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Technical Report Three

Mechanical Systems Existing Conditions Evaluation

Army National Guard

Readiness Center Addition

Arlington, Va.

Mitchell E. Peters

Mechanical

Dr. Bahnfleth – Advisor

10/11

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Executive Summary

The following report encompasses the goals, design, and function of the mechanical systems in the Army National Guard Readiness Center Addition (ArNG). It is intended to summarize the above criteria will providing an evaluation of the overall building operations.

The ArNG building houses a hydronic HVAC system consisting of a heating and chilled water 4 pipe system. This water is supplied to mechanical rooms on every floor containing AHU's as well as VAV terminals. There are a total of 17 AHU with one specified per tower level. The building is cooled the use of two 400 ton centrifugal water-cooled chillers specified in conjunction with two cooling towers. This system is coupled by Computer Room Cooling Units (CRAC) for telecom and data centers in which the sensible load is too great for the VAV terminals. Direct digital control is achieved through building automation systems (BAS) and building management systems. The BAS system controls all of the VAV terminals as well as damper systems.

The most important aspects of the mechanical system design were to provide substantial thermal comfort as well as indoor air quality. This was of primary concern, but energy efficiency was greatly considered as well.

The majority of the building is powered by delivered electricity, however there are several natural gas fired boilers on site. Although initial costs of the systems are still being explored, this system is fairly typical and should compare to a mid-rise multi use office building. The building utilizes 100% outdoor air (OA) which must be considered in these costs.

The mechanical system specified for the ArNG building is fairly typical and easy to maintain. This type of system can be very efficient with the right equipment. As the building utilizes energy efficient equipment, the ArNG building is not only efficient but it still satisfies ventilation and thermal comfort standards. The use of the BAS system adds to the buildings goal of being LEED silver.

Mechanical System Overview

Introduction

The ArNG Readiness Center addition will function as an administrative headquarters in conjunction with the existing complex on site. There are a total of 8 floors, 3 below grade and 5 above. The building houses open office spaces, fitness facilities, an auditorium, and Joint Operations Center to name a few. The building was design mechanically for efficiency and occupancy use in mind.

Design Objectives and Requirements

When the designers sat down to analyze the future mechanical systems for the ArNG building there were two main focuses. Meeting and or exceeding the necessary ASHRAE standards while striving for an energy efficient design. This energy efficient design should warrant LEED points for the goal of being certified LEED Silver. From the ASHRAE standards the ArNG building must meet thermal comfort as well as IAQ stipulations. To meet these requirements a simple VAV system was specified to condition the spaces. These VAV systems are used in conjunction with high efficiency chillers with cooling towers, boilers, and efficient CRAC units for high demand spaces.

Site and Budget

The site of the ArNG building is located in Arlington, Virginia. The building is owned by the Army National Guard and the facility is to be an expansion of an existing facility on the site. The site is located on a very soft and spongy soil making it difficult for the foundation system. This is due to an unknown source of water entering the site from several sides. Current information is being obtained on budget information but the initial project budget was roughly $89 million with a budget of $9.7 million for the mechanical system. This is protected due to the government use of the building and that it is still under construction.

System Initial Cost

Only the cost per square foot could be procured at this time. For the mechanical system and plumbing (fire protection) the cost is around $43.98/SF.

Lost Space

There is quite a large amount of lost space as a result of mechanical equipment. There are a total of 8 floors with three of these floors being underground. The underground floors are labeled as follows: 3P, 2P, and 1P. These floors have one large mechanical space which houses a single air handling units (AHU) with two subsequent mechanical spaces. Level 2P has a mechanical mezzanine which holds 5 AHU's. As for the above ground levels labeled 1T, 2T, 3T, 4T, and 5T each have one mechanical space housing a single air handling unit. These spaces house all of the mechanical shafts and therefor there is no need to account for any other lost space. The lost space in square feet is broken down by floor in Table 1 shown below.

Level	Lost Space (SF)
3P	819
2P	2662
1P	1672
1T	703
2T	703
3T	703
4T	699
5T	703
Mech. Penthouse	11591
Total	**20,255**

Table 1

Energy Sources

The ArNG building has two sources of energy availably, delivered electricity and a natural gas line. Dominion Virginia Power is specified as the utility provider however the specifics rates cannot be produced. As a result, standard rates for Arlington, Va. were used and are shown in Table 2 below.

