Apr. 27, 2010

Final Report

Alternative Systems Analysis

Army National Guard

Readiness Center Addition

Arlington, Va.

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Mechanical

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10/11

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http://www.engr.psu.edu/ae/thesis/portfolios/2011/mep5065/index.html

Design/Construction Team

Owner: army national guard
General Contractor: Tompkins Builders, Inc.
Architect: CH2MHILL
Engineer: DMJM H&N/ AECOM

Project Overview:

Function: Administrative/Office/Federal
Size: 251,000 SF
Stories: Total 8, 5 above grade
Cost: $100,000,000
Dates of Construction: December 2008-March 2011
Delivery Method: Design-Bid-Build

Architecture:

-Function as an administrative headquarters in conjunction with existing building
-Expand on the current facilities and account for future growth.
-Below grade levels house open office spaces, an auditorium, and Joint Operations Center
-Above grade levels used for general office space, conference rooms, as well as a library.
-Plaza(green roof) area created where the tower emerges from the lower levels
-The most unique architectural feature(aesthetic only) is the large steel tricorn
-Incorporates required standoff distances, blast walls, berms, and internal reinforcing

Structural:

-Combination of cast-in-place concrete and structural steel
-Two-way concrete slab on metal deck, bay size 20'x25'-20'x30' typical
-Reinforced concrete columns 1'-10"x1'-10" typ.
-Lateral bracing for shear support
-HSS steel specified

Foundation:
-Multilayer mat slab with spread footing

Envelope:
-Glazed aluminum curtain wall system
-Batter/Ribbed precast concrete panels

Roofing:
-Green roofing system doubling as plaza
-Single-ply roofing membrane over tower

Electrical/Lighting:

Electrical:
-35.4kV Utility Load
-(2)15kV voltage feeders to building
-480/277, 3 phase, 4 wire system distributed in building

Lighting:
-208/120, 3 phase, 4 wire system
-Fluorescent lighting typical at 277V
-Programmable fixtures
-Moderate occupant control

Emergency: Housed in Mechanical Penthouse
-(2)15kW diesel generators for back-up power

Mechanical:

-Hydronic HVAC system consisting of a heating/chilled water 4-pipe system
-System distributes water to Air Handling Units and Variable Air Volume terminals on each floor
-AHU range from 1500 to 2450 cfm supplied by 100% outdoor air (forced air system)
-Individual VAV terminals/ Fan coil units distributed as appropriate throughout each floor
-(2) 400 ton centrifugal water-cooled chillers
-Building Automation System (BAS) monitors temperatures of spaces, controls individual units, as well as FCU's.

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Acknowledgments

The Pennsylvania State University Architectural Engineering Faculty

Advisor: William Bahnfleth, Ph.D., PE

Sponsor: Turner Construction

Main Contact: Arne Kvinnesland, LEED AP

Special Thanks to my friends and family for their continuing support.

Brittany Baker for keeping me on track and focused, you were always there.

JP Peno, Dan Saxton, Sara Pace, and Bryan Pieffer for being my AE group throughout the five years.

1.0 Executive Summary

The following report has been prepared to determine the benefits of implementing a Dedicated Outdoor Air System (DOAS) in conjunction with Active Chilled Beams (ACB) and DOAS Fan Coil Units. This system will be placed with the current hydronic VAV system and compared with the as designed documents.

To begin, an overview of the building is provided. The existing mechanical system design as well as operational forecasts were analysised closely to provide a benchmark for comparison. The proposed system is then described followed with the actual design.

The redesign started with a summary of preliminary research on the units which would be used. Using Trane TRACE 700 block analysis and required ventilation rates and design temperatures to determine the buildings loads. With this determined, humidity ratios as well as cooling coil loads. The sensible cooling capacity for the supply was determined and subtracted from the total sensible load to find the ACB load. It was determined that 1,277 2'x4' ACB's would be needed.

Resizing of the existing mechanical system was conducted and cost analysis performed. Though information was limited, a payback of 9 yrs was determined. Energy analysis showed this system provided a 24% reduction in load, however, the system and this payback could be undesirable for the owner. As this is a Government project, this might not be the case.

An analysis on the impacts on cost and scheduling was investigated to determine how this system would affect construction. The nature of the building offered interesting acoustical studies, one particular space (SCIF), required acoustical isolation for security purposes.

2.0 Existing Conditions

2.1 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.

2.2 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.

2.3 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.

2.4 System Initial Cost

Original cost for the mechanical system is unknown but othe budget was $9.7 million, any redesign should be under this amount. Only the cost per square foot could be procured at this time.

2.5 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

2.6 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

2.7 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

2.8 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					
		Capacity (MBH)			
Unit	Type	Input	Output	GPM	Supply Temp ^{0}F
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.

