NASA Langley Research Center – Administration Office Building One

Hampton, VA

TECHNICAL REPORT 3

Mechanical Systems Existing Conditions Evaluation

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Executive Summary

The purpose of this report is to summarize the mechanical systems of the NASA Langley Administrative Office Building 1, known as AOB1. The report explores the design requirements and influences, hardware components, and system configuration, controls and operating characteristics.

The mechanical system plant consists of a geothermal transfer field which supplies chilled and hot water to the building, without the assistance of additional boilers or chillers. The well field is equipped with six identical water-to-water heat pumps, each contain three-way valves which direct water to either the cooling or heating system. The controls for the heat pumps are set up to allow the heating and cooling systems to both be running at the same time. The cooling load heat pump start sequence is opposite of the heating sequence, with heating considered priority.

The air side mechanical system consists of a dedicated outdoor air unit and five air handling units. The main distribution method is under the floor supply and ceiling return for all offices and teaming spaces. For this, there is an air handling unit located on each floor which is supplied with ventilation air from the dedicated outdoor air unit. Another air handling unit is supplied from the outdoor air unit, which supplies the second and third floor conference rooms with overhead supply. The first floor conference rooms are on their own separate air handling unit with individual outdoor air intake, which allows this unit to run alone outside of regular business hours without running the large dedicated outdoor air unit.

An ASHRAE Standard 62.1 ventilation calculation was performed, which determined that the dedicated outdoor air unit was sized appropriately. However, due to zone population changes between the original mechanical design and the final furniture layout, the air handling unit for the first floor conference rooms does not supply the amount of outdoor air the calculation determined. Additionally, a load calculation done through Trane TRACE 700 determined that the second and third floor under floor air distribution air handling units were not provided with enough cooling tons to satisfy the peak demand. All other equipment appeared sufficient for outdoor air and loads.

Overall, the building has an energy performance higher than the national averages. AOB1's operational cost per square foot is 37.3% lower than the national average for office buildings, and the site EUI is also below the national average. The original building received a LEED Platinum rating through v2.2, and is anticipated to receive at least a minimum rating through the newer version (v4). Therefore, the design intentions were fulfilled through the current system design.

Building Overview

NASA LANGLEY

The NASA Langley Research Center was founded in 1917 as the first civil aeronautical research laboratory, and currently has approximately 110 buildings that were constructed over 50 years ago. NASA decided to implement a five-phase revitalization program, which would replace existing buildings with newer, more efficient ones. Their goals for these new buildings were sustainability/efficiency, functionality of the interior environment, pedestrian friendly, and curb appeal. The revitalization program is known as the New Town program, and the first phase consisted of the construction of AOB1.

NEW TOWN PHASE 1

AOB1 is the new headquarters building for NASA's Langley Research Center. The project broke ground in July of 2009 and occupancy began in May 2011. The three story building is approximately 79,000 square feet, with a mechanical penthouse. The building was designed to give viewers a perception of flight. The image below, a rendering from the bridging drawings created by AECOM, demonstrates this original concept, with the glass curtainwall and metal paneling façade and parallelogram footprint with the overhanging upper floors.

Figure 1 – South façade rendering from AECOM Bridging Drawings

The exterior form matches the interior function, with the vertical form towards the center of the building indicating the location of the elevators and lobby. This vertical section also helps to separate the first floor into two sections: employee offices, with a glass façade providing adequate daylighting matching the rest of the building, and large conference rooms for hosting events with its stone façade and windows that are more practical for visual presentations (5)(6).

Mechanical System Operation

SYSTEM OPERATION AND SCHEMATICS

Water Side

A geothermal transfer field handles the entire heating and cooling load of the building, with 90 boreholes that are six inches in diameter and 500 feet deep. The well field is connected to six water to water heat pumps (WWHP) with scroll compressors located in the penthouse. The WWHP's have an EER of fourteen and a heating COP of 3.25.

As Figure 2 shows, there are four sets of pumps (eight total pumps): one set for the geothermal field, two sets for the chilled water, and one set for the heating hot water set. The chilled water and hot water pumps are equipped with variable frequency drives. All supply pipes contain flow meters; the chilled and hot water flow meters can be found to the right of the figure, just after the respective pumps, and the geothermal flow meter is on the line back to the field. The chilled water system is equipped with a three-way valve that allows for water to bypass the pumps. These valves are controlled to modulate appropriately to divert return water to maintain a 55^{0}F supply water temperature. To prevent short cycling, both the chilled and hot water systems are set to operate for a minimum of five minutes when activated.

Each of the six heat pumps is configured like the one shown, with an individual pump on the return and three-way valves on the supply and return lines that allow for the system to send the water to either the chilled water system or the hot water system. Whenever heating or cooling is called upon by the equipment, the first stage of the two-stage compressor is enacted. If the loop set point temperature is not achieved, the second compressor will be activated. After enacting both compressors, if the set point temperature is still not achieved the controller will stage the heat pumps on and off. The staging of the heat pumps for heating is opposite of that for cooling, allowing both heating and cooling water to be supplied at one time. However, the controls for the heat pumps place heating demand as a priority over cooling.

After the water is sent through the pumps, it continues past what Figure 2 shows. The chilled water in the system is supplied to all AHU, FCU, BCU, and the DOAS unit. The heating hot water continues to all AHU, BCU, CUH, UH, and re-heat coils in FPB, and the DOAS unit.

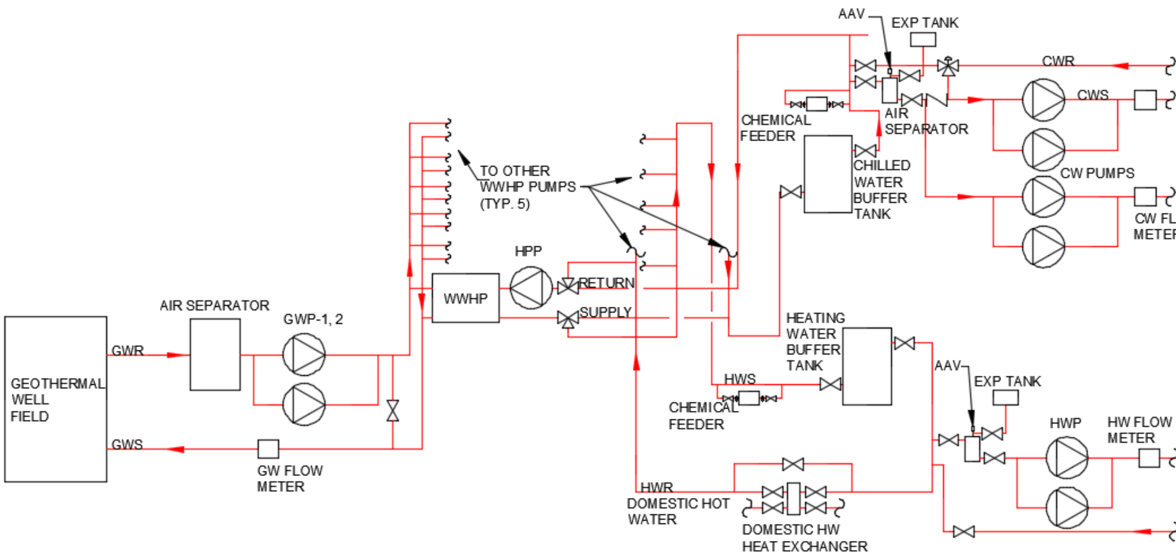


Figure 2 - Flow Diagram

Air Side

The main air distribution system of the building is an under floor air distribution (UFAD) system, with ventilation air supplied from a dedicated outdoor air (DOAS) unit located in the penthouse. This unit contains heating, cooling and reheat coils, and is set-up for dehumidification. The cooling coil is set to run whenever the supply air temperature exceeds five degrees above the setpoint and the outdoor air temperature is above 50 degrees. The heating coil operates the same way, with five degrees below setpoint and outdoor air temperature below 50 degrees. If the freezestat in the DOAS unit OA duct is on, the heating coil will open 100% to prevent freezing of the pipes.

