	0.000	0.000	94.97	0	0.00	0.000
	24	4.86	94.97	0	0	0.00	0.00	0	0	0	0	5	0	0	0	0.000	1.000	0.000	0.000	94.97	0	0.00	0.000

Month	Hour	Electric Demand (KW)	Monlthy Electric Consumption (KWh)	Heating (Btu)	Cooling (Tons)	Heat to Power Ratio (λ_{pu})	(λ_p) inclduing absorption cooling	Useful Exhaust (Btu)	$Q_{e,CHP}$ (Btu)	$Q_{e,Boiler}$ (Btu)	$e_{p,CHP}$ (KW)	$e_{p,GTD}$ (KW)	Absorption Cooling (Tons)	Electric Cooling (Tons)	Wasted Exhaust (Btu)	$f_{e,CHP}$	$f_{e,GTD}$	$f_{h,CHP}$	$f_{h,Boiler}$	Monlthy Electric Consumption From grid	Sell back to Grid (KW)	Monlthy Electric Sell back To Grid	Boiler Fuel Consumption (Therms/h)
May	1	1.22	25.12	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	25.12	0	0.00	0.000
	2	1.22	25.12	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	25.12	0	0.00	0.000
	3	1.22	25.12	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	25.12	0	0.00	0.000
	4	1.22	25.12	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	25.12	0	0.00	0.000
	5	1.22	25.12	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	25.12	0	0.00	0.000
	6	1.22	25.12	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	25.12	0	0.00	0.000
	7	4.42	91.00	0	0	0.00	0.00	0	0	0	0	4	0	0	0	0.000	1.000	0.000	0.000	91.00	0	0.00	0.000
	8	40.33	830.30	17,922	8	0.13	0.82	235,800	17922	0	30	10	8	0	81,421	0.483	0.517	1.000	0.000	0.00	0	69.70	0.000
	9	60.34	1242.23	2,122	14	0.01	0.80	235,800	2122	0	30	30	14	0	192	0.471	0.529	1.000	0.000	342.23	0	0.00	0.000
	10	73.96	1522.77	5,331	24	0.02	0.66	235,800	5331	0	30	44	13	11	0	0.387	0.613	1.000	0.000	622.77	0	0.00	0.000
	11	101.20	2083.41	5,487	48	0.02	0.48	235,800	5487	0	30	71	13	34	0	0.283	0.717	1.000	0.000	1183.41	0	0.00	0.000
	12	116.86	2405.87	4,821	60	0.01	0.42	235,800	4821	0	30	87	13	47	0	0.245	0.755	1.000	0.000	1505.87	0	0.00	0.000
	13	111.71	2299.90	2,913	58	0.01	0.44	235,800	2913	0	30	82	14	44	0	0.255	0.745	1.000	0.000	1399.90	0	0.00	0.000
	14	128.67	2649.14	1,979	69	0.00	0.38	235,800	1979	0	30	99	14	56	0	0.221	0.779	1.000	0.000	1749.14	0	0.00	0.000
	15	120.58	2482.51	2,214	61	0.01	0.40	235,800	2214	0	30	91	14	48	0	0.236	0.764	1.000	0.000	1582.51	0	0.00	0.000
	16	137.22	2825.17	2,538	74	0.01	0.35	235,800	2538	0	30	107	14	61	0	0.207	0.793	1.000	0.000	1925.17	0	0.00	0.000
	17	127.41	2623.03	4,379	67	0.01	0.38	235,800	4379	0	30	97	13	53	0	0.224	0.776	1.000	0.000	1723.03	0	0.00	0.000
	18	97.62	2009.73	7,595	60	0.02	0.50	235,800	7595	0	30	68	13	46	0	0.294	0.706	1.000	0.000	1109.73	0	0.00	0.000
	19	22.52	463.64	5,116	2	0.07	0.07	0	0	5116	0	23	0	2	0	0.000	1.000	0.000	1.000	463.64	0	0.00	0.051
	20	37.58	773.70	9,431	16	0.07	0.07	0	0	9431	0	38	0	16	0	0.000	1.000	0.000	1.000	773.70	0	0.00	0.094
	21	23.15	476.61	6,502	11	0.08	0.08	0	0	6502	0	23	0	11	0	0.000	1.000	0.000	1.000	476.61	0	0.00	0.065
	22	14.07	289.67	4,179	7	0.09	0.09	0	0	4179	0	14	0	7	0	0.000	1.000	0.000	1.000	289.67	0	0.00	0.042
	23	8.87	182.62	2,993	4	0.10	0.10	0	0	2993	0	9	0	4	0	0.000	1.000	0.000	1.000	182.62	0	0.00	0.030
	24	7.44	153.18	2,577	2	0.10	0.10	0	0	2577	0	7	0	2	0	0.000	1.000	0.000	1.000	153.18	0	0.00	0.026
June	1	1.00	18.61	1,620	4	0.47	0.47	0	0	1620	0	1	0	4	0	0.000	1.000	0.000	1.000	18.61	0	0.00	0.016
	2	3.77	70.16	1,034	3	0.08	0.08	0	0	1034	0	4	0	3	0	0.000	1.000	0.000	1.000	70.16	0	0.00	0.010
	3	1.00	18.61	0	2	0.00	0.00	0	0	0	0	1	0	2	0	0.000	1.000	0.000	0.000	18.61	0	0.00	0.000
	4	1.49	27.73	0	1	0.00	0.00	0	0	0	0	1	0	1	0	0.000	1.000	0.000	0.000	27.73	0	0.00	0.000
	5	1.37	25.50	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	25.50	0	0.00	0.000
	6	1.34	24.94	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	24.94	0	0.00	0.000
	7	4.61	85.79	0	1	0.00	0.00	0	0	0	0	5	0	1	0	0.000	1.000	0.000	0.000	85.79	0	0.00	0.000
	8	87.08	1620.57	0	56	0.00	0.56	235,800	0	0	30	57	14	42	0	0.000	1.000	0.000	0.000	720.57	0	0.00	0.000
	9	100.91	1877.94	0	50	0.00	0.48	235,800	0	0	30	71	14	36	0	0.000	1.000	0.000	0.000	977.94	0	0.00	0.000
	10	110.25	2051.76	0	57	0.00	0.44	235,800	0	0	30	80	14	43	0	0.000	1.000	0.000	0.000	1151.76	0	0.00	0.000
	11	138.55	2578.42	0	75	0.00	0.35	235,800	0	0	30	109	14	62	0	0.000	1.000	0.000	0.000	1678.42	0	0.00	0.000
	12	159.19	2962.52	0	89	0.00	0.30	235,800	0	0	30	129	14	75	0	0.000	1.000	0.000	0.000	2062.52	0	0.00	0.000
	13	153.86	2863.33	0	86	0.00	0.31	235,800	0	0	30	124	14	72	0	0.000	1.000	0.000	0.000	1963.33	0	0.00	0.000
	14	173.15	3222.32	0	97	0.00	0.28	235,800	0	0	30	143	14	83	0	0.000	1.000	0.000	0.000	2322.32	0	0.00	0.000
	15	178.26	3317.41	0	104	0.00	0.27	235,800	0	0	30	148	14	91	0	0.000	1.000	0.000	0.000	2417.41	0	0.00	0.000
	16	176.09	3277.03	0	97	0.00	0.27	235,800	0	0	30	146	14	83	0	0.000	1.000	0.000	0.000	2377.03	0	0.00	0.000
	17	176.41	3282.99	0	104	0.00	0.27	235,800	0	0	30	146	14	90	0	0.000	1.000	0.000	0.000	2382.99	0	0.00	0.000
	18	136.99	2549.39	0	87	0.00	0.35	235,800	0	0	30	107	14	74	0	0.000	1.000	0.000	0.000	1649.39	0	0.00	0.000
	19	28.01	521.26	6,112	9	0.06	0.06	0	0	6112	0	28	0	9	0	0.000	1.000	0.000	1.000	521.26	0	0.00	0.061
	20	50.87	946.68	9,497	28	0.05	0.05	0	0	9497	0	51	0	28	0	0.000	1.000	0.000	1.000	946.68	0	0.00	0.095
	21	37.54	698.61	7,599	21	0.06	0.06	0	0	7599	0	38	0	21	0	0.000	1.000	0.000	1.000	698.61	0	0.00	0.076
	22	23.46	436.59	4,973	15	0.06	0.06	0	0	4973	0	23	0	15	0	0.000	1.000	0.000	1.000	436.59	0	0.00	0.050
	23	14.91	277.47	3,874	11	0.08	0.08	0	0	3874	0	15	0	11	0	0.000	1.000	0.000	1.000	277.47	0	0.00	0.039
	24	11.22	208.80	3,166	8	0.08	0.08	0	0	3166	0	11	0	8	0	0.000	1.000	0.000	1.000	208.80	0	0.00	0.032