2.9 System Operation

2.9.1 Schematics

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

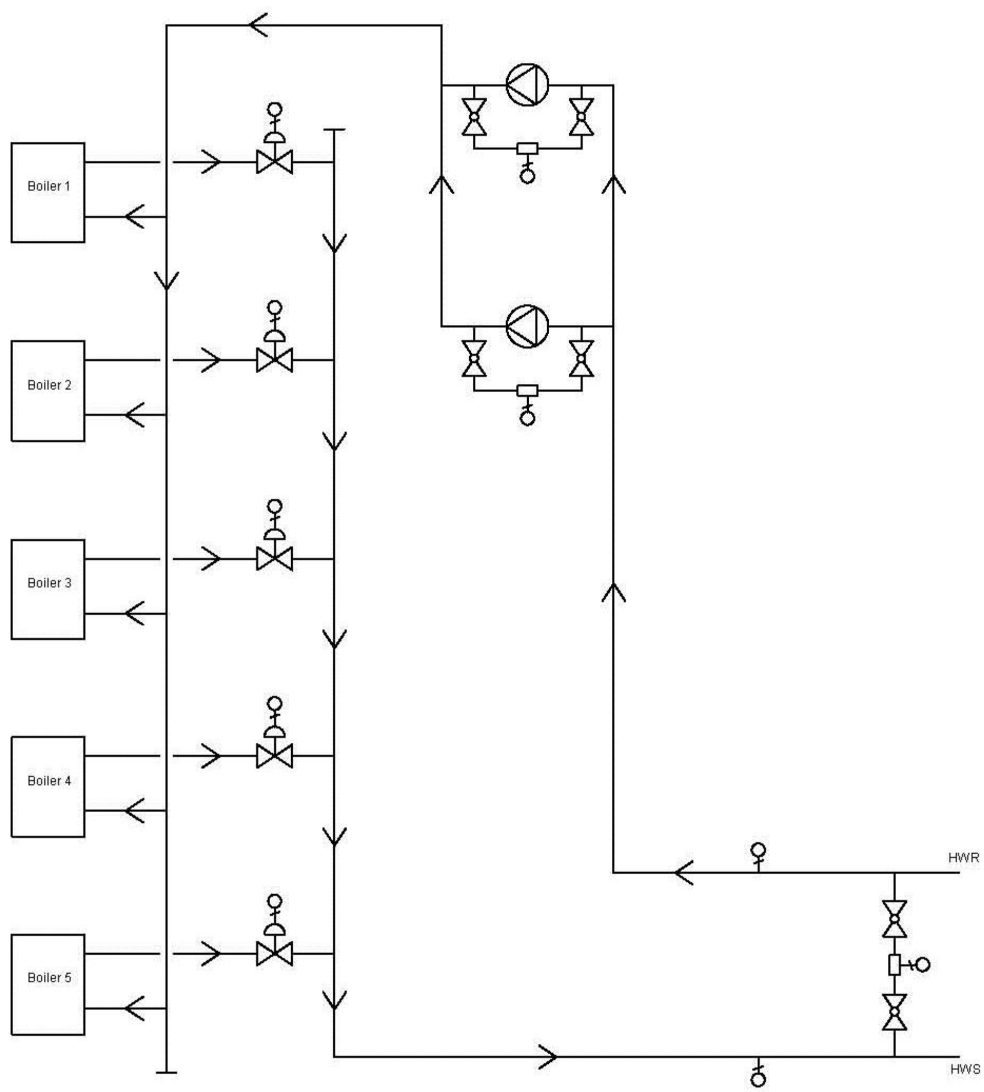

Figure 1

The following Figure 2 shows the chilled water system

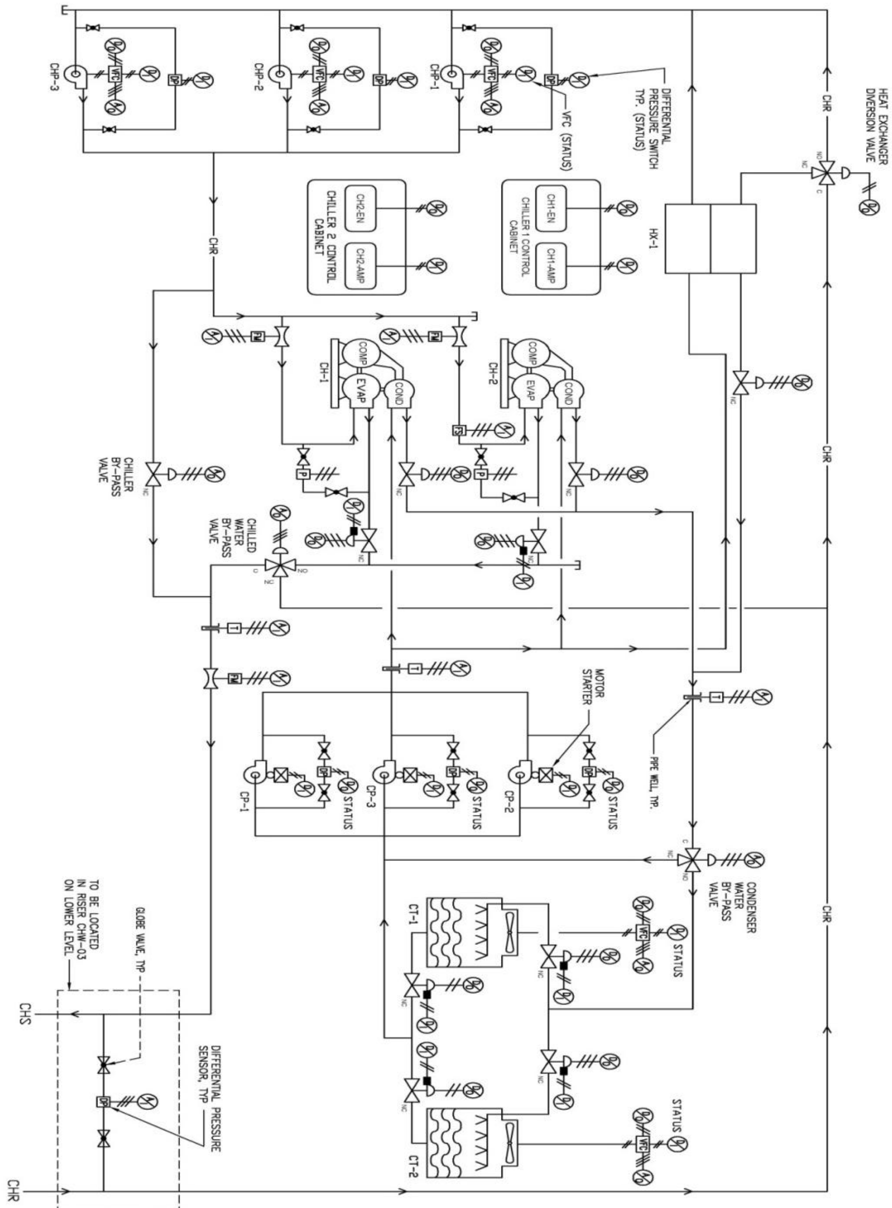

Figure 2
Figure 2 was taken from the design documents. A personal schematic had been drawn but the file had become corrupt.

2.9.2 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.

2.9.3 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.

3.0 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.

3.1 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.

3.1.1 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.

3.1.2 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.

3.1.3 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.

3.2 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.

3.2.1 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 12 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

3.2.2 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

3.2.3 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.

3.3 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.

3.3.1 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 on the following page.

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

Table 14

The on-peak utility cost as stated in Table 2 on page 9 is 8.97 cents/kWh.
The off-peak utility cost is 6.07 cents/kWh. No mid peak rate is provided so it was assumed to be close to the on-peak rate of 8.97. These particular rates are fairly high, Dominion power would not release the values used and standard rates for Arlington VA had to be used. Government use of the building could lead to significantly lower costs.