Each floor contains an air handling unit (AHU-1, 2, 3) which supplies air into the under floor plenum, where occupant adjustable floor diffusers serve the air to the offices and teaming rooms. Fan powered boxes (FPB) are located around the perimeter of the building with hot water reheat coils. A ceiling return plenum is used to bring return air back to each AHU. This double plenum can be seen in Figure 3 - Air Riser Diagram, which is also found in APPENDIX A. As shown in this figure, each of these AHU's has a return fan and is either ducted back to the unit or to an exhaust duct. This exhaust air, as well as that from the core building restrooms, is sent through a heat recovery wheel on the DOAS unit and helps with the preconditioning. The heat recovery wheel is constant volume with a bypass damper. The DOAS unit also contains a bypass damper, for when recovery energy is not desired.

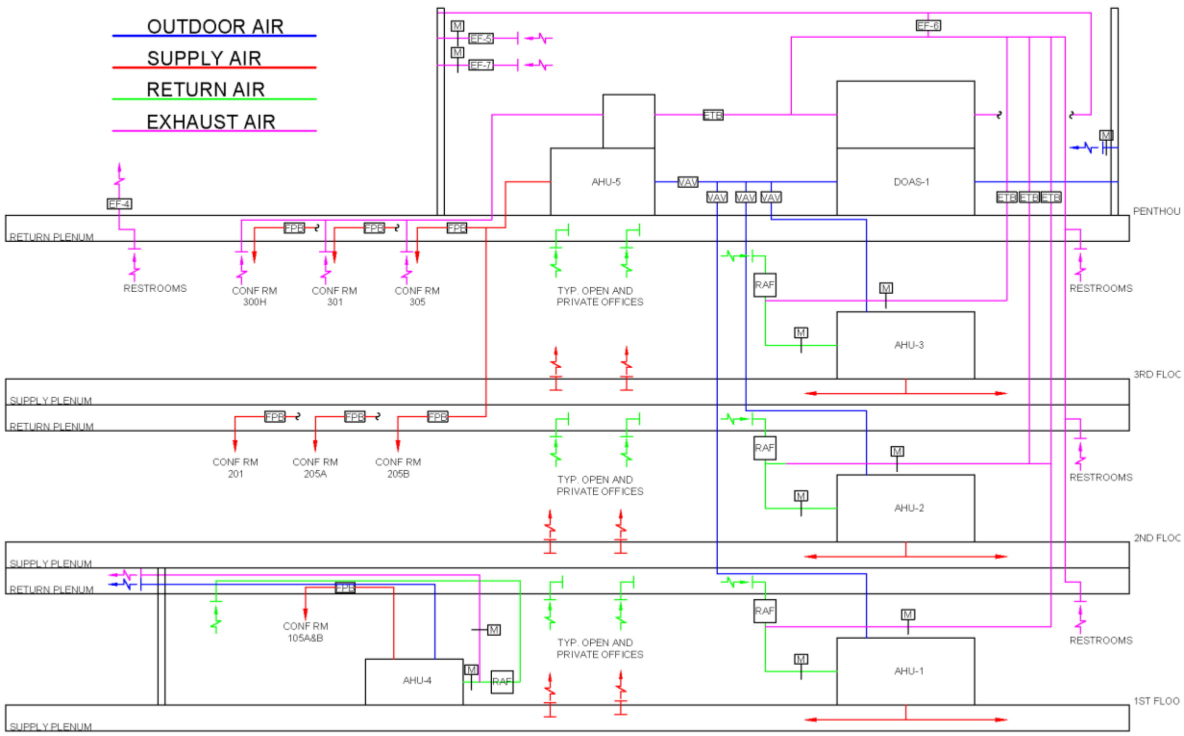


Figure 3 - Air Riser Diagram

AHU-5, which is seen in the penthouse in Figure 3, supplies air to the second and third floor conference room with overhead supply and return, and is also connected to the DOAS unit. Each of these conference rooms has individual carbon dioxide and temperature sensors, unlike the UFAD system, which groups areas into zones for temperature sensor control.

As seen in the figure, there are five variable air volume (VAV) boxes located in the penthouse on each branch of the outdoor air supply from the DOAS unit. This allows for control of the amount of outdoor air being supplied to each AHU.

The AHU on the first floor in the schematic (AHU-4), which is not connected to the DOAS unit, supplies the large conference rooms on the first floor. It has individual exhaust and its own outdoor air intake, which are located on the west wall of the building under the overhang with the exhaust further south and ducted away from the outdoor air intake.

Although the AHU's do not all serve the same purpose, they all have the same basic controls and operation. Figure 4 shows the components that are a part of every AHU, including supply and return fans, temperature sensors, smoke detectors, chilled and hot water coils, and a high static shutdown on the supply. Additionally, AHU-1, 2, and 3 have humidity sensors on the supply air, and are equipped with CO_2 demand control. Each AHU's control sequence of operations is programmed to handle supply air temperature set points for heating and cooling mode, and return air humidity limits. Not shown in the schematic are the variable frequency drive (VFD) devices on each fan, which is typical for all AHU's.

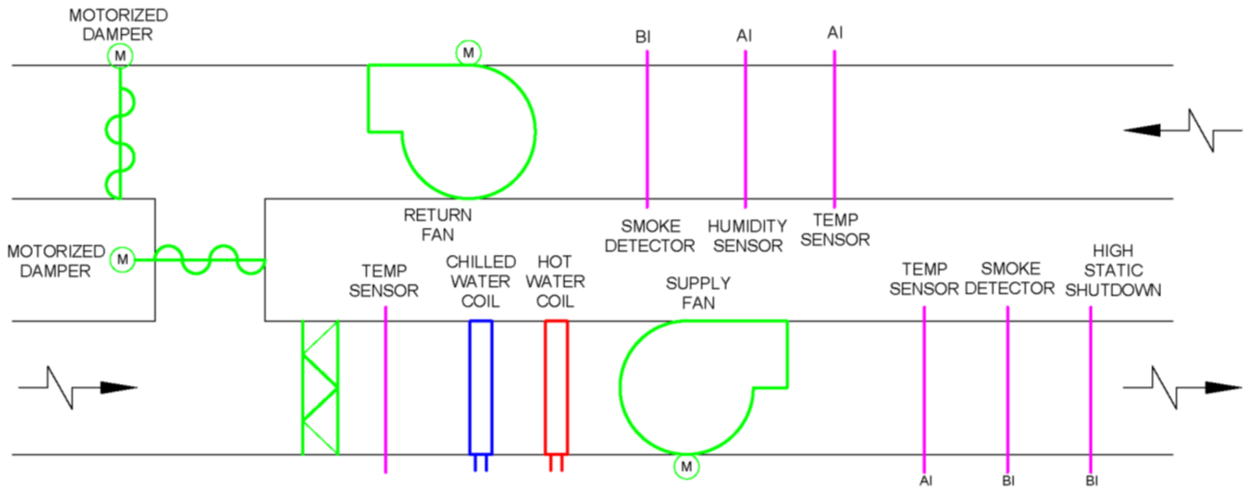


Figure 4 - AHU Schematic

In addition to the AHU's, blower coil units (BCU) serve the atrium and lobby spaces, and fan coil units (FCU) are used for the IT rooms on each floor. There are some areas that are not directly supplied, which include spaces such as stairwells, elevators, restrooms, kitchenettes, mechanical rooms and electrical rooms. A floor plan with this basic breakdown is given below in Figure 5:

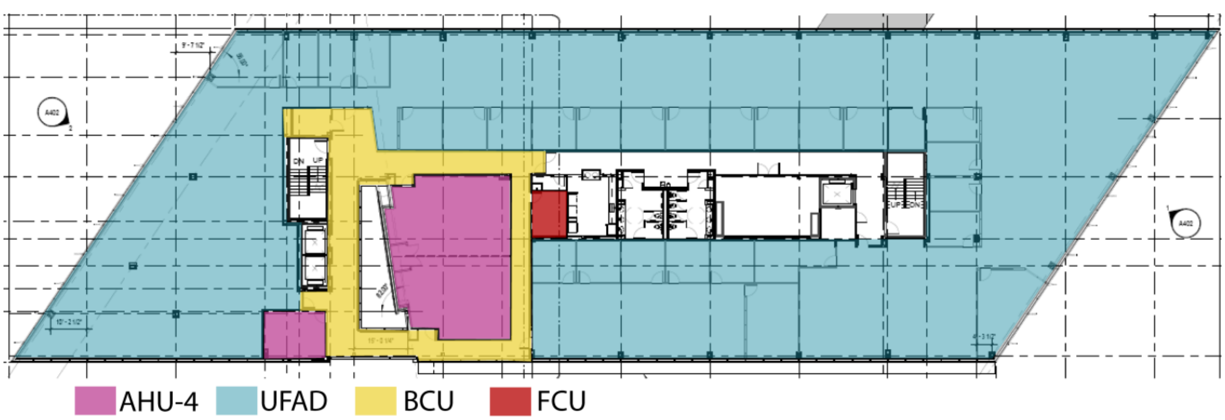


Figure 5 - Second Floor Air Side Supply

Mechanical Design Overview

DESIGN OBJECTIVES, REQUIREMENTS AND INFLUENCES

The mechanical system was designed to maximize energy efficiency, provide optimal occupant comfort, and provide an operational system that is flexible. The building was to achieve a minimum LEED rating of Gold, and surpassed this requirement with a Platinum rating. Striving for this goal influenced many of the mechanical system design decisions, as well as other systems in the building. The mechanical systems narrative from the bridge documents states required system components of geothermal transfer field as a heat source and sink, high efficiency heat water to water heat pumps connected to the well field, airside economizers on the air handling units, and an energy recovery unit. The size of the geothermal transfer field was restricted to the small available area provided on site, between the building and the existing tree line that was to be unharmed through construction. The energy supply for all HVAC components is electricity, which provides the power for the heating and chilled water distribution of the building.

The Direct Digital Control (DDC) Building Automation System (BAS) is provided to lower operating costs, increase efficiency, and increase ease of operation by the maintenance staff. The Building Automation System (BAS) was required to be coordinated with the NASA Langley campus system.

In additional to energy performance objectives, the building was designed to provide desired noise criteria through sound attenuating features of the HVAC system. The noise criteria level was designed to not exceed 35 NC in offices and 30 NC in conference rooms.

DESIGN CONDITIONS AND LOAD ANALYSIS

AOB1 is located in climate zone 4A, and the weather data file obtained from the mechanical engineers provided the information found in Table 1.

Table 1- TMY Weather Data

COOLING MAX 0.4%			DEHUMIDIFICATION MAX 0.4%			WINTER DESIGN 99.6%
DB	**MCWB**	**DP**	**DB**	**MCWB**	**DP**	**DB**
93.2	77.5	71.7	83.9	79.02	77.3	20.5

Table 2 - Construction Parameters

	U-FACTOR (BTU/H*FT^2*^{o}F)	SHADING COEFFICIENT		HEIGHTS (FT.)
Slab	0.21		**Wall**	14.75
Roof	0.063		**Floor to floor**	14.75
Wall	0.113			

Window	0.37	0.29	**Plenum**	2.8
Skylight	0.46	0.39		

The construction parameters obtained from the mechanical engineer are listed in Table 2. The U-Factor for the windows were adjusted from the glass submittals to account for the curtainwall installation affects.

ASHRAE Standard 62.1-2004/2007 was used for the original design ventilation, and a 30% increase over baseline requirements was used for the CFM rates. The fan static pressures designed ranged from 1.5 to 2.0 in. wg for each unit. The lighting power density anticipated for all space types was 1.0 W/SF, and a power density of 0.3 W/SF for lobbies, conference rooms and training rooms, and 1.0 W/SF for office areas. The thermostat schedule and temperature set points are summarized below in Table 3.

Table 3 - Thermostat Schedule

COOLING STAT			HEATING STAT		
		WEEKDAYS			
Start Time	**End Time**	**Setpoint (^{0}F)**	**Start Time**	**End Time**	**Setpoint (^{0}F)**
Midnight	7 a.m.	90	Midnight	7 a.m.	55
7 a.m.	8 a.m.	80	7 a.m.	8 a.m.	65
8 a.m.	5 p.m.	75	8 a.m.	5 p.m.	72
5 p.m.	6 p.m.	80	5 p.m.	6 p.m.	60
6 p.m.	Midnight	90	6 p.m.	Midnight	55
		WEEKENDS			
Midnight	Midnight	90	Midnight	Midnight	60

A load analysis was created for Technical Report 2: Building and Plant Energy Analysis Report. This analysis utilized Trane TRACE 700, and the design conditions given above were used. For more detailed information than what is summarized here, see the original report.

The heating and cooling loads obtained from this analysis and the design drawings are summarized in Table 4. Because the dedicated outdoor air system (DOAS) preconditions the air before serving AHU-1, 2, 3, and 5, the cooling and heating capacity of this unit was added to each respective air handling units schedule value based on the CFM percentage each received. According to the calculation results, AHU-2 and AHU-3 did not provide the required cooling tons to fully condition the space at peak load.

Table 4 - Design and Calculated Airflow Rates

EQUIPMENT	RESULT TYPE	COOLING CFM	COOLING TON	HEATING MBH
AHU-1	Design	17000	37	491
	Calculated	8520	29.7	217

AHU-2	Design	17000	37	491
	Calculated	12212	41.8	337
AHU-3	Design	17000	37	491
	Calculated	12367	42.3	341
AHU-4	Design	2600	8.3	37.7
	Calculated	1958	6.5	53.3
AHU-5	Design	6500	20.5	85
	Calculated	2562	10.8	58.4

An ASHRAE Standard 62.1-2013 Section 6 ventilation rate calculation was performed for Technical Report 1: ASHRAE Standard 62.1 Ventilation and Standard 90.1 Energy Design Evaluations. The ventilation rate requirements for each air handling unit are compared to the design values obtained from the schedules in Table 5, and their compliance with the Standard is evaluated. All air handling units associated with the DOAS unit met compliance. However, AHU-4, which services the first floor conference rooms, did not meet eh outdoor air requirements. This is due to a change in zone population between the original design and final furniture layout.

Table 5 - Ventilation Rates

	EQUIPMENT		DESIGN CFM	OA CALC RESULTS	COMPLIANCE
DOAS	AHU-1		3060	1605	YES
	AHU-2		3060	2019	YES
	AHU-3		3060	1804	YES
	AHU-5		1950	1395	YES
		DOAS:	11000	6823	YES
	AHU-4		780	837	NO

The TRACE 700 model simulated a peak block load of 113.7 tons of cooling and 1091 MBh heating capacity. The total cooling and heating capacity obtained from the water to water heat pump schedule values are 172.5 tons of cooling and 1773 MBh heating, which represents the load capacity obtained from the geothermal transfer field.

Energy and Cost

ENERGY SOURCES, RATES, AND ANNUAL USE

The only energy source used on the site is electricity. The rate provided from the Mechanical Engineer to determine the economic impacts of the mechanical system is $0.077/kWh.

The same TRACE 700 model used to analyze the heating and cooling loads was also used to analyze the energy consumption of AOB1. The results of this analysis showed that the total building energy consumption was approximately 46,000 Btu/ft^2*year and 137,000 Btu/ft^2*year source energy consumption. This gives a site Energy Use Intensity (EUI) value of 46 and source EUI of 137, both below the national site and source averages of 67.3 and 148.1, respectively (4).