Arlington, Va. Utility Costs		
Electricity (cents/kWh)	on-peak	8.97
	off-peak	6.07
Natural Gas ($/therm)		0.261

Table 2

Design Air Conditions

The buildings location was specified as Washington, D.C. which is different than the buildings actual location. Arlington VA. is very close to the D.C. area and should provide the best approximation for the model. ASHRAE Design conditions for Washington, D.C. can be found in Table 3 below, taken from the ASHRAE Handbook of Fundamentals 2009.

ASHRAE Design Conditions for Washington, D.C. (.4% and 99.6%)		
Summer		Winter
DB (^oF)	MCWB (^oF)	DB (^oF)
82.1	65.9	20.8

Table 3

As for the indoor design conditions, the values utilized for the ArNG building model were specified by the designer. These values are given in Table 4 below.

Indoor Design Conditions	
Heating DB	70^{o}F
Cooling DB	75^{o}F
Relative Humidity	50%

Table 4

Equipment Summaries

The ArNG building has multiple uses; as a result the mechanical system has to be able to handle the various types of loads. From this, 17 AHU's are specified throughout the floors which feed VAV units which are spread throughout the various spaces as needed. This system is supported through the use of CRAC units in spaces with higher thermal demands. This system has been proven adequate and efficient for buildings of similar use and is very practical in this situation. The AHU's and VAV terminals are supplied with chilled water by means of 2 chillers coupled with 2 cooling towers. Heating is done through hot water which is supplied by 5 gas fired boilers. To supply this water the use of pumps is extremely important. The majority of these pumps are variable frequency controlled. The following Tables 5-10 display the specifications for the AHU's (max and min design OA), chillers and cooling towers, CRAC units, boilers, and pumps.

Air Handling Unit Schedule		
Unit	**Max/Min OA CFM**	**Supply Fan CFM**
AHU-3P-A1	2450	11800
AHU-3P-B1	1200	9500
AHU-3P-B2	950	2900
AHU-3P-B3	275	1650
AHU-3P-B4	900	12000
AHU-3P-B5	900	12000
AHU-2P-A1	2140	11800
AHU-1P-A1	2410	13400
AHU-1P-A2	0	9100
AHU-1P-B1	650	5700
AHU-1P-B2	4250	5400
AHU-1P-B3	1500	6400
AHU-1T-A1	1550	11900
AHU-2T-A1	1550	11900
AHU-3T-A1	1550	11900
AHU-4T-A1	1550	11900
AHU-5T-A1	1550	12600

Table 5 Air handling unit schedule depicting supply air flow as well as Outdoor Air usage.

Centrifugal Chiller Schedule									
		Chilled Water				**Condenser Water**			
Unit	Capacity Ton	Flow GPM	EWT ^{0}F	LWT ^{0}F	Ft. H_2O	Flow GPM	EWT ^{0}F	LWT ^{0}F	Ft. H_2O
CH-1	400	800	56	44	20	1200	85	95	20
CH-2	400	800	56	44	20	1200	85	95	20

Table 6 Chiller Schedule with flow rates and entering and leaving wet bulb temperatures specified.

Cooling Tower Schedule				
Unit	Flow GPM	Fan HP	EWT ^{0}F	LWT ^{0}F
CT-1	1200	25	95	85
CT-2	1200	25	95	85

Table 7 Cooling Tower Schedule with entering and leaving wet bulb temperatures as well as flow rates.

Computer Room Air Conditioner Schedule		
Unit	Total Capacity (MBH)	CFM
CRAC-1P-A1	245	9100
CRAC-2P-A1	140	6050
CRAC-2P-A2	140	6050
CRAC-3P-B1	72	2800

Table 8 CRAC unit schedule with specified cfm supply and cooling capacity.

Hot Water Boiler Schedule					
Unit	Type	Capacity (MBH)		GPM	Supply Temp ^{0}F
		Input	Output		
B-1	Natural Gas	1000	930	90	180
B-2	Natural Gas	1000	930	90	180
B-3	Natural Gas	1000	930	90	180
B-4	Natural Gas	1000	930	90	180
B-5	Natural Gas	1000	930	90	180

Table 9 Natural Gas fired boiler schedule showing its capacity and supply temperatures.

Pump Schedule					
Unit	Service	Capacity GPM	Head FT.	Max HP	Max RPM
CHWP-1	Chiller	800	105	30	1750
CHWP-2	Chiller	800	105	30	1750
CHWP-3	Chiller	800	105	30	1750
CWP-1	Cooling Tower	1200	80	30	1750
CWP-2	Cooling Tower	1200	80	30	1750
CWP-3	Cooling Tower	1200	80	30	1750
HWP-1	Heating Boilers	450	85	15	1750
HWP-2	Heating Boilers	450	85	15	1750

Table 10 Primary Pump schedule for water use in the ArNG building cover all chillers, cooling towers, and boilers.