Month	Hour	Electric Demand (KW)	Monlthy Electric Consumption (KWh)	Heating (Btu)	Cooling (Tons)	Heat to Power Ratio (λ)	(λ) inclduing absorption cooling	Useful Exhaust (Btu)	Q CHP (Btu)	Q Boiler (Btu)	e CHP (KW)	e GTP (KW)	Absorption Cooling (Tons)	Electric Cooling (Tons)	Wasted Exhaust (Btu)	f CHP	f GTP	f CHP	f Boiler	Monlthy Electric Consumption From grid	Sell back to Grid (KW)	Monlthy Electric Sell back To Grid	Boiler Fuel Consumption (Therms/h)
July	1	1.00	18.98	2,296	7	0.67	0.67	0	0	2296	0	1	0	7	0	0.000	1.000	0.000	1.000	18.98	0	0.00	0.023
	2	1.00	18.98	1,729	5	0.51	0.51	0	0	1729	0	1	0	5	0	0.000	1.000	0.000	1.000	18.98	0	0.00	0.017
	3	1.00	18.98	1,286	4	0.38	0.38	0	0	1286	0	1	0	4	0	0.000	1.000	0.000	1.000	18.98	0	0.00	0.013
	4	3.54	67.19	983	2	0.08	0.08	0	0	983	0	4	0	2	0	0.000	1.000	0.000	1.000	67.19	0	0.00	0.010
	5	1.00	18.98	728	1	0.21	0.21	0	0	728	0	1	0	1	0	0.000	1.000	0.000	1.000	18.98	0	0.00	0.007
	6	1.51	28.66	0	1	0.00	0.00	0	0	0	0	2	0	1	0	0.000	1.000	0.000	0.000	28.66	0	0.00	0.000
	7	7.08	134.37	1,106	3	0.05	0.05	0	0	1106	0	7	0	3	0	0.000	1.000	0.000	1.000	134.37	0	0.00	0.011
	8	120.99	2296.35	0	82	0.00	0.40	235,800	0	0	30	91	14	68	0	0.000	1.000	0.000	0.000	1396.35	0	0.00	0.000
	9	130.94	2485.20	0	73	0.00	0.37	235,800	0	0	30	101	14	59	0	0.000	1.000	0.000	0.000	1585.20	0	0.00	0.000
	10	140.55	2667.59	0	79	0.00	0.34	235,800	0	0	30	111	14	65	0	0.000	1.000	0.000	0.000	1767.59	0	0.00	0.000
	11	171.43	3253.68	0	101	0.00	0.28	235,800	0	0	30	141	14	88	0	0.000	1.000	0.000	0.000	2353.68	0	0.00	0.000
	12	175.32	3327.51	0	109	0.00	0.28	235,800	0	0	30	145	14	96	0	0.000	1.000	0.000	0.000	2427.51	0	0.00	0.000
	13	174.74	3316.50	0	102	0.00	0.28	235,800	0	0	30	145	14	88	0	0.000	1.000	0.000	0.000	2416.50	0	0.00	0.000
	14	176.76	3354.84	0	110	0.00	0.27	235,800	0	0	30	147	14	96	0	0.000	1.000	0.000	0.000	2454.84	0	0.00	0.000
	15	179.95	3415.38	0	111	0.00	0.27	235,800	0	0	30	150	14	97	0	0.000	1.000	0.000	0.000	2515.38	0	0.00	0.000
	16	179.19	3400.96	0	107	0.00	0.27	235,800	0	0	30	149	14	93	0	0.000	1.000	0.000	0.000	2500.96	0	0.00	0.000
	17	178.56	3389.00	0	114	0.00	0.27	235,800	0	0	30	149	14	100	0	0.000	1.000	0.000	0.000	2489.00	0	0.00	0.000
	18	156.14	2963.48	0	102	0.00	0.31	235,800	0	0	30	126	14	88	0	0.000	1.000	0.000	0.000	2063.48	0	0.00	0.000
	19	27.65	524.78	5,616	9	0.06	0.06	0	0	5616	0	28	0	9	0	0.000	1.000	0.000	1.000	524.78	0	0.00	0.056
	20	52.29	992.44	9,229	29	0.05	0.05	0	0	9229	0	52	0	29	0	0.000	1.000	0.000	1.000	992.44	0	0.00	0.092
	21	40.36	766.01	6,484	23	0.05	0.05	0	0	6484	0	40	0	23	0	0.000	1.000	0.000	1.000	766.01	0	0.00	0.065
	22	25.39	481.89	4,946	16	0.06	0.06	0	0	4946	0	25	0	16	0	0.000	1.000	0.000	1.000	481.89	0	0.00	0.049