3.3.2 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 3 below clearly shows the peaks for summer and winter heating/cooling respectively.

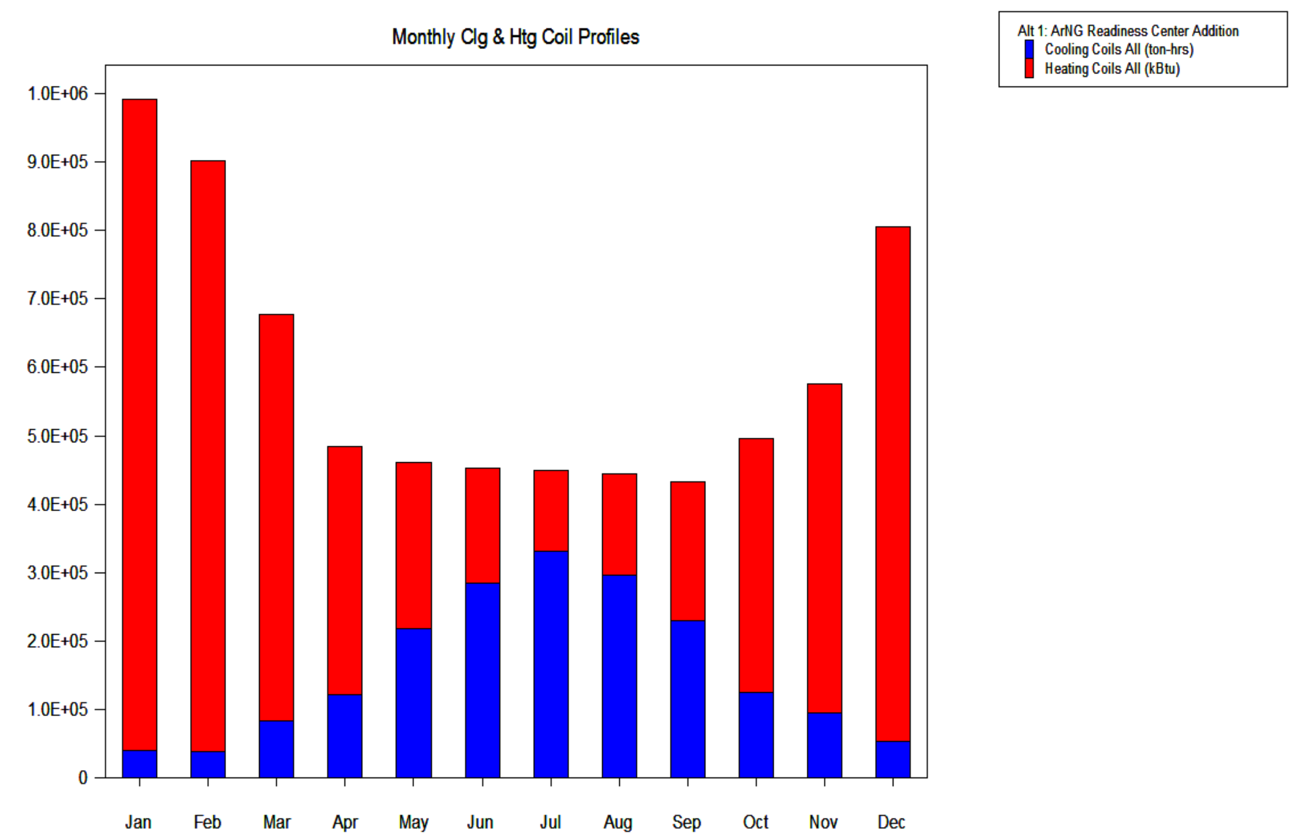

Figure 3

The following figure 4 breaks down the energy cost per year for electricity and natural gas.

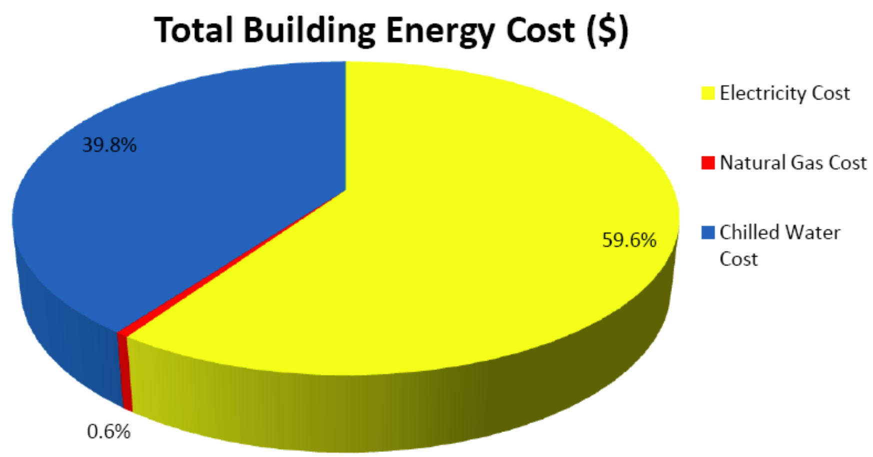

Figure 4

3.4 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.

3.5 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.

3.6 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.

4.0 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 $1.95/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.

5.0 Proposed Alternative Systems

The ArNG mechanical system is sufficient for this type of building use. It meets the LEED certifications while complying with ASHRAE Standards 62.1 and 90.1. There is however always room for improvement. The following alternative solutions are intended to reduce operating costs which is directly tied to increasing efficiency. Load reduction with DOAS and implementation into a GSHP system can be compared with the current system showcasing the potential gains.

5.1 System Optimization

5.1.5 Dedicated Outdoor Air System

The first alternative is known as a DOAS. With this type of system 100% outdoor air (OA) is used to ventilate a space. Because only OA is being used for ventilation, duct sizes can be significantly reduced in comparison to that of a standard VAV system. It is important to note that sensible and latent loads must be treated separately. This type of system is often coupled with fan-coil units, chilled beams, and other methods to meet remaining sensible loads within the space. Specifically, latent loads will be handled at the AHU.

The DOAS setup consists of the following: an enthalpy wheel, AHU's, coupled with some form of terminal units. With any system there needs to be some form of regulations and ASHRAE Standard 90.1 stipulates that preconditioning the air is a requirement. This system uses 100% OA for the supply and thus has no mixing requiring total heat recovery. A standard VAV system mixes OA with return air (RA) accomplishing preconditioning before the coils. The heat recovery unit utilized uses energy from within the building in a process with the OA.