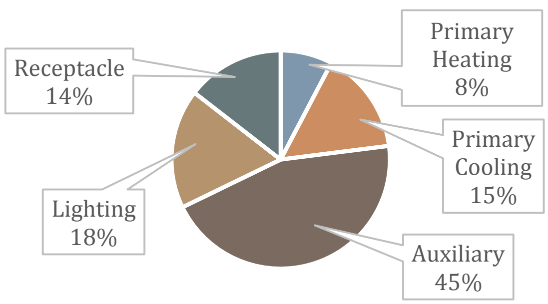


Figure 6 - Energy Consumption Summary

The breakdown of energy use of the building is provided in Figure 6. The estimated operating cost, based on the rate given above, was $67,200 a year, which came to about $0.91/ft^2. This cost per square foot is about 37.3% of the national average for commercial buildings (7). For a more information, please see Technical Report 2.

MECHANICAL SYSTEMS FIRST COSTS

The Whiting-Turner Contracting Company provided the budget for AOB1, broken down loosely by division. The overall building budget was $26,115,000. The costs associated with the HVAC system were split into mechanical and geothermal:

- Mechanical budget: $2,778,933
- Geothermal budget: $413,887

The total cost for the entire mechanical system was approximately $3,193,000, about 12.2% of the total budget. On a building area basis, this is loosely $40.42 per square foot. The pie chart below (Figure 7) shows a breakdown for the budget by division. It is important to note that Division 15: Mechanical includes the sprinkler system, which was not included in the HVAC data above.

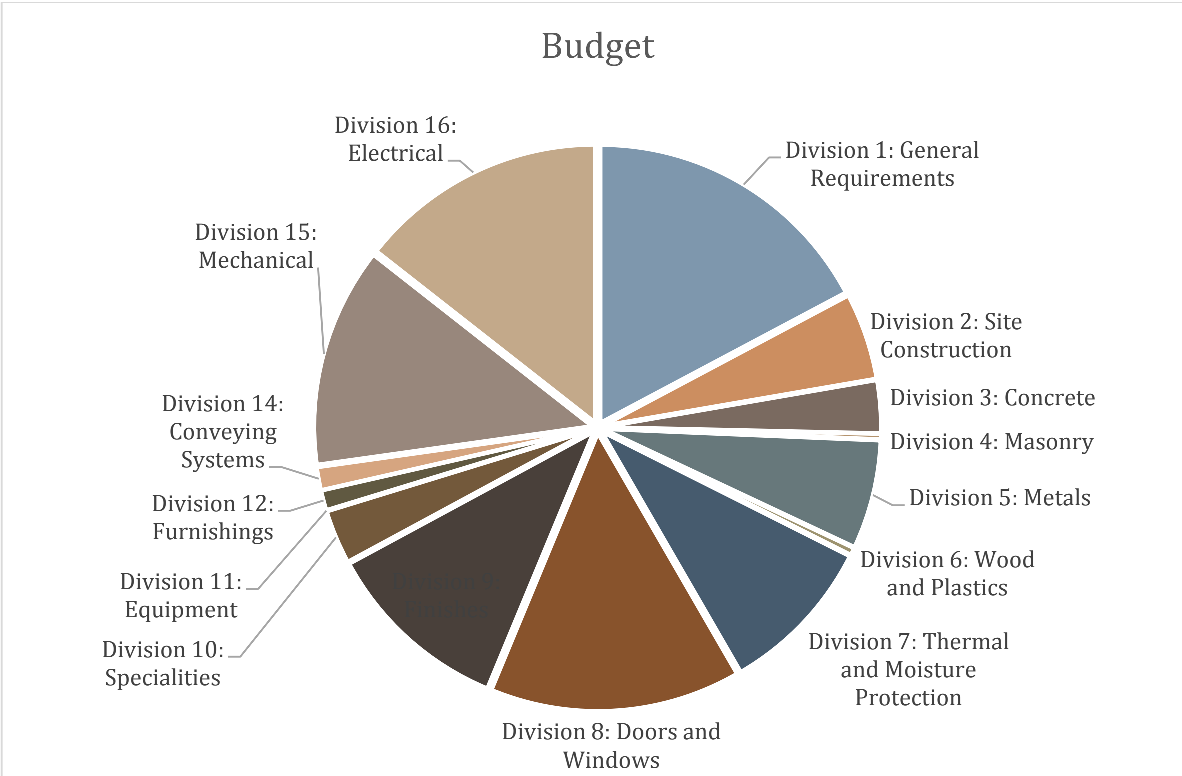


Figure 7 - Budget Breakdown by Division

Equipment and Space Requirements

COOLING AND HEATING PLANT EQUIPMENT

The cooling and heating requirements of AOB1 are served by a geothermal transfer field. Two buffer tanks, one for heating and one for cooling, accompany this system. No additional boilers or chillers are used. The well field is connected to six equally sized water-to-water heat pumps, with characteristics shown in Table 6. These heat pumps are provided with two sets of three-way control valves, which allow the pumps to switch between cooling and heating operation, and are equipped with variable frequency drives.

Table 6 - WWHP Schedule

	REF	COOLING MBH	EER	HEATING MBH	COP	GPM	SOURCE PD (FT)	LOAD PD (FT)
WWHP-1, 2, 3, 4, 5, 6	R-410a	345	14	296.5	3.25	86	3.5	4.4

The conditioned water is supplied to coils inside the air handling units, fan coil units, unit heaters, energy recovery wheel, blower coil units, and hot water coils in fan powered boxes.

AIRSIDE EQUIPMENT

The main air distribution system in the building is an under floor air distribution system (UFAD). Each floor contains a mechanical room with one air handling unit, AHU-1, 2, and 3, which service this system on each respective floor. These air handling units do mixed air and conditioning at the unit, and receive ventilation air from a dedicated outdoor air system (DOAS) located in the penthouse mechanical room. This unit is equipped with an energy recovery wheel and preconditions the outdoor air before supplying the other air handling units for further conditioning and distribution. The supply to each air handling unit, AHU-1, 2, 3, and 5, is controlled by variable volume boxes for each. AHU-1, 2, and 3 are equally sized units serving the UFAD systems. AHU-5, which is also supplied from the DOAS unit and is located in the penthouse, services the second and third floor conference rooms. None of these air handling units are equipped with a return air fan.

AHU-4 is not supplied by the DOAS unit. Instead, it has its own individual outdoor air supply in the first floor mechanical room, which is located next to the first floor conference rooms which is supplies. This unit does contain a return air fan, with a static pressure of 1.55 inches, 93% efficiency and a variable frequency drive.

Table 7 - AHU and DOAS Schedule

				COOLING COIL		HEATING COIL
	TOTAL CFM	% OA	EXT SP (IN)	TOTAL MBH	SENS MBH	TOTAL MBH
AHU-1, 2, 3	17000	18	1.5	234	231	237.6
AHU-4	2600	30	2	100	59.7	37.7
AHU-5	6500	30	2	150.6	107.7	48.2
DOAS-1	11000	100	0.3 INITIAL 0.7 FINAL	633	402	345

The airflow and cooling and heating capacities of each unit are given in Table 7. All air handling units are equipped with a MERV-7 pre-filter and a MERV-13 final filter, and are three phase, 460 Volts and equipped with variable frequency drives. The DOAS unit has a MERV-8 filter. The energy recovery wheel connected to the DOAS unit has a total summer efficiency of 64% and a total winter efficiency of 65.6%.

In addition to the main air distribution equipment, the building also contains fan coil units for the IT rooms, unit heaters for vestibules and stairwells, and blower coil units for the atrium and lobby, with various heating and cooling characteristics (Table 8). The fan powered boxes, used at the perimeter of the building for the UFAD system, are each equipped with hot water coils. These coils range from 5.8 MBH to 35 MBH and 1 GPM to 4.7 GPM, and have either 1 or 2 rows of coils. All fan powered boxes are single phase, 277 V.