	23	17.31	328.53	4,100	13	0.07	0.07	0	0	4100	0	17	0	13	0	0.000	1.000	0.000	1.000	328.53	0	0.00	0.041
	24	13.01	246.92	3,446	10	0.08	0.08	0	0	3446	0	13	0	10	0	0.000	1.000	0.000	1.000	246.92	0	0.00	0.034
August	1	1.00	19.81	1,497	4	0.44	0.44	0	0	1497	0	1	0	4	0	0.000	1.000	0.000	1.000	19.81	0	0.00	0.015
	2	3.42	67.73	1,767	2	0.15	0.15	0	0	1767	0	3	0	2	0	0.000	1.000	0.000	1.000	67.73	0	0.00	0.018
	3	3.13	61.99	1,284	1	0.12	0.12	0	0	1284	0	3	0	1	0	0.000	1.000	0.000	1.000	61.99	0	0.00	0.013
	4	1.42	28.12	0	1	0.00	0.00	0	0	0	0	1	0	1	0	0.000	1.000	0.000	0.000	28.12	0	0.00	0.000
	5	1.34	26.54	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	26.54	0	0.00	0.000
	6	1.22	24.16	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	24.16	0	0.00	0.000
	7	6.13	121.41	1,328	0	0.06	0.06	0	0	1328	0	6	0	0	0	0.000	1.000	0.000	1.000	121.41	0	0.00	0.013
	8	95.33	1888.06	0	63	0.00	0.51	235,800	0	0	30	65	14	50	0	0.000	1.000	0.000	0.000	988.06	0	0.00	0.000
	9	109.86	2175.83	0	59	0.00	0.44	235,800	0	0	30	80	14	45	0	0.000	1.000	0.000	0.000	1275.83	0	0.00	0.000
	10	124.69	2469.54	0	69	0.00	0.39	235,800	0	0	30	95	14	55	0	0.000	1.000	0.000	0.000	1569.54	0	0.00	0.000
	11	153.14	3033.00	0	89	0.00	0.32	235,800	0	0	30	123	14	75	0	0.000	1.000	0.000	0.000	2133.00	0	0.00	0.000
	12	170.55	3377.81	0	101	0.00	0.28	235,800	0	0	30	141	14	87	0	0.000	1.000	0.000	0.000	2477.81	0	0.00	0.000
	13	169.84	3363.75	0	98	0.00	0.28	235,800	0	0	30	140	14	85	0	0.000	1.000	0.000	0.000	2463.75	0	0.00	0.000
	14	171.99	3406.33	0	106	0.00	0.28	235,800	0	0	30	142	14	92	0	0.000	1.000	0.000	0.000	2506.33	0	0.00	0.000
	15	175.19	3469.70	0	100	0.00	0.28	235,800	0	0	30	145	14	86	0	0.000	1.000	0.000	0.000	2569.70	0	0.00	0.000
	16	174.42	3454.45	0	104	0.00	0.28	235,800	0	0	30	144	14	90	0	0.000	1.000	0.000	0.000	2554.45	0	0.00	0.000
	17	166.27	3293.04	0	93	0.00	0.29	235,800	0	0	30	136	14	79	0	0.000	1.000	0.000	0.000	2393.04	0	0.00	0.000
	18	133.89	2651.75	0	86	0.00	0.36	235,800	0	0	30	104	14	72	0	0.000	1.000	0.000	0.000	1751.75	0	0.00	0.000
	19	22.27	441.06	3,169	2	0.04	0.04	0	0	3169	0	22	0	2	0	0.000	1.000	0.000	1.000	441.06	0	0.00	0.032
	20	40.84	808.85	5,804	19	0.04	0.04	0	0	5804	0	41	0	19	0	0.000	1.000	0.000	1.000	808.85	0	0.00	0.058
	21	27.12	537.12	5,311	15	0.06	0.06	0	0	5311	0	27	0	15	0	0.000	1.000	0.000	1.000	537.12	0	0.00	0.053
	22	18.29	362.24	3,944	12	0.06	0.06	0	0	3944	0	18	0	12	0	0.000	1.000	0.000	1.000	362.24	0	0.00	0.039
	23	11.87	235.09	3,006	9	0.07	0.07	0	0	3006	0	12	0	9	0	0.000	1.000	0.000	1.000	235.09	0	0.00	0.030
	24	10.22	202.41	2,405	7	0.07	0.07	0	0	2405	0	10	0	7	0	0.000	1.000	0.000	1.000	202.41	0	0.00	0.024