The actual system operations will be covered in the next section and will describe how the various equipment work together.

System Operation

Schematics

The following Figure 1 depicts the heating water system for the ArNG building

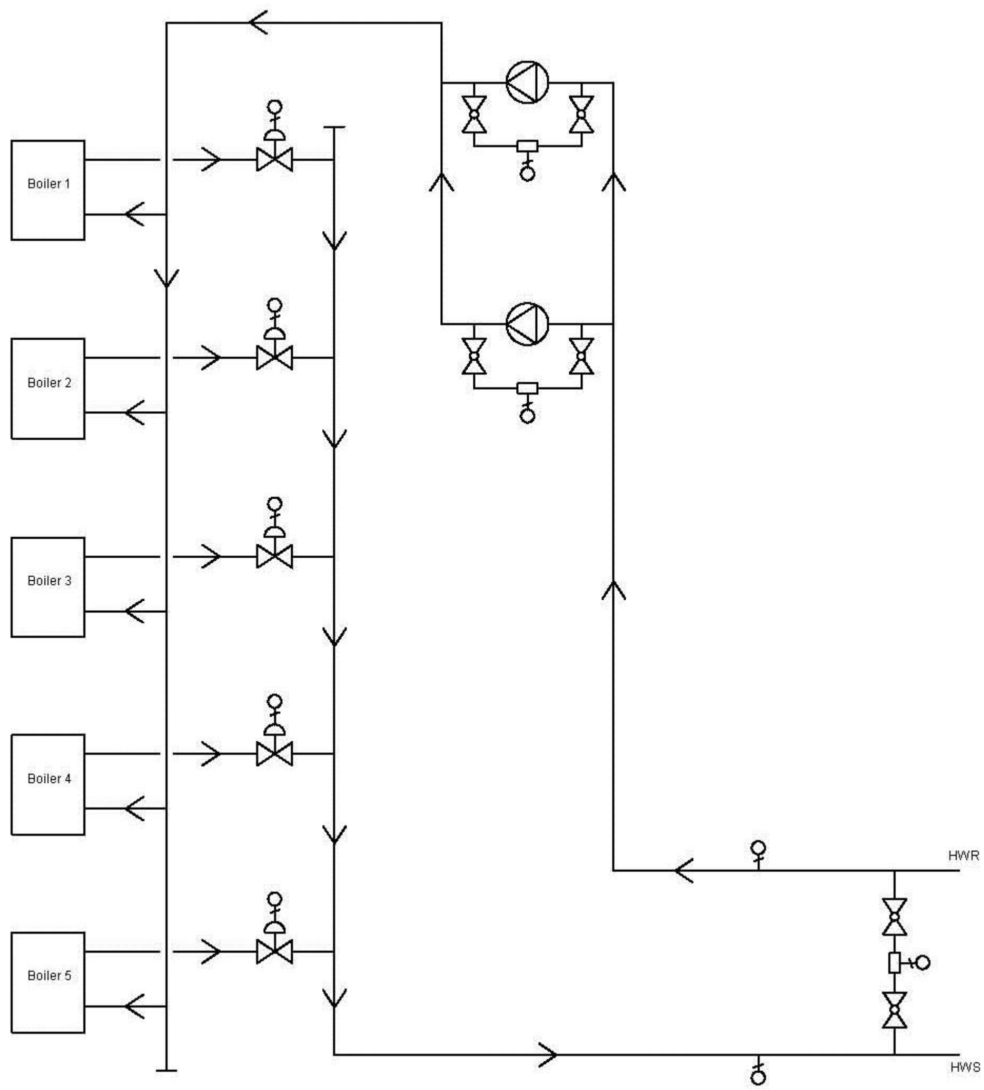

Figure 1

The following Figure 2 shows the chilled water system

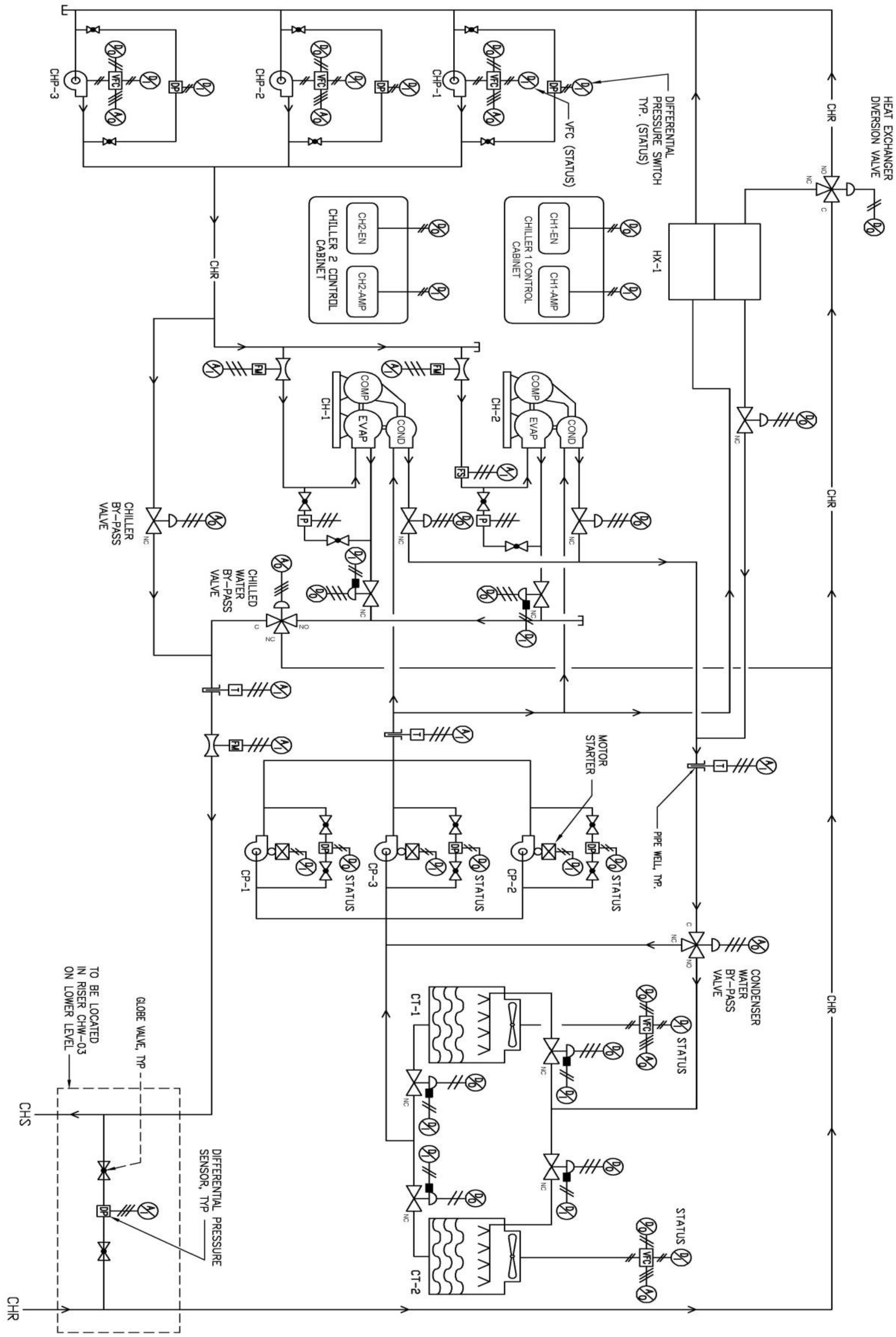

Figure 2

Figure 2 was taken from the design documents. A personal schematic had been drawn but the file had become corrupt. Such a schematic is being reproduced at this time and will be placed in an updated Tech. Assignment 3 on the CPEP website.

Air Side

The ArNG building utilizes a VAV system in which each unit is supplied by air from a corresponding AHU. The mechanical unit as a whole uses a Building Automation System (BAS). Such a system for example will control the variable frequency supply fans attached with the AHU's making the system very efficient. Such control of these supply and exhaust fans also manage the building pressurization. There is a 100% supply of OA at all times while utilizing humidity and temperature sensors to meet both cooling and heating loads.

Water Side

Cooling System:

The chilled water distribution system consists of three chilled water pumps with variable frequency controllers pumping chilled water through the evaporator of one or both chillers, the heat exchanger, and to the building loads. The system uses two pumps to achieve maximum flow with a third pump functioning as stand-by if needed. The required flow through the chilled water system is controlled by varying the speed of chilled water pumps and corresponding bypass valve. The flow to each chiller's evaporator is monitored by a flow sensor in the chilled water supply branch. The chilled water by-pass valve has the ability to modulate to maintain minimum chilled water flow to each active chiller. Finally the variable frequency controllers (VFC) modulate the speed of the chilled water pumps which maintain the differential pressure at a designated set point.