There are many potential advantages, some of which have been touched on previously. First and for most, this type of system has the ability to increase a buildings overall efficiency. There are several was this is accomplished. Reduced supply air requirements and decoupling of heating and cooling from ventilation air provided substantial gains. This however is only the tip of DOAS. Indoor air quality can remain the same or even increase while downsizing ductwork and fans. The system specified currently generally uses more OA than is required by DOAS. The VAV system can have trouble properly ventilating all spaces with fresh air, DOAS does not have this problem. This large amount of OA requires significant conditioning in both summer and winter which accounts for large energy consumption. Mechanical space requirements are reduced and impacts initial construction costs.

A DOAS system has the ability to achieve greater efficiency while treating 100% of the latent loads in the space. DOAS also handles 100% of the OA load requirements and a potentially large amount of the sensible loads.

5.1.2 Active Chilled Beams

This above system will be accompanied with the use of CRCP (chilled beams) and also fan coil units. With chilled beams there are two applications, passive and active and work by natural forces due from air temperature gradients. This allows for natural air movement and a reduction in fan energy.

Active chilled beams are connected to the DOAS for airflow from the unit. The beam itself activates air circulation after mixing with ventilation air.

Passive chilled beams do not provide the mixing with the ventilation air. The room air induction is for cooling purposes, the ventilation air is provided via alternative methods.

The major issues which can arise from the use of chilled beams is the general inexperience which contractors and maintenance workers. Also of significant importance is environment control to ensure condensation does not occur within the building and in possibly sensitive areas.

With chilled beams it can become an issue involving spaces which require both cooling and heating. Such spaces are often located around the buildings perimeter and would potentially require another technology in conjunction with the DOAS. This is a very simple solution using FCU's which can contain both a heating and cooling coil, non-condensing, within the unit itself. This type of technology is fairly typical and would have little installation and maintenance issues. These units can be placed where appropriate to cut down on zone load costs and handle more than one space at a time.

Though more research is pending, utilizing a DOAS setup for the ArNG building should have substantial savings in energy in both fan and chiller energy. It is unreasonable to assume that this system wouldn't use more energy in some area. Basis for comparison is in an upcoming section.

5.2 Breadth Topics

5.2.1 Construction Management

The proposed mechanical system alternatives will result in substantial scheduling issues and thus will impact costs. Using RS Mean information it will be possible to determine scheduling and cost impacts for the new system. This will greatly affect construction times and will be determine continuation with construction. Cost estimation due to these schedule changes will also need to be analyzed in an effort to fully understand the impact such a system would induce.

5.2.2 Acoustical

An interesting aspect of the ArNG building is directly tied to its function. It is an Army National Guard Readiness Center, as a result the building has some very distinct functions which require various considerations. One such function is that of its SCIF space. These areas are classified requiring very special care when it comes to privacy.

The building as a whole is mainly office spaces, but on the lowest level of the building these sensitive areas can be found. The function of these spaces are for conferencing between various government organizations and in an emergency will be used in a part, with other centers around the country, to run the United States. It is clear of the importance of these spaces and as a result they need to be heavily isolated from the spaces surrounding them.

From this it is proposed to conduct an acoustical analysis of these spaces. The acoustical requirements of such a space will be studied first. Then, current sound isolation measures which have been designed will be studied in an effort to determine possible room for improvement. From there it will be possible to propose alternative acoustical systems to either, provide better sound isolation from the corridors and other spaces or accomplish the same isolation with new materials in a more cost effective manner.

5.3 Tools for Analysis

5.3.1 Energy Modeling

One of the most influential tools at the disposal of a mechanical engineer is the ability to create energy models. With each potential alternative system, it is important to analyze all cost information as well as monthly and annual energy use. To generate the above information, energy modeling is a necessity. Trane TRACE, Carrier's HAP, Energy Plus, and eQuest are all viable modeling software but each have their limitations. Though familiarity with Energy Plus and eQuest are limited they should be considered to determine which above program offers the best accuracy in modeling.

First it will be necessary to analyze and model the load reduction efforts. It is vital that this particular model be as accurate as possible, as this will determine the validity of the remainder of the new design efforts. Trane Trace will be my program of choice and I know it has the capability to model a DOAS design. Once this data is collected it will be cross-checked against know commercial buildings energy usage.

5.4 Basis for Comparison

When considering options for redesign of a system, it is important to lay the guidelines for determining whether a redesign is an improvement. The following are the criteria used to meter the success of the alternate system analysis:

5.4.1 Initial Cost

Initial Costs is what the Owner can visible see upfront. It is the most critical aspect which must be analysis for feasibility on a project. This cost must be studied closely along with the operating future of the building. As the ArNG building will be in operation for many decades to come, it is reasonable to design economically now, to save in the future.

5.4.2 Lifecycle Cost

With a baseline system established, along with maintenance cost information, the Lifecycle Cost will truly show which system operates economically.

5.4.3 Indoor Air Quality

The office spaces will be most impacted by the implementation of the new system. As a result IAQ of these spaces will be compared with the baseline VAV system.

5.4.4 Energy Use

Using energy modeling, and holding indoor thermal comfort constant, the two systems can be compared to ensure a comfortable environment can be provided.

5.4.5 Environmental Impact

This is a very important aspect of the analysis. This impact will be assessed based on the amount of energy used. If such use is lowered, the negative affects on the environment should be reduced as well.

6.0 Dedicated Outdoor Air Systems

6.1 Preliminary Analysis

The first alternative is known as a DOAS. With this type of system 100% outdoor air (OA) is used to ventilate a space. Because only OA is being used for ventilation, duct sizes can be significantly reduced in comparison to that of a standard VAV system. It is important to note that sensible and latent loads must be treated separately. This type of system is often coupled with fan-coil units, chilled beams, and other methods to meet remaining sensible loads within the space. Specifically, latent loads will be handled at the AHU.

The DOAS setup consists of the following: an enthalpy wheel, AHU's, coupled with some form of terminal units. With any system there needs to be some form of regulations and ASHRAE Standard 90.1 stipulates that preconditioning the air is a requirement. This system uses 100% OA for the supply and thus has no mixing requiring total heat recovery. A standard VAV system mixes OA with return air (RA) accomplishing preconditioning before the coils. The heat recovery unit utilized uses energy from within the building in a process with the OA.