Month	Hour	Electric Demand (KW)	Monthly Electric Consumption (KWh)	Heating (Btu)	Cooling (Tons)	Heat to Power Ratio (λ_s)	(λ_s) inclduing absorption cooling	Useful Exhaust (Btu)	$Q_{ex,chp}$ (Btu)	$Q_{ex,boiler}$ (Btu)	$e_{s,chp}$ (KW)	$e_{s,grid}$ (KW)	Absorption Cooling (Tons)	Electric Cooling (Tons)	Wasted Exhaust (Btu)	$f_{ex,chp}$	$f_{e,grid}$	$f_{h,chp}$	$f_{h,boiler}$	Monthly Electric Consumption From grid	Sell back to Grid (KW)	Monthly Electric Sell back To Grid	Boiler Fuel Consumption (Therms/h)
September	1	3.03	52.40	1,212	1	0.12	0.12	0	0	1212	0	3	0	1	0	0.000	1.000	0.000	1.000	52.40	0	0.00	0.012
	2	1.22	21.10	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	21.10	0	0.00	0.000
	3	1.22	21.10	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	21.10	0	0.00	0.000
	4	1.22	21.10	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	21.10	0	0.00	0.000
	5	1.22	21.10	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	21.10	0	0.00	0.000
	6	1.22	21.10	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	21.10	0	0.00	0.000
	7	4.42	76.44	0	0	0.00	0.00	0	0	0	0	4	0	0	0	0.000	1.000	0.000	0.000	76.44	0	0.00	0.000
	8	63.07	1090.82	2,137	31	0.01	0.77	235,800	2137	0	30	33	14	17	0	0.451	0.549	1.000	0.000	190.82	0	0.00	0.000
	9	73.45	1270.32	1,007	24	0.00	0.66	235,800	1007	0	30	43	14	11	0	0.386	0.614	1.000	0.000	370.32	0	0.00	0.000
	10	105.86	1830.75	3,179	55	0.01	0.46	235,800	3179	0	30	76	14	42	0	0.269	0.731	1.000	0.000	930.75	0	0.00	0.000
	11	119.93	2074.02	3,688	65	0.01	0.41	235,800	3688	0	30	90	14	51	0	0.238	0.762	1.000	0.000	1174.02	0	0.00	0.000
	12	137.48	2377.63	0	78	0.00	0.35	235,800	0	0	30	107	14	64	0	0.000	1.000	0.000	0.000	1477.63	0	0.00	0.000
	13	138.03	2387.14	0	79	0.00	0.35	235,800	0	0	30	108	14	65	0	0.000	1.000	0.000	0.000	1487.14	0	0.00	0.000
	14	143.11	2474.99	0	82	0.00	0.34	235,800	0	0	30	113	14	68	0	0.000	1.000	0.000	0.000	1574.99	0	0.00	0.000
	15	138.85	2401.32	0	76	0.00	0.35	235,800	0	0	30	109	14	62	0	0.000	1.000	0.000	0.000	1501.32	0	0.00	0.000
	16	138.50	2395.23	1,364	75	0.00	0.35	235,800	1364	0	30	108	14	61	0	0.205	0.795	1.000	0.000	1495.23	0	0.00	0.000
	17	136.98	2369.01	1,833	74	0.00	0.35	235,800	1833	0	30	107	14	60	0	0.207	0.793	1.000	0.000	1469.01	0	0.00	0.000
	18	84.10	1454.43	4,571	47	0.02	0.58	235,800	4571	0	30	54	13	34	0	0.340	0.660	1.000	0.000	554.43	0	0.00	0.000
	19	21.96	379.78	2,283	0	0.03	0.03	0	0	2283	0	22	0	0	0	0.000	1.000	0.000	1.000	379.78	0	0.00	0.023
	20	19.21	332.22	7,811	6	0.12	0.12	0	0	7811	0	19	0	6	0	0.000	1.000	0.000	1.000	332.22	0	0.00	0.078
	21	16.32	282.24	5,904	8	0.11	0.11	0	0	5904	0	16	0	8	0	0.000	1.000	0.000	1.000	282.24	0	0.00	0.059
	22	11.82	204.42	1,113	6	0.03	0.03	0	0	1113	0	12	0	6	0	0.000	1.000	0.000	1.000	204.42	0	0.00	0.011
	23	8.01	138.53	1,224	4	0.04	0.04	0	0	1224	0	8	0	4	0	0.000	1.000	0.000	1.000	138.53	0	0.00	0.012
	24	7.19	124.35	1,308	2	0.05	0.05	0	0	1308	0	7	0	2	0	0.000	1.000	0.000	1.000	124.35	0	0.00	0.013
October	1	1.22	25.77	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	25.77	0	0.00	0.000
	2	1.22	25.77	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	25.77	0	0.00	0.000
	3	1.22	25.77	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	25.77	0	0.00	0.000
	4	1.22	25.77	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	25.77	0	0.00	0.000
	5	1.22	25.77	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	25.77	0	0.00	0.000
	6	1.22	25.77	0	0	0.00	0.00	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	25.77	0	0.00	0.000
	7	5.98	126.30	3,458	0	0.17	0.17	0	0	3458	0	6	0	0	0	0.000	1.000	0.000	1.000	126.30	0	0.00	0.035
	8	40.86	862.90	123,863	3	0.89	1.17	235,800	123863	0	30	11	3	0	55,708	0.686	0.314	1.000	0.000	0.00	0	37.10	0.000
	9	59.70	1260.92	95,176	3	0.47	0.62	235,800	95176	0	30	30	3	0	97,424	0.361	0.639	1.000	0.000	360.92	0	0.00	0.000
	10	64.40	1360.09	23,593	5	0.11	0.36	235,800	23593	0	30	34	5	0	132,150	0.212	0.788	1.000	0.000	460.09	0	0.00	0.000
	11	72.77	1536.93	31,169	9	0.13	0.56	235,800	31169	0	30	43	9	0	49,488	0.330	0.670	1.000	0.000	636.93	0	0.00	0.000
	12	74.41	1571.59	21,578	15	0.08	0.68	235,800	21578	0	30	44	12	2	0	0.396	0.604	1.000	0.000	671.59	0	0.00	0.000
	13	74.05	1563.99	18,653	19	0.07	0.68	235,800	18653	0	30	44	13	7	0	0.396	0.604	1.000	0.000	663.99	0	0.00	0.000
	14	81.31	1717.38	14,233	27	0.05	0.61	235,800	14233	0	30	51	13	14	0	0.357	0.643	1.000	0.000	817.38	0	0.00	0.000
	15	82.58	1744.19	14,918	26	0.05	0.60	235,800	14918	0	30	53	13	13	0	0.352	0.648	1.000	0.000	844.19	0	0.00	0.000
	16	75.10	1586.14	17,386	18	0.07	0.66	235,800	17386	0	30	45	13	5	0	0.389	0.611	1.000	0.000	686.14	0	0.00	0.000
	17	76.14	1608.21	12,855	17	0.05	0.65	235,800	12855	0	30	46	13	4	0	0.381	0.619	1.000	0.000	708.21	0	0.00	0.000
	18	49.42	1043.75	12,978	7	0.08	0.60	235,800	12978	0	30	19	7	0	95,964	0.353	0.647	1.000	0.000	143.75	0	0.00	0.000
	19	20.23	427.27	0	0	0.00	0.00	0	0	0	0	20	0	0	0	0.000	1.000	0.000	0.000	427.27	0	0.00	0.000
	20	16.30	344.27	7,083	0	0.13	0.13	0	0	7083	0	16	0	0	0	0.000	1.000	0.000	1.000	344.27	0	0.00	0.071
	21	11.48	242.47	6,775	0	0.17	0.17	0	0	6775	0	11	0	0	0	0.000	1.000	0.000	1.000	242.47	0	0.00	0.068
	22	7.45	157.35	0	0	0.00	0.00	0	0	0	0	7	0	0	0	0.000	1.000	0.000	0.000	157.35	0	0.00	0.000
	23	4.86	102.65	0	0	0.00	0.00	0	0	0	0	5	0	0	0	0.000	1.000	0.000	0.000	102.65	0	0.00	0.000
	24	4.86	102.65	0	0	0.00	0.00	0	0	0	0	5	0	0	0	0.000	1.000	0.000	0.000	102.65	0	0.00	0.000