When OA temperature is at a low enough point, chilled water can be provided without the operation of the chillers. This is because the system contains a heat exchanger, working in conjunction with the condenser water system; known as a water side economizer.

Heating System:

The heating water distribution system consists of two heating water pumps with variable frequency controllers pumping water through any one of the five boilers and heating coils throughout the building. The system uses 1 pump for system flow and the second as a stand-by if needed. The required flow through the heating water system is controlled by varying the speed of the heating water pumps. The VFC's are in place to modulate the speed of the pumps to maintain the differential pressure at a designated set point.

Previous Technical Report Information

The following section on ventilations, heating/cooling loads, and energy use were covered in previous Technical Reports one and two. ASHRAE Standard 62.1 and 90.1 analyses are repeated in the following section as is the annual energy use or building load analysis.

Ventilation Requirements

The purpose of section 6 of ASHRAE Standard 62.1 is to determine the minimum outdoor air intake rates based on occupancy type, floor area, and design population. Ventilation rates were calculated for a descriptive section of the building. The ArNG Building has several different types of occupancies varying from offices to training facilities. By picking critical zones of the building it should provide a good representation of the rest of the building. From this it is then possible to label the building for compliance or non-compliance of Section 6 of ASHRAE Standard 62.1. The zones which were checked for ventilation are shown in Figures 62.1-1 and 62.1-2.

Outdoor Air Flow Calculation Assumptions

1. Levels 2T and 1P were used to gather an accurate representation of the building as a whole.
2. Zone populations were tabulated based on table 6-1 in ASHRAE Standard 62.1.

Results (ASHRAE 62.1 section 6)

The critical spaces found were both an elevator lobby located in relatively that same area of the building but at different levels. This was the maximum Zp value resulting from the large default population which ASHRAE specified in table 6-1. The supply air to these spaces ended up being too low as a result. Another interesting note is the amount of cfm's for the primary supply for level 2T. The AHU for level 2T is specified to handle 11,900 cfm's. The calculations are fairly near to this value showing the unit running at an efficient level.

ASHRAE 62.1 Conclusion

From the above analyses it is safe to say that the ArNG building does a very good job of adhering to Section 5 and 6 of ASHRAE Standard 62.1. Areas for improvement would be to reanalyze Section 6 and try and account for the low ventilation rates for a few of the spaces.

Heating and Cooling Loads

The program utilized for the ArNG building modeling was Trane Trace 700. This program was chosen above other such software due to its user interface and my prior experiences. Trace uses an 8760 hour analysis to determine design loads, performance, and energy consumption. To construct the building model, information was gathered from DMJM H&N/AECOM and corresponding engineers. To properly model the ArNG building, several assumptions were made as follows.

Assumptions

- To simplify the modeling process while producing an accurate model, the building's various spaces were first placed into blocks as shown earlier in this document.
- The two centrifugal water-cooled chillers were modeled as a single unit in the cooling plant to simplify the model
- The façade was modeled in accordance to the specified U values for the design wall materials

All internal loads for the ArNG model were based off of space function and type. From this, activity and occupancy levels were determined and found to mainly revolve around moderate office specifications. As for the lighting and miscellaneous loads, these were specified by the engineers on the project and inserted into the model. Such internal loads can be found in Table 11 below.

Internal Lighting/Miscellaneous Loads		
Function	**Lighting (W/SF**	**Miscellaneous (W/SF)**
Office	1	1.5
Conference	1	1.5
Control/Telecom	1	9
Corridor	1	0
Electrical/Data	1	12
Media	1	3.5
Storage	1	0
Mechanical	1	0
Warehouse	1	0

Table 11

It is important for the energy model to follow some standard schedules for lighting as well as occupancy. Such schedules better analyze the full impact of the above loads on the various spaces. It is unreasonable to state that each space will be used 24 hours a day at full capacity.

As a result, Table 5 shows the breakdown of light usage and occupancy as a percentage during various hours of the day.