There are many potential advantages, some of which have been touched on previously. First and for most, this type of system has the ability to increase a buildings overall efficiency. There are several was this is accomplished. Reduced supply air requirements and decoupling of heating and cooling from ventilation air provided substantial gains. This however is only the tip of DOAS. Indoor air quality can remain the same or even increase while downsizing ductwork and fans. The system specified currently generally uses more OA than is required by DOAS. The VAV system can have trouble properly ventilating all spaces with fresh air, DOAS does not have this problem. This large amount of OA requires significant conditioning in both summer and winter which accounts for large energy consumption. Mechanical space requirements are reduced and impacts initial construction costs.

A DOAS has the ability to achieve greater efficiency while treating 100% of the latent loads in the space. DOAS also handles 100% of the OA load requirements and a potentially large amount of the sensible loads.

Trane Trace was used to model DOAS with a total enthalpy wheel for latent conditioning. The results which were collected correlated with the findings of several works, in which 100% of space latent loads, 100% of OA latent loads, 30% of total sensible load with total enthalpy wheel employed, leaving only 40% of design chiller load to be picked up. Though there are several limitations within the Trace program on DOAS, the results correlate nicely with the before mentioned percentages.

6.2 Active Chilled Beams (ACB)

The application of Active Chilled Beams is basically and induction unit. By using air at varying temperatures, and the natural buoyancy of air, flow can be established. By using high pressure nozzles, turbulent flow can be established to aid in mixing. Better mixing allows for warmer water temperatures in comparison to standard VAV (Approx 10-15 deg F increase). There are some disadvantages of Active Chilled Beams. Heating issues can arise and often require perimeter heating, also inexperience of contractors as well as maintenance doesn't allow for full potential. The threat of condensation is also always a real possibility, but can be avoided when handled correctly. Figure 5 is an example of an Active Chilled Beam.

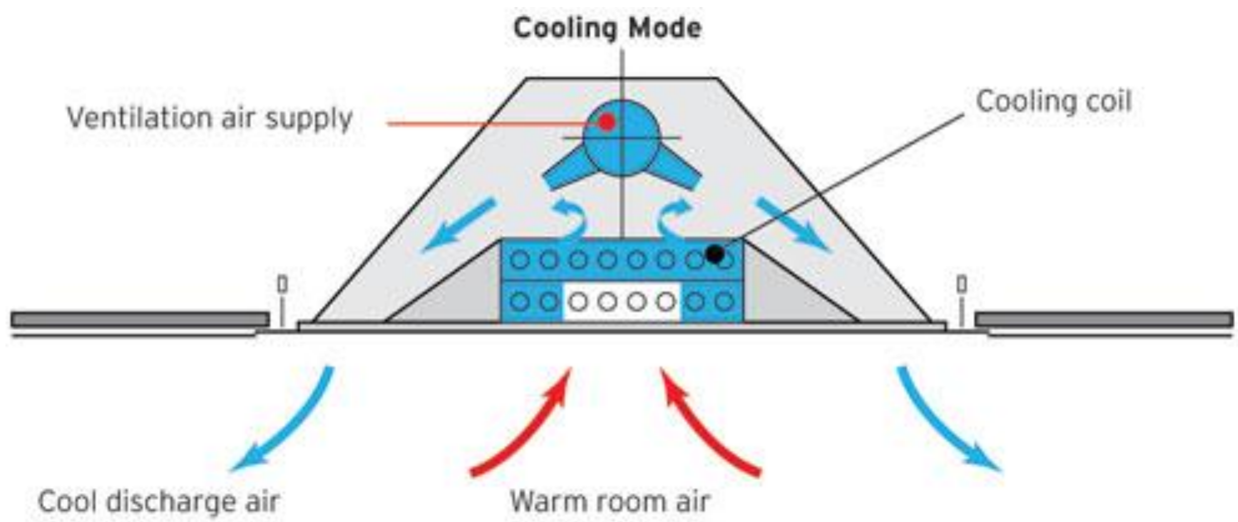

Figure 5

6.3 DOAS Fan Coil Unit

DOAS Fan coil units are another possibility which must be explored. ACB fall short for heating a space, but these units can handle those loads. This type of technology is common, so contractors and maintenance staff would have no trouble installing and maintaining. DOAS FCU's allow for much lower zone costs.

As stated before, ACB's need to be used in conjunction with some form of perimeter heating. These systems would work very well with such an application. A single unit can heat, cool, and provide necessary ventilation air. Another positive is that these units can serve more than one space where as ACB's cannot.

6.4 System Modeling

To begin modeling this system it was first necessary to determine new design temperatures. From substantial research it was clear that standard dry blub temperature for ACB's can be a few degree's higher than necessary for convention VAV. This is based on an increase in radiation transfer from human occupants to the ACB's themselves. With this increase in radiation transfer, a slightly elevated dry bulb temperature is possible without effecting occupant comfort. This comes from "DOAS Supply Air Conditions" by Stanley Mumma, as well as other articles of the like. The resulting temperture for cooling is now 77 deg F with 50% RH and a resulting dew point of 57.3 deg F. It is very important that the ACB's are maintained above this temperature. If the necessary temperature difference for the beams and water temperature was on average 15 deg F, this gives a value of 62 deg F for the beams which is above the dew point.

The next step was to determine the necessary ventilation rates based on ASHRAE 62.1. This is the main basis for sizing the DOAS unit. To begin, occupancy levels were determined based on typical occupancy densities and the amount of floor area. The amount of ventilation air was then calculated based on the CFM/person as well as the CFM/SF which are established in the standard itself. The total outdoor air required would then be the sum of all the required ventilation air to every space and the make-up air which is required due to the exhaust system.

Along with this, internal generation loads were tabulated based on occupancy level and type of activity occurring in each space. Sensible loads calculated on lighting density, equipment loads, as well as occupancy levels.

An example of ASHRAE 62.1 ventilation requirements is provided in Appendix A. These are typical levels for the building as a whole. The remainder were omitted for length.

Using Trane Trace, two variations where utilized using DOAS. First was DOAS with strictly ACB. With this system wall heating units where needed to handle additional heating requirements. A total enthalpy wheel, as stated before, was specified, though only effectiveness could be imputed.