Month	Hour	Electric Demand (KW)	Monthly Electric Consumption (KWh)	Heating (Btu)	Cooling (Tons)	Heat to Power Ratio (λ_{pu})	(λ_p) inclduing absorption cooling	Useful Exhaust (Btu)	$Q_{p,chp}$ (Btu)	$Q_{p,boiler}$ (Btu)	$e_{p,chp}$ (KW)	$e_{p,grid}$ (KW)	Absorption Cooling (Tons)	Electric Cooling (Tons)	Wasted Exhaust (Btu)	$f_{p,chp}$	$f_{p,grid}$	$f_{q,chp}$	$f_{q,boiler}$	Monthly Electric Consumption From grid	Sell back to Grid (KW)	Monthly Electric Sell back To Grid	Boiler Fuel Consumption (Therms/h)
November	1	2.78	58.35	3,860	0	0.41	0.41	0	0	3860	0	3	0	0	0	0.000	1.000	0.000	1.000	58.35	0	0.00	0.039
	2	2.78	58.35	4,661	0	0.49	0.49	0	0	4661	0	3	0	0	0	0.000	1.000	0.000	1.000	58.35	0	0.00	0.047
	3	2.78	58.35	12,697	0	1.34	1.34	0	0	12697	0	3	0	0	0	0.000	1.000	0.000	1.000	58.35	0	0.00	0.127
	4	2.78	58.35	43,865	0	4.62	4.62	0	0	43865	0	3	0	0	0	0.000	1.000	0.000	1.000	58.35	0	0.00	0.439
	5	2.80	58.77	65,185	0	6.82	6.82	0	0	65185	0	3	0	0	0	0.000	1.000	0.000	1.000	58.77	0	0.00	0.652
	6	2.80	58.77	72,588	0	7.60	7.60	0	0	72588	0	3	0	0	0	0.000	1.000	0.000	1.000	58.77	0	0.00	0.726
	7	6.00	125.94	77,106	0	3.77	3.77	0	0	77106	0	6	0	0	0	0.000	1.000	0.000	1.000	125.94	0	0.00	0.771
	8	44.72	938.67	482,420	2	3.16	3.16	235,800	235800	246620	30	15	0	2	0	0.905	0.095	0.489	0.511	38.67	0	0.00	2.466
	9	63.22	1326.99	257,614	3	1.19	1.19	235,800	235800	21814	30	33	0	3	0	0.640	0.360	0.915	0.085	426.99	0	0.00	0.218
	10	57.62	1209.37	126,803	4	0.64	0.91	235,800	126803	0	30	28	4	0	34,940	0.532	0.468	1.000	0.000	309.37	0	0.00	0.000
	11	66.69	1399.86	49,358	4	0.22	0.43	235,800	49358	0	30	37	4	0	118,727	0.249	0.751	1.000	0.000	499.86	0	0.00	0.000
	12	70.54	1480.60	49,798	8	0.21	0.60	235,800	49798	0	30	41	8	0	52,459	0.349	0.651	1.000	0.000	580.60	0	0.00	0.000
	13	66.26	1390.71	35,582	10	0.16	0.70	235,800	35582	0	30	36	10	0	23,990	0.412	0.588	1.000	0.000	490.71	0	0.00	0.000
	14	69.50	1458.77	38,282	12	0.16	0.74	235,800	38282	0	30	39	12	1	0	0.436	0.564	1.000	0.000	558.77	0	0.00	0.000
	15	72.48	1521.28	36,724	14	0.15	0.71	235,800	36724	0	30	42	12	2	0	0.417	0.583	1.000	0.000	621.28	0	0.00	0.000
	16	71.14	1493.26	31,344	12	0.13	0.71	235,800	31344	0	30	41	12	0	1,828	0.418	0.582	1.000	0.000	593.26	0	0.00	0.000
	17	71.66	1504.06	42,618	8	0.17	0.56	235,800	42618	0	30	42	8	0	57,239	0.330	0.670	1.000	0.000	604.06	0	0.00	0.000
	18	45.64	958.06	30,888	5	0.20	0.56	235,800	30888	0	30	16	5	0	124,684	0.327	0.673	1.000	0.000	58.06	0	0.00	0.000
	19	20.23	424.63	0	0	0.00	0.00	0	0	0	0	20	0	0	0	0.000	1.000	0.000	0.000	424.63	0	0.00	0.000
	20	16.15	338.99	6,523	0	0.12	0.12	0	0	6523	0	16	0	0	0	0.000	1.000	0.000	1.000	338.99	0	0.00	0.065
	21	11.29	236.98	6,653	0	0.17	0.17	0	0	6653	0	11	0	0	0	0.000	1.000	0.000	1.000	236.98	0	0.00	0.067
	22	8.86	185.97	0	0	0.00	0.00	0	0	0	0	9	0	0	0	0.000	1.000	0.000	0.000	185.97	0	0.00	0.000