Table 8 - Misc. Airside Equipment Schedule

		COOLING COIL		HEATING COIL	
	CFM	MBH	GPM	MBH	GPM
FCU-1	660	11	11	-	-
FCU-2	235	8.5	1.7	-	-
CUH-1	166	-	-	5.43	0.38
CUH-2	438	-	-	10.5	0.73
CUH-3	139	-	-	4.94	0.4
HUH-1	245	-	-	8	0.8
HUH-2	580	-	-	24.8	2.5
BCU-1	1200	45	9	101	10.1
BCU-2	800	24	4.8	18.7	1.3

Table 9 - Exhaust Fan Schedule

	CFM	STATIC PRESSURE
EF-1, 2, 3, 8	75	0.125
EF-4	150	0.75
EF-5	400	0.75
EF-6	3125	1
EF-7	1300	0.75

The exhaust fans for the building, which serve spaces such as the restrooms, kitchenettes, and mechanical and electrical rooms, have a wide range of characteristics, as shown in Table 9. They are controlled by either thermostats, sensors, or the BAS system.

PUMPS

Although there is only one supply of conditioned water from the heating and cooling plant, there are separate sets of pumps for heating and cooling. There are two heating water pumps, in duty/standby operation, and are two sets of duty/standby pumps for the chilled water, making for a total of four chilled water pumps. All hot water and chilled water pumps are equipped with variable frequency drives. The GPM, efficiency and feet of head provided by each pump can be found in Table 10.

Table 10 - Pump Schedule

	GPM	FT HD	EFF
HWP-1, 2	394	48	76
CWP-1, 2	135	38	68
CWP-3, 4	150	46	63.8
HPP-1, 2, 3, 4, 5, 6	86	46	64
GWP-1, 2	540	92	80

Each water-to-water heat pump is equipped with one inline pump, in the duty operation. The geothermal transfer field also has its own set of duty/standby pumps, which is constant speed.

SPACE REQUIREMENTS

There are 500 square foot mechanical rooms on each floor for the UFAD system, and an additional 275 square foot mechanical room on the first floor for the air handling unit for the conference rooms. The main mechanical equipment is located in a rooftop penthouse, another 4,000 square feet. Altogether, the mechanical rooms take up 5,775 square feet of floor space. The shaft space is included in this area. In addition to the horizontal floor space consumed by the mechanical equipment, the vertical height of the building had to account for the under floor supply air plenum and the ceiling supply air plenum, which added to the building height.

LEED Evaluation

The USGBC's Leadership in Energy and Environmental Design (LEED) rating is a system which measures a buildings performance and sustainability in design. A checklist is submitted for a project and a point system is used. There are four ratings, from lowest to highest: certified, silver, gold, and platinum. AOB1 had a design goal of a gold rating, but received a platinum rating based on LEED for New Construction v2.2. The following is an assessment of the current standard, which is v4.

ENERGY AND ATMOSPHERE

EA Prerequisite 1: Fundamental Commissioning and Verification

This prerequisite requires that new construction work be commissioned. A commissioning plan was created for AOB1, and therefore the prerequisite requirements were met.

EA Prerequisite 2: Minimum Energy Performance

The purpose of this prerequisite is to provide a minimum energy improvement over ASHRAE Standard 90.1 baseline. AOB1 would have complied with Option 1: Whole-Building Energy Simulation. According to the original LEED submittal, this requirement was met and exceeded at 28%.

EA Prerequisite 3: Building-Level Energy Metering

This prerequisite did not exist in v2.2. New construction is required to provide building-level energy meters or submeters. AOB1's electrical system was set up for remote monitoring of the electrical meter through the building's energy management control system. Electrical submetering was also specified in Specification Section 262713.

EA Prerequisite 4: Fundamental Refrigerant Management

This requirement states that no CFC's are to be used in new construction. The HVAC system uses chilled and hot water, and the refrigerant used in the water to water heat pumps is R410a. No CFC's were specified.

EA Credit 1: Enhanced Commissioning (3/6)

The intention of this credit is to encourage commissioning early in the design phase as well as continuously through building occupancy, but enhanced energy, water, indoor environmental quality, and durability.. AOB1 qualifies for at least three points with this credit, for the enhanced commissioning in option 1. It is unknown if the building meets all requirements for the additional point from monitoring-based commissioning.

EA Credit 2: Optimize Energy Performance (12/20)

This credit outlines points awarded for improvement percentages over an energy baseline for new construction. According to the original LEED scorecard, AOB1 fell into the 31.5% improvement category (meaning it ranged between 31.5% and 34.9%), and has been moved down to the 29% category for the new version, since the exact value of improvement was unknown.

EA Credit 3: Advanced Energy Metering (0/1)

Compliance with this credit allows for building-level and system-level energy use tracking to save energy. It is not known if all required characteristics of the energy metering system were met to comply with this credit.

EA Credit 4: Demand Response (0/2)

This credit requires participation in an available demand response program or that infrastructure is provided in the design to incorporate future demand response programs. It is unknown if a demand response program was anticipated or participated in.

EA Credit 5: Renewable Energy Production (1/3)

If renewable energy is produced on site, points may be awarded if a minimum percentage of energy is anticipated to come from the renewable resources. The number of points awarded are based on that percentage. The original LEED v2.2 scorecard listed that at least 2.5% of the buildings energy came from renewable energy. The new point system is based on 1%, 3%, 5% and 10%. Since the exact amount of renewable energy anticipated is unknown and cannot be assumed to be at least 3%, compliance with 1% is conservatively assumed.

EA Credit 6: Enhanced Refrigerant Management (1/1)

The first option for this credit is awarded if no refrigerants are used, or if the refrigerants have a ODP of zero and GWP less than 50. If this requirement is not met, a calculation can be made for the refrigerant impact. R410a is the only refrigerant used in the system. This refrigerant has an ODP of zero, but the GWP is greater than 50 and therefore does not meet the requirements of option 1. The calculation for option 2 has not been changed since v2.2, for which a point was awarded in the original scorecard.

EA Credit 7: Green Power and Carbon Offsets (0/2)

This credit requires that at least 50% of energy be from green power or carbon offsets. In LEED v2.2, this minimum value was 35% and the point was earned. It is unknown if AOB1 met this points requirements.

EA Credit Total: 17 points

INDOOR ENVIRONMENTAL QUALITY

EQ Prerequisite 1: Minimum Indoor Air Quality Performance

Option 1 of this prerequisite requires compliance with ASHRAE Standard 62.1-2010. Through the calculation done in Technical Report 1: ASHRAE Standard 62.1 Ventilation and Standard 90.1 Energy Design Evaluations, it was found that with the final furniture layout design, compliance with this standard was not met. However, using the population densities provided in the Standard over the final furniture layout, compliance would have been met. For the purpose of this report, it is assumed that this prerequisite is met.

EQ Prerequisite 2: Environmental Tobacco Smoke Control

This prerequisite limits the locations around the building in which smoking is acceptable. AOB1's design intention fulfilled this prerequisite.

EQ Prerequisite 3: Minimum Acoustical Performance

This requirement does not apply to AOB1.

EQ Credit 1: Enhanced Indoor Air Quality Strategies (1/1)

This credit specifies strategies to improve indoor air quality. Option 1 addresses requirements for different space types. Below is a summary of these requirements:

- Entry way system for the first ten feet into building from entrance
- A minimum of 0.5 CFM/SF of exhaust to prevent cross-contamination from janitors closets and restrooms
- Minimum of MERV 13 filter on AHU's supplying outdoor air
- Compliance with CIBSE Applications Manual

While the first three requirements are met, it is unknown if the design complied with CIBSE, and therefore compliance with this option is unknown. However, Option 2 is based on ventilation types. One means of fulfilling this requirement was to provide a 30% increase over the minimum ventilation requirements. In the original design, based on the population densities provided in ASHRAE Standard 62.1, this requirement was fulfilled. Out of consistency with EQ Prerequisite 1, these original design calculations are assumed to be correct.