Lighting/Occupancy Schedules		
Time	Lighting (%)	Occupancy (%)
Midnight-7am	0	0
7am-8am	40	30
8am-6pm	100	100
6pm-7pm	40	10
7pm-Midnight	0	0

Table 12

Computed Load

From the above assumptions the ArNG model was complete and the analysis was initiated. The systems referred to in Table 6 (1P, 2P, 3P, 1T, 2T, 3T, 4T, 5T) correspond to an individual air handling unit per floor. This is not that case as floors 1P and 3P utilize multiple units, however they were combined as a whole to simplify the model. The following Table 6 provides the results of the Trace analysis, summarizing the cooling Sf/ton, heating Btuh/SF, total supply air cfm/SF, and ventilation supply cfm/SF)

Computed Loads					
System	Area (SF)	Cooling (SF/ton)	Heating (Btuh/SF)	Supply (CFM/SF)	Ventilation (CFM/SF)
1P	58811	297.28	30.47	0.68	0.231
2P	58129	738.1	10.67	0.2	0.098
3P	55343	331.62	29.06	0.9	0.146
1T	18497	389.03	31.05	0.64	0.174
2T	18447	370.76	33.09	0.65	0.193
3T	18478	376.18	32.19	0.64	0.188
4T	18486	378.05	32	0.64	0.187
5T	18420	347.64	35.51	0.68	0.213

Table 13

Heating and Cooling Load Conclusion

Due to the sensitive nature of the building, design loads could not be acquired without a certain level of clearance. The engineer on the project was unaware of a student analyzing the mechanical systems and when approached could not procure the necessary documentation at this time. If such documents could be procured during the remainder of the year it would then be possible to compare the above computed loads with that of the design. Only speculation is possible to the accuracy of the above analysis; however there is a high level of confidence in my work. The values acquired are all fairly consistent for the size and use of the building.

Such areas which would lead to discrepancies would be the analysis method used such as block loading or a room by room method and the software used. Programs such as eQuest are fairly common in the industry and use a different interface than Trace.

Annual Energy Use

The Trace model which was used for the load calculations was again used for the annual energy consumption analysis. The majority of the building is powered by delivered electricity, however there are several natural gas fired boilers on site. Because the ArNG building is a hopeful LEED silver design, it is very important to take advantage of the following information to produce the most efficient and environmentally friendly building as possible.

Assumptions

To generate the most accurate representation of the building which is to be built, the following analysis was based entirely off of the efficiencies and equipment specified by the engineers on the project.
A Standard schedule of rates was established to showcase the peak, mid-peak, and off-peak hours for usage. This is shown in Table 14.

Schedule Rates	
Time	**Rate Specification**
11pm-7am	off-peak
7am-8am	mid-peak
8am-6pm	peak
6pm-11pm	mid-peak

Table 14

Annual Energy Consumption (Modeled)

The ArNG building has not had an energy analysis performed from what I have researched. After talking with my contact he disclosed such information would be available once the systems could be tested in the field. The results from the Trace energy analysis for consumption can be found in the following Table 15.

Annual Energy Consumption(Modeled)		
	Electric (kWh)	**Gas (kBtu)**
Heating	4,810	6,320,662
Cooling	1,406,332	
Lighting	2,023,751	
Pumps	415,511	
Fans	1,294,561	

Table 15

Majority of energy use is from lighting at 31.1 percent of the total building energy. Heating provided 29.2 percent and cooling contributed 21.6 percent to the total. These values can be broken down further to view individual contributions due to various parts of the system and such analysis shows large consumptions by receptacles and data/com centers. It would be extremely interesting to compare these results to that of the ArNG building design and will be done when the appropriate documents can be determined and released.

Table 16 below is a breakdown by month for energy consumption. It is shown how drastic heating and electrical demands can vary by season. Electrical demands peak in the summer due to its use for the cooling systems and Natural gas demands peak in the winter due to its particular use for heating.

Monthly Energy Consumption												
Electricity												
	January	**Feburary**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
On-Pk Cons. (kWh)	321,317	291,975	350,933	366,752	430,715	454,871	491,895	470,658	424,473	378,624	349,573	332,411
On-Pk Demand (kW)	473	486	546	582	663	745	783	753	692	584	563	504
Natural Gas												
On-Pk Cons. (kWh)	11,441	10,375	7,152	4,370	2,294	2,031	1,406	1,771	2,437	4,447	5,786	9,036
On-Pk Demand (kW)	22	21	15	10	5	4	3	4	5	10	12	18
Water												
Cons. (1000gal)	151	144	305	440	780	1,017	1,191	1,062	821	451	348	202

Table 16

Along with the above monthly breakdown, it is more pertinent to see a visual representation of the monthly energy consumption. Figure 1 below clearly shows the peaks for summer and winter heating/cooling respectively.