	23	4.86	102.01	0	0	0.00	0.00	0	0	0	0	5	0	0	0	0.000	1.000	0.000	0.000	102.01	0	0.00	0.000
	24	6.42	134.76	46	0	0.00	0.00	0	0	46	0	6	0	0	0	0.000	1.000	0.000	1.000	134.76	0	0.00	0.000
December	1	2.79	59.03	61,103	0	6.42	6.42	0	0	61103	0	3	0	0	0	0.000	1.000	0.000	1.000	59.03	0	0.00	0.611
	2	2.80	59.24	79,554	0	8.33	8.33	0	0	79554	0	3	0	0	0	0.000	1.000	0.000	1.000	59.24	0	0.00	0.796
	3	2.80	59.24	91,700	0	9.60	9.60	0	0	91700	0	3	0	0	0	0.000	1.000	0.000	1.000	59.24	0	0.00	0.917
	4	2.83	59.87	129,647	0	13.43	13.43	0	0	129647	0	3	0	0	0	0.000	1.000	0.000	1.000	59.87	0	0.00	1.296
	5	2.84	60.09	141,127	0	14.56	14.56	0	0	141127	0	3	0	0	0	0.000	1.000	0.000	1.000	60.09	0	0.00	1.411
	6	2.87	60.72	163,420	0	16.69	16.69	0	0	163420	0	3	0	0	0	0.000	1.000	0.000	1.000	60.72	0	0.00	1.634
	7	6.10	129.06	173,981	0	8.36	8.36	0	0	173981	0	6	0	0	0	0.000	1.000	0.000	1.000	129.06	0	0.00	1.740
	8	45.60	964.76	693,505	0	4.46	4.46	235,800	235800	457705	30	16	0	0	0	0.887	0.113	0.340	0.660	64.76	0	0.00	4.577
	9	63.08	1334.58	431,330	0	2.00	2.00	235,800	235800	195530	30	33	0	0	0	0.642	0.358	0.547	0.453	434.58	0	0.00	1.955
	10	63.08	1334.58	331,546	0	1.54	1.54	235,800	235800	95746	30	33	0	0	0	0.642	0.358	0.711	0.289	434.58	0	0.00	0.957
	11	64.30	1360.39	221,791	0	1.01	1.01	235,800	221791	0	30	34	0	0	14,009	0.592	0.408	1.000	0.000	460.39	0	0.00	0.000
	12	64.53	1365.26	158,131	0	0.72	0.72	235,800	158131	0	30	35	0	0	77,669	0.421	0.579	1.000	0.000	465.26	0	0.00	0.000
	13	61.04	1291.42	125,555	0	0.60	0.60	235,800	125555	0	30	31	0	0	110,245	0.353	0.647	1.000	0.000	391.42	0	0.00	0.000
	14	61.02	1291.00	97,959	0	0.47	0.47	235,800	97959	0	30	31	0	0	137,841	0.276	0.724	1.000	0.000	391.00	0	0.00	0.000
	15	63.24	1337.96	113,025	0	0.52	0.52	235,800	113025	0	30	33	0	0	122,775	0.307	0.693	1.000	0.000	437.96	0	0.00	0.000
	16	63.24	1337.96	130,112	0	0.60	0.60	235,800	130112	0	30	33	0	0	105,688	0.353	0.647	1.000	0.000	437.96	0	0.00	0.000
	17	64.13	1356.79	159,405	0	0.73	0.73	235,800	159405	0	30	34	0	0	76,395	0.427	0.573	1.000	0.000	456.79	0	0.00	0.000
	18	44.14	933.87	212,316	0	1.41	1.41	235,800	212316	0	30	14	0	0	23,484	0.825	0.175	1.000	0.000	33.87	0	0.00	0.000
	19	21.79	461.01	6,381	0	0.09	0.09	0	0	6381	0	22	0	0	0	0.000	1.000	0.000	1.000	461.01	0	0.00	0.064
	20	16.15	341.68	10,540	0	0.19	0.19	0	0	10540	0	16	0	0	0	0.000	1.000	0.000	1.000	341.68	0	0.00	0.105
	21	11.29	238.86	11,009	0	0.29	0.29	0	0	11009	0	11	0	0	0	0.000	1.000	0.000	1.000	238.86	0	0.00	0.110
	22	8.86	187.45	13,398	0	0.44	0.44	0	0	13398	0	9	0	0	0	0.000	1.000	0.000	1.000	187.45	0	0.00	0.134
	23	6.42	135.83	39,252	0	1.79	1.79	0	0	39252	0	6	0	0	0	0.000	1.000	0.000	1.000	135.83	0	0.00	0.393
	24	6.43	136.04	64,126	0	2.92	2.92	0	0	64126	0	6	0	0	0	0.000	1.000	0.000	1.000	136.04	0	0.00	0.641