EQ Credit 2: Low-Emitting Materials (0/3)

The purpose of this credit is to reduce harmful chemical contaminants. In LEED v2.2, all requirements for this credit were met. However, the compliance method changed from specific volume amounts to threshold percentages. It is unknown if all materials meet these threshold values.

EQ Credit 3: Construction Indoor Air Quality Management Plan (1/1)

This credit addresses indoor air quality during the construction phases. This credit was acquired for the original evaluation, which had it split between during construction and before occupancy, and has had little change. Therefore, it is assumed that this credit is still applicable.

EQ Credit 4: Indoor Air Quality Assessment (1/2)

This credit deals with indoor air quality after construction. Option 1 of this credit is similar to the second part of LEED v2.2 Indoor Air Quality Management Plan for before occupancy, addressed above. Again, it is assumed that this credit still applies. Option 2 is also similar to the previous version, but has stricter concentration limitations. Therefore, it cannot be assumed that the second point would be achieved.

EQ Credit 5: Thermal Comfort (1/1)

Compliance with this credit requires the design to take into account thermal comfort standards through either ASHRAE Standard 55 or ISO and CEN Standards. Additionally, it requires thermal comfort controllers be provided for at least 50% of occupant spaces. LEED v2.2 had a credit for Thermal Comfort Design, which was achieved. The requirements are approximately the same, with the ASHRAE Standard year having been changed. For the purpose of this report, it is assumed to comply. As for thermal comfort controls, the interior offices are on a single control zone and contain one occupant controlled floor diffuser. Open offices also contain occupant controlled floor diffusers, providing air speed comfort controls for most of the building. Therefore, this credit is met.

EQ Credit 6: Indoor Lighting (1/2)

Indoor Lighting is split into two options, each worth one point: control and quality. For control, at least 90% of individual occupant spaces must provide individual lighting controls, multizone control in multioccupancy spaces, lighting for presentation or projection walls separately controlled, and the controls located within sight of luminaires. This credit is similar to LEED v2.2 EQ Credit 6.1: Controllability of Systems: Lighting, which was obtained. This previous credit did not specify that at least three lighting levels should be used, but according to the bridging document narrative, which was used as the lighting basis of design, this requirement is met.

The lighting quality option provides a list to choose four strategies from. It is unknown if the building complied with at least four of these strategies, therefore this point is not assumed to be awarded.

EQ Credit 7: Daylight (2/3)

The intent of this credit is to reduce electrical lighting through the means of natural daylight. Again, this credit is similar to LEEC v2.2 EQ Credit 8.1: Daylight and Views: Daylight 75% of Spaces, and is assumed to comply with the new version following either Simulation Option 2 or Measurement Option 3 for 75% of occupied floor area.

EQ Credit 8: Quality Views (1/1)

This credit is similar to LEED v2.2 EQ Credit 8.2: Daylight & Views: Views for 90% of Spaces. LEED v4 specifies more requirements for the kinds of views, but it is still assumed that this credit is met.

EQ Credit 9: Acoustical Performance (0/1)

Acoustical performance must meet certain HVAC background noise, sound transmission, reverberation time, and sound reinforcing and masking system requirements. Although the basis of design for sound attenuation specified an HVAC NC level, it is unknown if any calculations or measurements were made for any acoustical performance. Because of this, no points were assumed to be achieved from this credit.

EQ Credit Total: 8 points

LEED SUMMARY

Between the Energy & Atmosphere credits and the Indoor Environmental Quality credits, the same number of points are expected to be awarded through LEED v4 as were awarded in the original v2.2 version. However, more EA points and fewer EQ points were earned.

Table 11 - LEED Versions Point Comparison

	EA	EQ
LEED v2.2	10/17	15/15
LEED v4	17/33	8/16

As seen in Table 11, there were more points available for each category in the newer version than the previous version. The cutoffs for each LEED rating has also been adjusted as more points were added. The original cutoffs were as follows:

- Certified: 26-32
- Silver: 33-38
- Gold: 39-51
- Platinum: 52+

AOB1 received 52 credits, pushing it just over the Platinum rating. The new system has the following breakdown:

- Certified: 40-49
- Silver: 50-59
- Gold: 60-79
- Platinum: 80+

Due to the change in point distribution and that the EA and EQ point total did not increase, it is assumed that the building would no longer comply with the Platinum certification requirements.

System Evaluation

The design goal of AOB1 was to create an energy efficient and comfortable space for the occupants. This goal was relatively well achieved. Per LEED v2.2, the building received a Platinum rating, and would be expected to receive at least minimum certification per LEED v4. The site has an anticipated EUI of 46, below the national average of 67.3, and an operating cost that is 37.3% below the national average for office buildings. The average mechanical cost per square foot was $40.42, a higher than normal number, which is to be expected with energy efficient design strategies.

The outdoor air requirements were met and exceeded for all office spaces, with the only exception being the first floor conference rooms, which had a final furniture layout that exceeded the original design occupant density. The under floor air distribution system is equipped with adjustable floor diffusers that allow occupants to individually adjust their supply.

There are some areas to explore which could further improve the level of which the design goals are achieved. One possible area would be the way zones are conditioned. A chilled beam system may be evaluated over a floor supply of cold air, and the possibility of ceiling supply of warm air and floor return, the opposite of the current design, may be considered. Reversing the heating supply and return could increase the air distribution effectiveness of the zone and decrease the outdoor air requirements. Distributing air more effectively through a space would provide for better indoor air quality while also decreasing the amount of outdoor air required, which could reduce heating and cooling loads.

Overall, the mechanical design of AOB1 met design objectives. Evaluation of alternative system layouts may present more design options that further satisfy these goals. These alternative strategies, and others which are determined to be considerable options for analysis, will be further discussed in the AE 482 Mechanical Project Proposal.