Next DOAS Fan Coil Units where implemented. These were modeled as induction units with 4 pipes due to their similar construction and operation.

The following Figure 6, shows a DOAS set up with ACB.

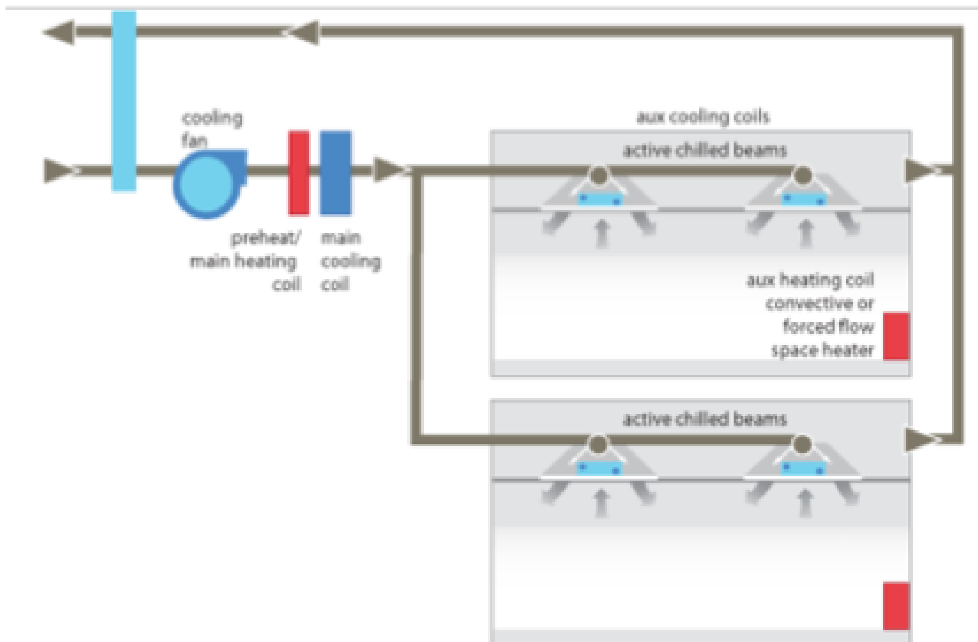

Figure 6

Equations of particular importance are as follows:

Supply Humidity Ratio

$Q_L=0.68V_{SA}(\Delta W)$, or $\mathbf{W_{SA}=W_{SP}-Q_L/(0.68V_{SA})}$

W_{SA}= Supply Air Humidity Ratio (gr/lb of dry air)
W_{SP}= Space Humidity Ratio (gr/lb of dry air)
Q_L= Space Latent Load (BTU/hr)
V_{SA}= Supply Air Flow Rate (CFM)

Sensible Load

$\mathbf{Q_S=1.08V_{SA}(\Delta T)}$

Q_S= Space Sensible Load (BTU/hr)
V_{SA}= Supply Air Flow Rate (CFM)
ΔT= Difference between Room Air DB and Supply Air DB (°F)

Cooling Coil Load

Q_{CC}=.06ρV_{SA}(ΔH)

Q_{CC}= Cooling Coil Load (kBTU/hr)
ρ = Average Density of Air (lb/ft^3)
V_{SA}= Total Supply Air Volume (CFM)
ΔH= Required Change in Enthalpy Across the Coil (BTU/lb)

Using these equations it was possible to determine all necessary aspects of the design. As stated earlier, DOAS supply air was established for every space and from this the critical space, or latent critical, was determined to be the library on level 3T. Flow needed to be increased to this space to bump the humidity ratio from approx. 30.01 gr/lb dry air to the necessary 42.1 gr/lb of dry air. With the standard VAV system without dehumidification enhancements usually don't remove enough moisture at a partial sensible load. By providing conditioned air that is drier than the air in this critical space, the DOAS unit can offset the local latent loads and maintain the desired or designed relative humidity. The space with the highest latent load cannot be the space which has the largest humidity-ratio rise. This is to avoid a design which delivers conditioned air at a humidity ratio or dew point temp. that equals the space target, as this cannot handle the latent loads.

To determine the overall necessity of perimeter fan coil units the following analysis was performed. The main space of importance is that of the office spaces throughout the tower perimeter. These spaces have the largest amount of occupants as well as the largest amount of exterior glass. Though experience in computational fluid models is limited, the following analysis was performed based on the following with instruction. In Phoenics the analysis was performed.

To represent this space accurately the established TRACE model was utilized. Loads from the exterior glazing from the model were taken and placed as heat flux to these exterior walls. The lighting loads were then assigned to the ceiling as the necessary heat flux. The airflow rates and supply temperatures were than used in the cooling mode to determine overall occupant comfort. Also of importance was ASHRAE Standard 55. This standard required that there be no more than a 5^{o}F difference from the head of an occupant to their feet. This standard will maintain thermal comfort in the space. See Figure 7 and 8 for temperature distribution profiles in an example perimeter space.