Appendix C: Cost Analysis

Combined Heat and Power Gas Costs					
Month	Microturbine Therms	Boiler Therms	Total Therms	Cost ($/Therm)	Total Cost Per Month
Jan	1179.0	737.7	1916.7	1.089	$2,087.34
Feb	1179.0	707.5	1886.5	1.112	$2,097.78
Mar	1179.0	392.4	1571.4	1.098	$1,725.44
Apr	1179.0	122.1	1301.1	1.198	$1,558.69
May	1179.0	9.2	1188.2	1.206	$1,433.02
Jun	1179.0	11.4	1190.4	1.201	$1,429.63
Jul	1179.0	12.6	1191.6	1.143	$1,361.98
Aug	1179.0	8.9	1187.9	1.011	$1,200.92
Sep	1179.0	6.3	1185.3	1.054	$1,249.26
Oct	1179.0	5.2	1184.2	1.080	$1,278.93
Nov	1179.0	168.5	1347.5	1.106	$1,490.32
Dec	1179.0	520.3	1699.3	1.101	$1,870.89
					$18,784.19

Separate Heat and Power Gas Costs			
Month	Natural Gas (Therms)	Cost ($/Therm)	Total Cost Per Month
Jan	2,112	$ 1.089	$2,299.58
Feb	1,824	$ 1.112	$2,028.69
Mar	983	$ 1.098	$1,079.59
Apr	343	$ 1.198	$410.35
May	29	$ 1.206	$34.74
Jun	27	$ 1.201	$32.64
Jul	15	$ 1.143	$17.65
Aug	13	$ 1.011	$13.38
Sep	18	$ 1.054	$18.86
Oct	430	$ 1.080	$463.94
Nov	736	$ 1.106	$814.44
Dec	1,704	$ 1.101	$1,876.46
			$9,090.30

Combined Heat and Power Electricity Costs										
Month	KW From Grid	KWh	KW Demand Charge 3.5$/KW	DC electric Cost ($/KWh)	Consumption Cost	Sell Back to Grid (Kwh)	Price to sell back ($/KWh)	Total Cost Sell Back	Total Cost Per Month
Jan	34.4	6,696	$120.33	$0.120	$803.462	0.00	0.03	$0.00	$923.79
Feb	34.4	5,118	$120.44	$0.122	$624.428	19.03	0.03	$0.57	$744.29
Mar	43.3	8,004	$151.45	$0.125	$1,000.516	0.00	0.03	$0.00	$1,151.97
Apr	48.9	5,910	$171.32	$0.124	$732.809	24.33	0.03	$0.73	$903.40
May	107.2	15,725	$375.28	$0.121	$1,902.712	69.70	0.03	$2.09	$2,275.90
Jun	148.3	23,064	$518.91	$0.132	$3,044.505	0.00	0.03	$0.00	$3,563.42
Jul	150.0	27,617	$524.83	$0.136	$3,755.936	0.00	0.03	$0.00	$4,280.77
Aug	145.2	25,620	$508.17	$0.139	$3,561.148	0.00	0.03	$0.00	$4,069.32
Sep	113.1	13,922	$395.89	$0.140	$1,949.014	0.00	0.03	$0.00	$2,344.90
Oct	52.6	7,651	$184.04	$0.135	$1,032.852	37.10	0.03	$1.11	$1,215.78
Nov	42.5	6,682	$148.67	$0.131	$875.321	0.00	0.03	$0.00	$1,023.99
Dec	34.5	5,997	$120.86	$0.131	$785.565	0.00	0.03	$0.00	$906.42
			$3,340.184		$20,068.269			$4.505	$23,403.95

Separate Heat and Power Electricty Costs						
Month	KW From Grid	KWh	KW Demand Charge 3.5$/KW	DC electric Cost ($/KWh)	Consumption Cost	Total Cost Per Month
Jan	64.87	16,596	$227.05	$0.120	$1,991.46	$2,218.51
Feb	64.92	14,999	$227.22	$0.122	$1,829.91	$2,057.13
Mar	66.01	17,904	$231.04	$0.125	$2,238.02	$2,469.05
Apr	87.94	15,785	$307.79	$0.124	$1,957.39	$2,265.18
May	153.89	25,555	$538.62	$0.121	$3,092.18	$3,630.79
Jun	195.19	32,964	$683.17	$0.132	$4,351.30	$5,034.47
Jul	196.88	37,517	$689.08	$0.136	$5,102.34	$5,791.42
Aug	192.11	35,520	$672.39	$0.139	$4,937.25	$5,609.63
Sep	160.28	23,822	$560.98	$0.140	$3,335.01	$3,895.99
Oct	92.01	17,514	$322.04	$0.135	$2,364.34	$2,686.38
Nov	74.63	16,582	$261.21	$0.131	$2,172.22	$2,433.43
Dec	65.23	15,897	$228.31	$0.131	$2,082.47	$2,310.77
			$4,948.860		$35,453.888	$40,402.75

Total System Savings							
Turbine	CHP Cost			SHP Cost			Savings
	Electricity	Natural Gas	Total	Electricity	Natural Gas	Total	
30KW	$23,403.95	$18,784.19	$42,188.14	$40,402.75	$9,090.30	$49,493.05	$7,304.90

Appendix D: Capstone Microturbine C30 Cut Sheet

C30 MicroTurbine Natural Gas

Capstone®

Robust power system achieves ultra-low emissions and reliable electricity from natural gas.