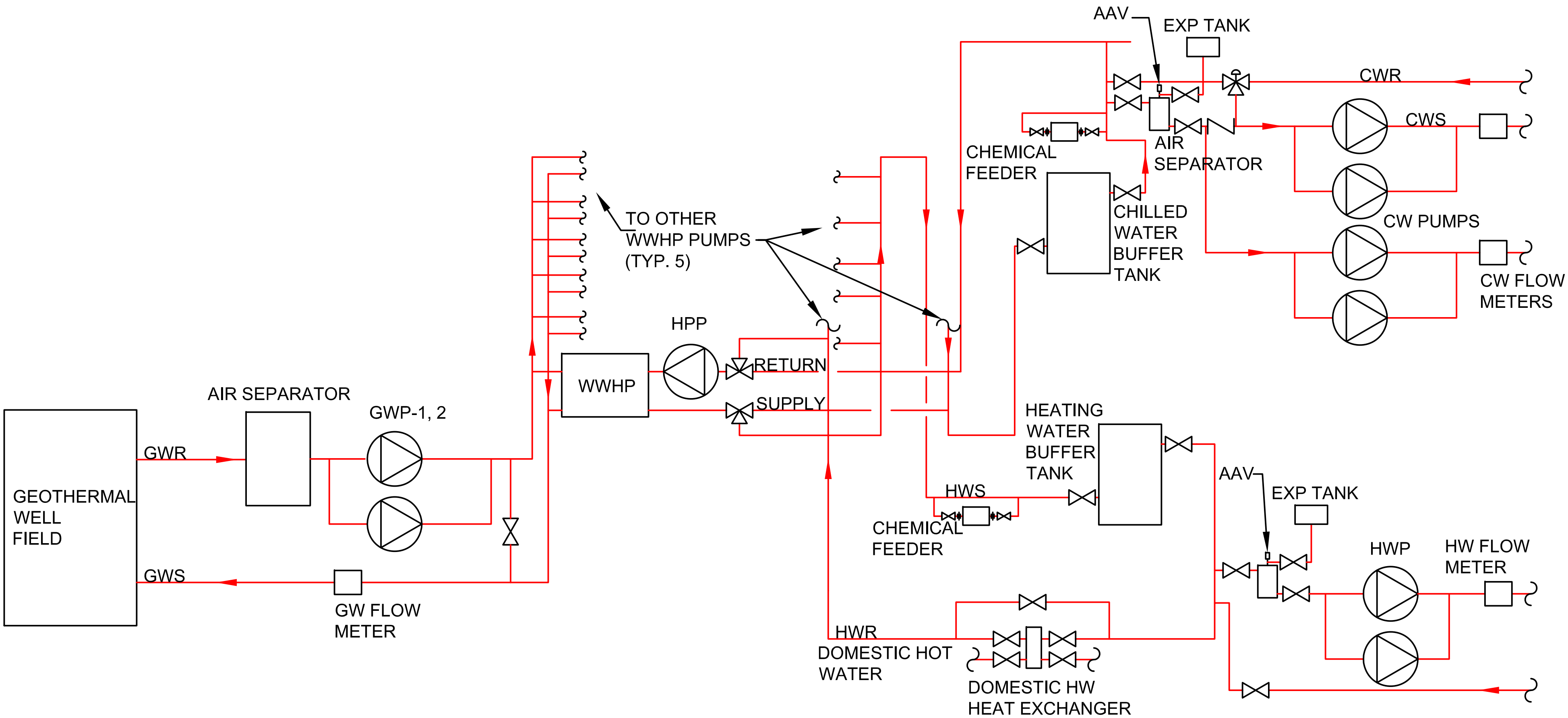
Resources

1. ANSI/ASHRAE. (2013). Standard 62.1-2013, *Ventilation for Acceptable Indoor Air Quality*. Atlanta, GA: American Society of Heating Refrigeration and Air Conditioning Engineers, Inc.
2. ANSI/ASHRAE. (2013). Standard 90.1-2013, *Energy Standard for Buildings Except Low Rise Residential Buildings*. Atlanta, GA: American Society of Heating Refrigeration and Air Conditioning Engineers, Inc.
3. ASHRAE. (2009). 2009 ASHRAE Handbook, *Fundamentals.*. Atlanta, GA: American Society of Heating Refrigeration and Air Conditioning Engineers, Inc.
4. Energy Star (2014, September). Portfolio Manager, *U.S. Energy Use Intensity by Property Type*. Retrieved October 10, 2014, from https://portfoliomanager.energystar.gov/pdf/reference/US National Median Table.pdf
5. Flynn, J. (2008, January 1). Visualizing the Future of NASA Langley Research Center. Retrieved September 12, 2014, from http://proceedings.esri.com/library/userconf/feduc08/papers/feduc.pdf
6. Quinville, T. (2009, September 16). New Town NASA Langley Research Center's Revitalization Initiative Report to Hampton Roads SAME Chapter. Retrieved September 12, 2014, from http://posts.same.org/hamptonroads/NASANewTownSep2009.pdf
7. U.S. Department of Energy (2008) Buildings Energy Data Book, *Buildings Energy Data Book.* Retrieved September 30, 2014, from http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.3.8.

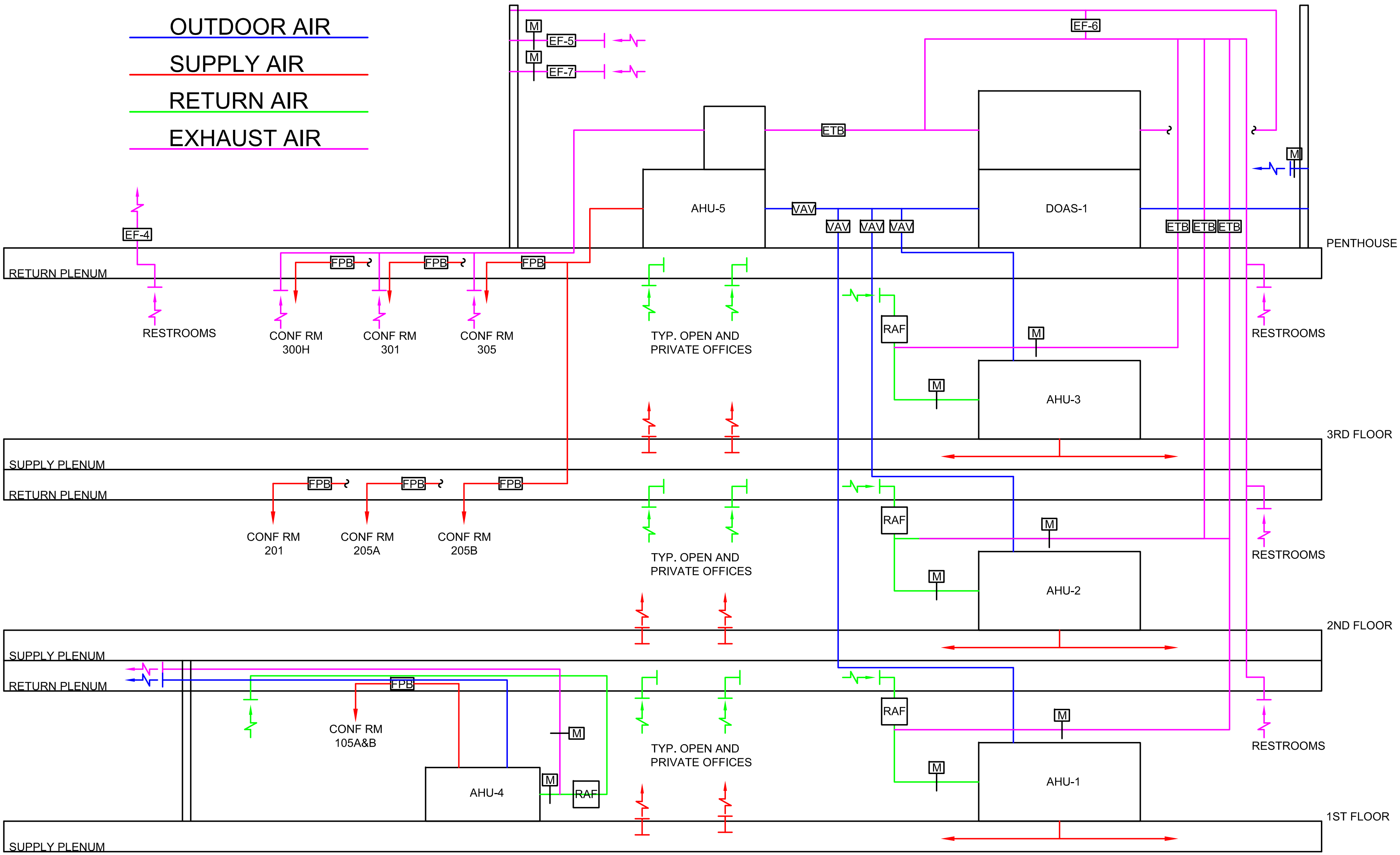
Renderings from AECOM bridging documents: www.aecom.com