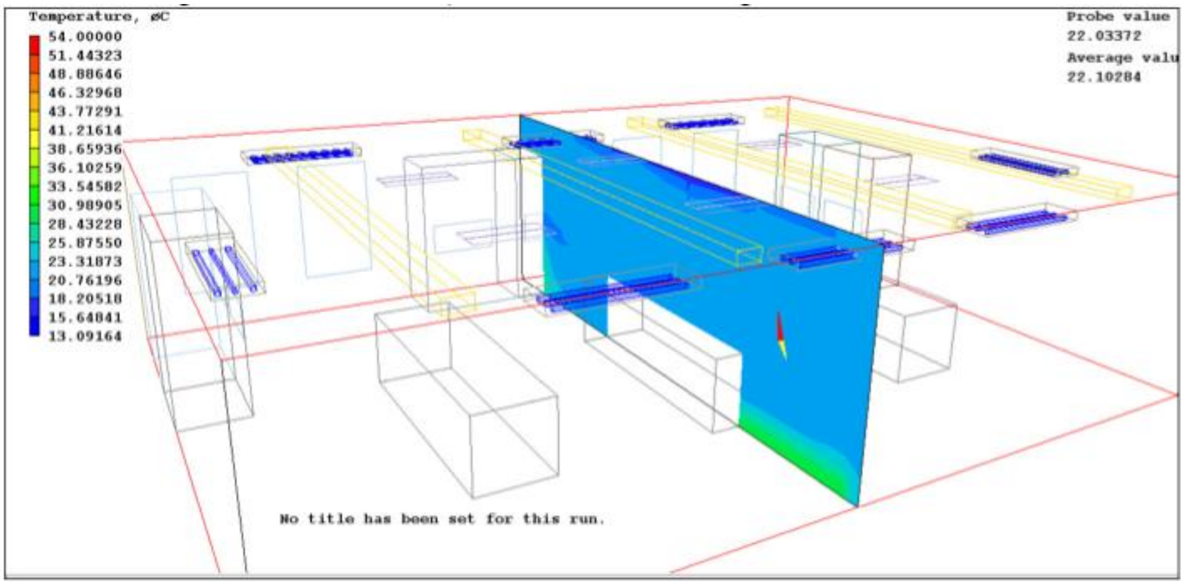

Figure 7 Temperature distribution in the x axis

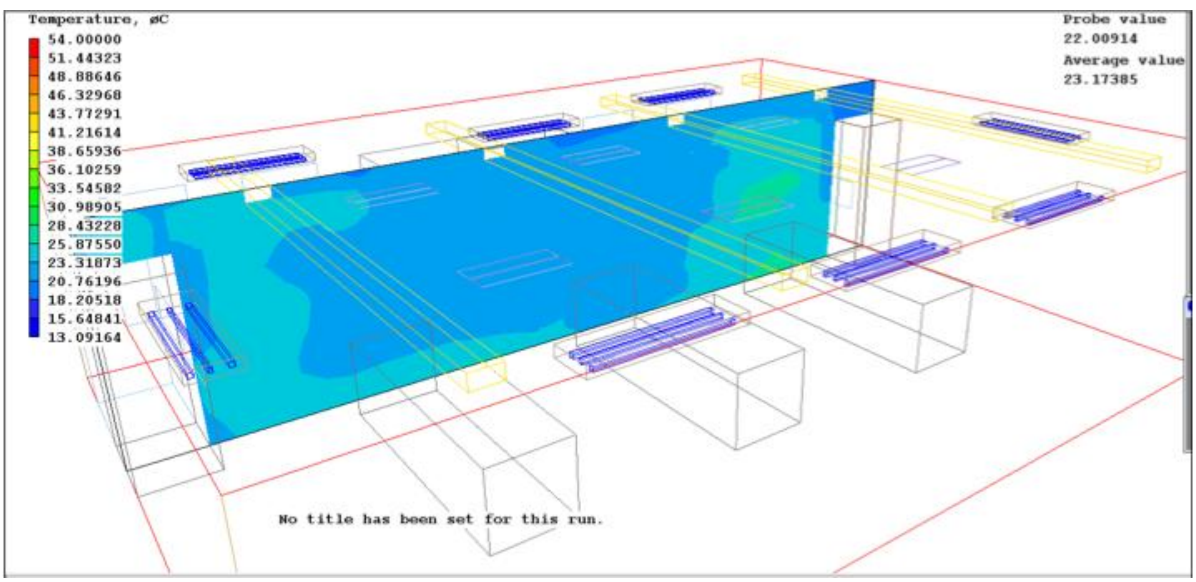

Figure 8 Temperature distribution in the y axis

Computation Time: 2hr 40m
Number of Iterations: 4600
Mass Residual: 0.88%
Temperature Residual: 0.1%

With the mass residual below 5%, it can be assumed that this model is fairly accurate.

This shows that indeed, the perimeter design of the ACB's results in the most desirable temperature profile. The ACB system has a very uniform temperature distribution with only 3^{o}F difference as a maximum. This shows that FCU around the perimeter to be unnecessary for the ACB layout as described.

Control Strategies

Zone reset of supply air temperature control. A combination of wall mounted zone sensors along with duct mounted sensors which provide supplemental sensible heating or cooling when appropriate. The zone sensor completes a feedback lopp to the controller so that the supply air temperature setpoint can be adjusted to meet the target zone temperature as a result of changing conditions within the zone. This is an appropriate application for this building due to the similar loading characteristics between spaces.

A single enthalpy wheel was chosen over a duel system for several reasons. A duel system is great for a system that requires high air change rates that is in regards to ventilation requirements. Spaces such as laboratories or hospitals are good candidates. As the ArNG building does not contain such “air-change driven” zones, it is not a necessary application. The lower first cost would be desirable. The requirements for this type of building is fairly straight forward, OA requirements are high but a simpler system would be desirable.

6.5 Results

The proposed systems both have nearly the same potential reduction in required cfms. This reduction amount was 150,000 cfm which is approximately a 25% reduction.

System	CFM	OA%	Reduction
ACB	52,100	100	148700
FCU/ACB	50,200	100	150600
Existing VAV	200,800		

Table 17

First Cost. From this it is possible to cut out several system components. The main take away is 4 AHU which are no longer required due to the DOAS pick up. Also 8 FCU will no longer be required where specified throughout the tower levels. With this reduction in cfm, duct sizes are also significantly reduced.

These savings are visible in Table 18, certain values were hard to find, such as RS Mean data on the AHU’s used in the ArNG building. Each was assumed to cost around $50,000. There will be an increase in pump requirements which needs to be analizyed futher but would result in approximately $150,000 extra. The ACB’s required number 1,277 (2’x4’)at a price of approximately $400 per unit.

Initial Cost	
Equip. Typ	cost
AHU	-200,000
VAV	-18,434
FCU	0
Pump	167,264
Fan	-15,645
ACB's	510,800
Total	443,985

Table 18

The values in table 18 must incorporate the remaining VAV and AHU systems which would increase this total to $620,321.

The above systems however offer differences in energy usage. The main potential for savings can be seen in the heating load. There is an approximate 24% reduction when compared to the existing system. As for the cooling load, the FCU/ABC combination results in a higher load. Possible reasons could be modeling issues for lack of consistency with the true equipment.

System	Cooling(TONS)	Heating(MBH)
ACB	656	4957.3
FCU/ACB	737	4803.2
Existing VAV	728	6320

Table 19

The next issue at hand is mechanical lost space. The prescribed ACB units need a place to go in the ceiling. As a result a study of this issue is as follows. The main area to focus on is the office space.

Required ceiling area: ACB=100.0 W/SF

Total Office: 6300 Tons x 3500W/Ton x 1/100 SF/W=220,500 SF required this is well under the 300,000 SF of available space.