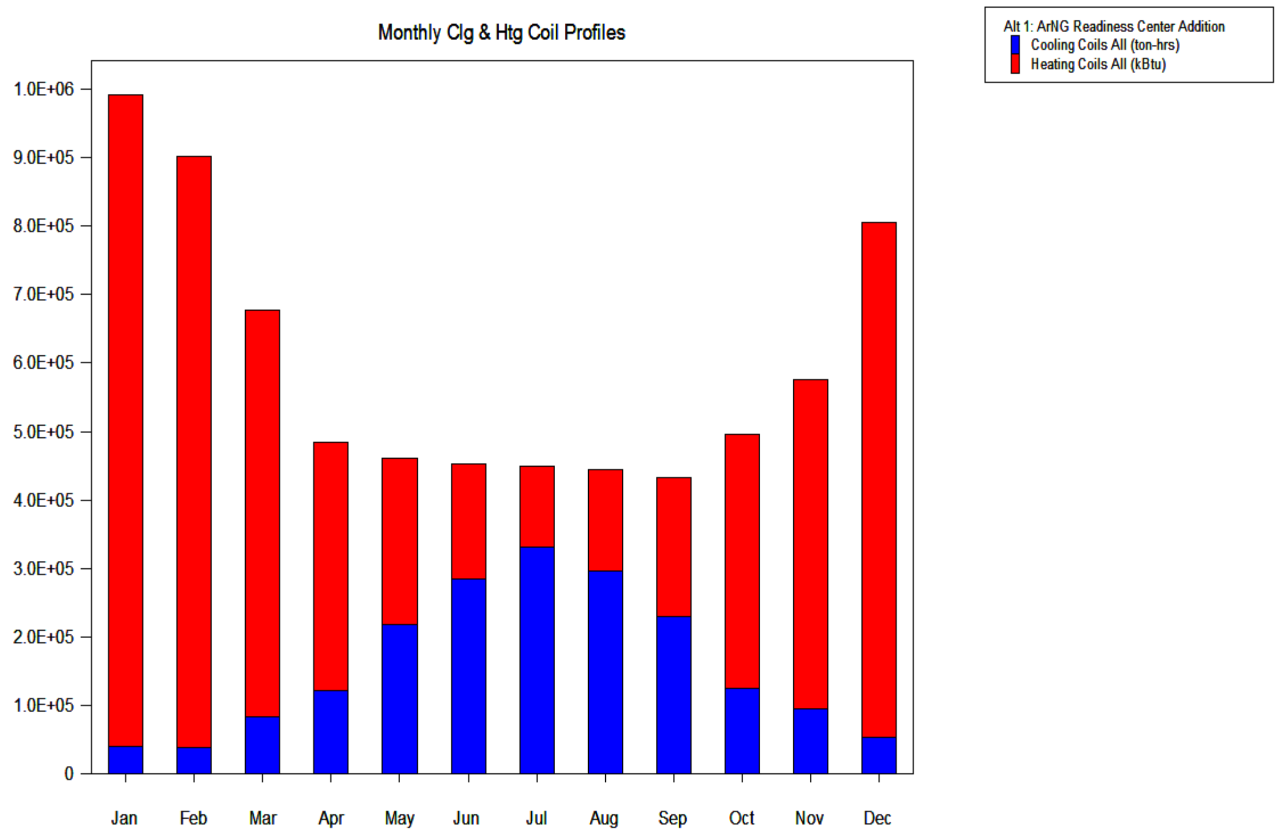

Figure 1

LEED Analysis for the Mechanical System

A LEED analysis was performed on the ArNG building using LEED-NC 2.2 (New Construction). From this LEED version there are two categories to be had for mechanical systems of a building: Energy and Atmosphere, and Indoor Environmental Quality.

Energy and Atmosphere has 3 prerequisites with 6 potential credit earning categories.

Indoor Environmental Quality has 2 prerequisites with 5 potential credit earning categories.

Energy and Atmosphere (EA)

EA Prerequisite 1 is to have fundamental commissioning of the building energy systems. This involves verification that the building's energy systems are installed, calibrated and performing according to the design. This is currently being performed and thus this prerequisite is obtained.

EA Prerequisite 2 involves the minimum energy performance required for the building. This is done by establishing the minimum level of energy efficiency for the proposed building and system. A baseline was established for this design thus complying with this prerequisite.