APPENDIX A

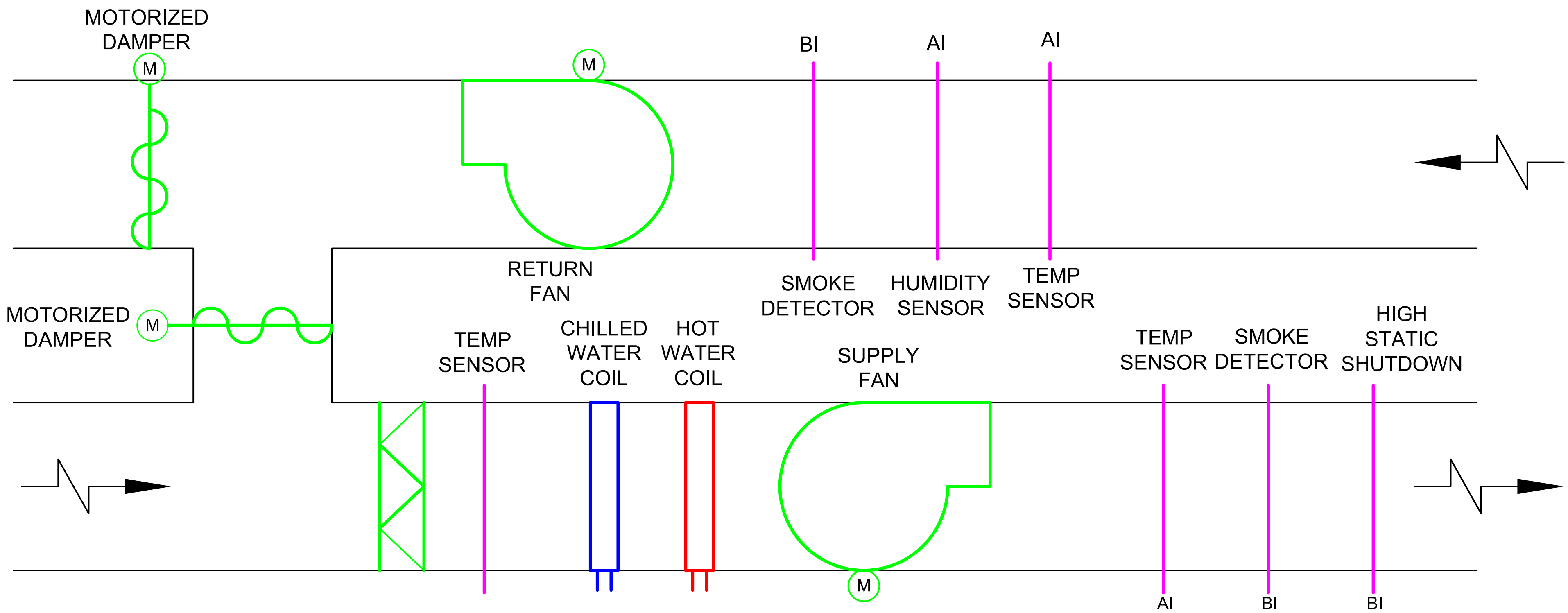
Diagrams and Schematics



Flow Diagram



Air Riser Diagram



Typical AHU Schematic

APPENDIX B

ASHRAE Standard 62.1 Ventilation Calculation

DOAS: 6823

AHU-1 **1605**

Equip.	Zone:	Floor Area (Az)	Zone Population (Pz)	Space type	Rp	Ra	Rp*Pz	Ra*Az	Vbz	Ez	Voz	Vpz	Zpz	Ev	Vps	Vot	D	Vou	Xs	Evz
AHU-1	1st floor UFAD	15780	119	office space	5	0.06	595	946.8	1542	0.7	2203	17000	0.130	0.961	17000	1604	1	1542	0.091	0.961
		Total Pz:	119			Total:	595	946.8	1542		2203			Total:	17000				Ev system:	0.961
	Ps=	119																		

AHU-2 **2019**

Equip.	Zone:	Floor Area (Az)	Zone Population (Pz)	Space type	Rp	Ra	Rp*Pz	Ra*Az	Vbz	Ez	Voz	Vpz	Zpz	Ev	Vps	Vot	D	Vou	Xs	Evz
AHU-2	2nd floor UFAD	19685	148	office space	5	0.06	740	1181.1	1921	0.7	2744	17000	0.161	0.952	17000	2019	1	1921	0.113	0.952
		Total Pz:	148			Total:	740	1181.1	1921		2744			Total:	17000				Ev system:	0.952
	Ps=	148																		

AHU-3 **1804**

Equip.	Zone:	Floor Area (Az)	Zone Population (Pz)	Space type	Rp	Ra	Rp*Pz	Ra*Az	Vbz	Ez	Voz	Vpz	Zpz	Ev	Vps	Vot	D	Vou	Xs	Evz
AHU-3	3nd floor UFAD	18750	120	office space	5	0.06	600	1125	1725	0.7	2464	17000	0.145	0.957	17000	1803	1	1725	0.101	0.957
		Total Pz:	120			Total:	600	1125	1725		2464			Total:	17000				Ev system:	0.957
	Ps=	120																		

AHU-5 **1395**

Equip.	Zone:	Floor Area (Az)	Zone Population (Pz)	Space type	Rp	Ra	Rp*Pz	Ra*Az	Vbz	Ez	Voz	Vpz	Zpz	Ev	Vps	Vot	D	Vou	Xs	Evz
FPB-219, 220	conference room	1460	62	conference/meeting	5	0.06	310	87.6	398	0.7	568	740	0.768	0.742	2030	1394	1	1035	0.510	0.742
FPB-221	215 conference r	230	10	conference/meeting	5	0.06	50	13.8	64	0.7	91	125	0.729	1.967	610	526	1	1035	1.696	1.967
FPB-323	318 conference r	635	18	conference/meeting	5	0.06	90	38.1	128	0.7	183	305	0.600	1.489	950	695	1	1035	1.089	1.489
FPB-321	314 conference	1500	54	conference/meeting	5	0.06	270	90	360	0.7	514	700	0.735	0.796	1950	1300	1	1035	0.531	0.796
FPB-322	315 conference r	250	14	conference/meeting	5	0.06	70	15	85	0.7	121	150	0.810	1.648	710	628	1	1035	1.457	1.648
		Total Pz:	158			Total:	790	244.5	1035		1478			Total:	6250				Ev system:	0.742
	Ps=	158																		

AHU-4 **837**

Equip.	Zone:	Floor Area (Az)	Zone Population (Pz)	Space type	Rp	Ra	Rp*Pz	Ra*Az	Vbz	Ez	Voz	Vpz	Zpz	Ev	Vps	Vot	D	Vou	Xs	Evz
AHU-4	117A & 117B	1460	64	conference/meeting	5	0.06	320	87.6	408	0.8	510	765	0.666	0.493	2590	836	1	413	0.159	0.493
		Total Pz:	64			Total:	320	87.6											Ev system:	0.493
	Ps=	65																		

APPENDIX C

U.S. Department of Energy Buildings Energy Data Book: 3.3 Commercial Sector Expenditures

3.3.8 Average Annual Energy Expenditures per Square Foot of Commercial Floorspace, by Year ($2010)

Year	$/SF
1980 (1)	2.12
1981	2.22 (2)
1982	2.24
1983	2.21
1984	2.25
1985	2.20
1986	2.06
1987	2.00
1988	1.99
1989	2.01
1990	1.98
1991	1.92
1992	1.86
1993	1.96
1994	2.05
1995	2.12
1996	2.10
1997	2.08
1998	1.97
1999	1.88
2000	2.06
2001	2.20
2002	2.04
2003	2.13
2004	2.16
2005	2.30
2006	2.36
2007	2.35
2008	1.71
2009	2.43
2010	**2.44**
2011	2.44
2012	2.35
2013	2.28
2014	2.27
2015	2.29
2016	2.29
2017	2.28
2018	2.29
2019	2.29
2020	2.29
2021	2.31
2022	2.32
2023	2.32
2024	2.32
2025	2.32
2026	2.32
2027	2.33
2028	2.32
2029	2.31
2030	2.31
2031	2.32
2032	2.35
2033	2.37
2034	2.39
2035	2.42

Note(s): 1) End of year 1979. 2) Square footage estimated for years 1981, 1982, 1984, 1985, 1987, 1988, 1990, 1991, 1993, 1994, 1996, 1997, 1998, 2000, 2001, 2002, 2004, and 2005.

Source(s): EIA, State Energy Data Prices and Expenditures Database, June 2011 for 1980-2009; EIA, Annual Energy Outlook 2012 Early Release, Jan. 2012, Summary Reference Case Tables, Table A2, p. 3-5 and Table A5, p. 11-12 for consumption, Table A3, p. 6-8 for prices for 2008-2035; EIA, Annual Energy Review 2010, Oct. 2011, Appendix D, p. 353 for price deflators. for price deflators; EIA, AEO 1994, Jan. 1994, Table A5, p. 62 for 1990 floorspace; and PNNL for 1980 floorspace.