- Ultra-low emissions
- One moving part – minimal maintenance and downtime
- Patented air bearing – no lubricating oil or coolant
- 5 and 9 year Factory Protection Plans available
- Remote monitoring and diagnostic capabilities
- Integrated utility synchronization and protection[1]
- Small, modular design allows for easy, low-cost installation
- Reliable – tens of millions of run hours and counting


C30 MicroTurbine

Electrical Performance[2]	High Pressure	Onboard Gas Compressor Option
Electrical Power Output	30kW	28kW
Voltage	400–480 VAC	400–480 VAC
Electrical Service	3-Phase, 4 wire	3-Phase, 4 wire
Frequency	50/60 Hz, grid connect operation 10–60 Hz, stand alone operation	50/60 Hz, grid connect operation 10–60 Hz, stand alone operation
Maximum Output Current	46A, grid connect operation 46A, stand alone operation[3]	46A, grid connect operation 46A, stand alone operation[3]
Electrical Efficiency LHV	26%	25%

Fuel/Engine Characteristics[2]	High Pressure	Onboard Gas Compressor Option
Natural Gas HHV	30.7–47.5 MJ/m³ (825–1,275 BTU/scf)	30.7–47.5 MJ/m³ (825–1,275 BTU/scf)
Inlet Pressure	379–414 kPa gauge (55–60 psig)	1.4–69 kPa gauge (0.2–10 psig)
Fuel Flow HHV	457 MJ/hr (433,000 BTU/hr)	444 MJ/hr (420,000 BTU/hr)
Net Heat Rate LHV	13.8 MJ/kWh (13,100 BTU/kWh)	14.4 MJ/kWh (13,700 BTU/kWh)

Exhaust Characteristics[2]	High Pressure	Onboard Gas Compressor Option
NOx Emissions @ 15% O_2[4]	< 9 ppmvd (18 mg/m³)	< 9 ppmvd (18 mg/m³)
NOx / Electrical Output[4]	0.22 g/bhp-hr (0.64 lb/MWhe)	0.22 g/bhp-hr (0.64 lb/MWhe)
Exhaust Gas Flow	0.31 kg/s (0.68 lbm/s)	0.31 kg/s (0.68 lbm/s)
Exhaust Gas Temperature	275°C (530°F)	275°C (530°F)

Reliable power when and where you need it. Clean and simple.

Dimensions & Weight(5)(6)

Width x Depth x Height	0.76 x 1.5 x 1.8 m (30 x 60 x 70 in)
Weight – Grid Connect Model	405 kg (891 lb)
Weight – Dual Mode Model	578 kg (1,271 lb)

Minimum Clearance Requirements(7)

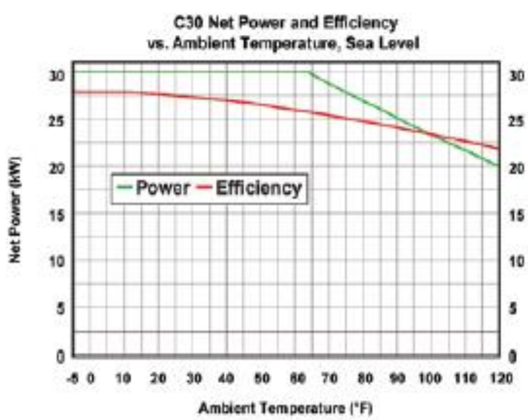
Vertical Clearance	0.61 m (24 in)
Horizontal Clearance	
Left & Right	0.76 m (30 in)
Front	0.93 m (37 in)
Rear	0.92 m (36 in)

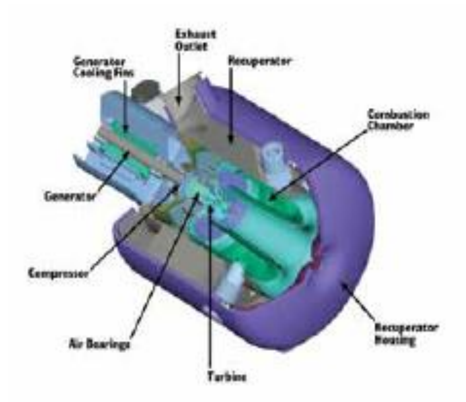
Sound Levels

Acoustic Emissions at Full Load Power	
Nominal at 10 m (33 ft)	65 dBA

Certifications

- Certified to UL 2200 for stand alone natural gas operation (UL files AU2687, E209370)
- Materials Equipment Acceptance (MEA) approval for New York City
- Models available with optional equipment for CE Marking





(1) Some utilities may require additional equipment for grid interconnectivity
(2) Nominal full power performance at ISO conditions: 59°F, 14.696 psia, 60% RH
(3) With linear load
(4) Exhaust emissions for standard Natural Gas at 39.4 MJ/Nm³ (1,000 BTU/scf) (HHV)
(5) Approximate dimensions and weights
(6) Height dimensions are to the roof line. Exhaust outlet extends at least 7 in above the roof line
(7) Clearance requirements may increase due to local code considerations
Specifications are not warranted and are subject to change without notice.

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