EA Prerequisite 3 is a requirement to manage refrigerant use in the building. This requires that no CFC based refrigerants can be used in the building. The ArNG building has selected all equipment which refrains from using CFC refrigerants and thus is in compliances.

EA Credit 1 is established to reduce environmental and economic impacts associated with excessive energy use. The ArNG building is project to save around 11% of energy use of its baseline. From this, the building receives 1 point.

EA Credit 2 looks for potential use of on-site renewable energy or self-supplies to reduce environmental and economic impacts from fossil fuel usage. The ArNG building has no know sources of on-site energy and thus receives no points out of a potential 1-7.

EA Credit 3 requires beginning the commissioning process early in the design process while establishing additional activities to verify system performance after construction. The ArNG building receives 1 point under this category.

EA Credit 4 covers refrigerant management. This is implemented to reduce ozone depletion and support early compliance with the Montreal Protocol while minimizing contributions to global warming. The total refrigerant impact per ton must be less than 100 which the ArNG building easily complies with. This is good for 1 point.

EA Credit 5 is for measurement and verification to monitor energy consumption over time. The ArNG building is under construction. It can however be assumed that a plan for measurement and verification has been set in place and will be enacted when systems are up and running. Such a plan will award 1 point.

EA Credit 6 encourages the use of renewable energy technologies on a net zero pollution basis. This requires that at least 35% of the buildings electricity is from renewable sources for at least two years. The ArNG building is not seeking to achieve this point.

Indoor Environmental Quality

EQ Prerequisite 1 is to establish a minimum for indoor air quality (IAQ). This requires that ASHRAE standard 62.1 be met for IAQ. From the engineers analysis it was found that the ArNG building is in compliance with this prerequisite. From Technical Report 1 it was found that some spaces were non-compliance but this could be contributed to occupancy assumptions.

EQ Prerequisite 2 is to control environmental tobacco smoke. The ArNG building is a non-smoking facility and is thus in compliance.

Only EQ credits 1, 2, 6.2, 7.1, and 7.2 deal with the mechanical systems of the ArNG building and have thus been explored below.

EQ Credit 1 is the monitoring of the outdoor air being delivered. This will allow for increased and sustained occupant comfort and well-being. The main requirement is that CO2 monitoring must be done in every densely occupied space. The ArNG building complies and is thus awarded 1 point.

EQ Credit 2 is to increase ventilation which will improve IAQ for occupant comfort, well-being, and productivity. To increase ventilation there must be a compromise on energy consumption. To use the least amount of energy possibly, this was not considered for the ArNG building.

EQ Credit 6.2 demands individual occupant control for thermal comfort. It requires that 50% of the building occupants be able to adjust the system to suit individual task needs and preferences. The ArNG building has several open office spaces which are feed by several VAV boxes. Some of these boxes however feed into conference rooms as well as the office spaces. From this it is determined that no points be awarded.

EQ Credit 7.1 is design of thermal comfort which supports the productivity and well-being of building occupants. Based on the calculations done for EQ 7.1, Standard 55-2004 is satisfied and 1 point is awarded.

EQ Credit 7.2 is the verification and assessment of thermal comfort over time. This credit requires only the agreement that a thermal comfort survey be conducted within six to 18 months after occupancy. This awards 1 point to the ArNG building.

Overall Evaluation

From an overall standpoint, the mechanical system of the ArNG building seems to be fairly typical. It is not only efficient, but it seems to have been implemented in a timely and cost effective manner. The specified VAV system in conjunction with high efficiency equipment can satisfy nearly any kind of load thrown at it, that is if it has been implemented in the correct fashion. Being that that this building will function as a multi-use administrative office building, a VAV system is a fairly common solution for the mechanical system.

The majority of the building is powered by delivered electricity, however there are several natural gas fired boilers on site. Although initial costs of the systems are still being explored, this system is fairly typical and should compare to a mid-rise multi use office building. The building utilizes 100% outdoor air (OA) which must be considered in these costs.

As for the total annual consumption for the ArNG building, it was found to be 4,664,299 kWh for electricity and 6,320,662 kBtu for gas. The majority of these values arise from space heating of the tower and lighting fixtures throughout the building. From the above energy consumption, it was determined that the ArNG building will require around $0.31/SF a year to operate. The system is fairly common and thus typical building engineers will be familiar with its operation and maintenance.

A VAV design is fairly simple and when in place with the BAS controls allow for high efficiency. Areas for improvement are currently under review but will revolve around a potentially new system instead of the common VAV design.