The Environmental impact will be significantly less with the implementation of this system. It was shown above that there will be approximately 24% reduction in energy demands. Because this system will be integrated into the current hydronic VAV set up, it is reasonable to conclude that impacts will be reduced equivalently to this reduction.

Indoor Air Quality is of particular importance with this system. One of the major positives of a DOAS layout is the use of only outdoor air for supply. Even as loads decrease, this value remains 100%.

With the DOAS FCU, 100% OA, there is still the terminal unit itself which uses dampers in an effort to condition the space. Any errors involved with this system can lead to poor ventilation and thus poor IAQ. As for the existing VAV system, recirculated air is utilized, as a result there is always the chance for contaminants. It is because of this that the DOAS ACB/FCU application would clearly lead to a much better IAQ than could be achieved with the current VAV system.

Annual Energy Use (kBTU/SF*yr)		
	Existing VAV	ACB
Cooling	19.11	14.52
Heating	25.18	19.14
Pump	5.65	12.34
Ran	17.6	14.11
Total:	67.54	60.11

Table 20

The following figure shows that both electricity and chilled water consumption and demand have dropped. This is directly due to the DOAS with ACB setup. The following figure 9 shows these percentages.

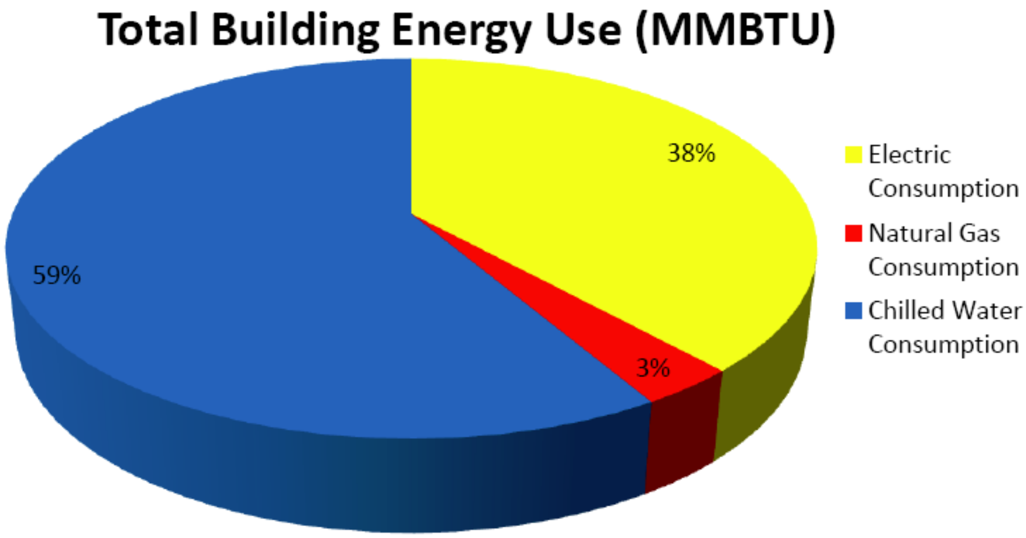

Figure 9

Mechanical Cost/SF Comparison			
System	Total Cost	Total SF	Cost/SF
Existing VAV	489,450	251,000	1.95
DOAS/ACB	620,321	251,000	2.47
Difference	130,871		0.52

Table 21

With the initial cost established along with a cost savings estimated at $15,714 the system has a payback period of roughly 9 yrs.

7.0 Construction Management

With the new proposed system it would be beneficial to get an idea of the construction impacts. To do so I used RS mean data, but such data is limited. For example, the ABC could not be included because they are not covered by the RS Mean data to this point. Estimating of various other system components was deemed necessary where appropriate, but the schedule should be fairly accurate to a point. The current system for the ArNG building is still under construction. It was however proposed to take approximately 3 months and was proposed and had a budget of $9.7 million.

First it was important to look at all new connections which must be made which accounts for the pumps and specified connections. After this the AHU, ductwork, and ACB's were analyzed.

RS Mean Data						
Equip. Typ	Crew	Daily Output	Hours	Material	Labor	Total
10 HP Fan	Q9	2	8	5025	325	5350
100 HP Pump	Q2	1.3	23	25,000	1670	26,670
10 HP Motor Connection	1-Elec	4.2	1.905	16	90	105
100 HP Motor Connection	1-Elec	1.5	5.333	194	251	445
10 HP CBRK	1-Elec	3.2	2.5	430	118	548
100 HP CBRK	2-Elec	1.6	10	2,050	470	2520

Table 20

From this the time of install and cost is as follows in Table 21.

Time of Installation/Cost					
Equipment	Units	Days for One Crew	Crews	Days	Cost (Dollars)
10 HP Fan	1	0.5	1	0.5	5350
100 HP Pump	8	6.154	3	2.05	213360
10 HP Motor Connection	1	0.238	1	0.238	105
100 HP Motor Connection	8	5.333	3	1.778	3560
10 HP CBRK	1	0.3125	1	0.3125	548
100 HP CBRK	8	5	3	1.667	20160

Table 21

Description	QTY	Unit	Bare Unit Cost Material	Bare Unit Cost Labor	Bare Unit Cost Equipment	Taxes	Ovderhead	Sub total
AHU	1	EA	$50,000	10,000	1,000	3,550.00	2,000	86,550
Ductwork	800	lb	0.75	2.75	0.5	0.06	0.55	22,971
New ACB		EA	750			37.5	0	510,800
Total								620,321

Table 22

Typical ACB Instal	5 days
Instal ACB	2 days
ACB Balancing	1 days
Commission ACB	1 days

Table 23

The above table 23 is for a single crew at work. Although a schedule was not broken out the above table shows the main system which will impact construction. With the number of ACB's which need installed, 1,277, and adjusting for 12 crews for installation, this results in 530 days of installation. This is well over the 3 month prescribed period for the existing design. This potentially shows that the VAV system as stated would be the most viable option and require less crews.

8.0 Acoustical

The ArNG building provides several interesting areas mainly because of its purpose. It is Readiness Center, and as a result contains certain rooms that are of a sensitive nature. One such space is the SCIF, Sensitive Compartmented Information Facility, located on level 3P, the deepest floor of the building. Figure 8 shows the SCIF area.

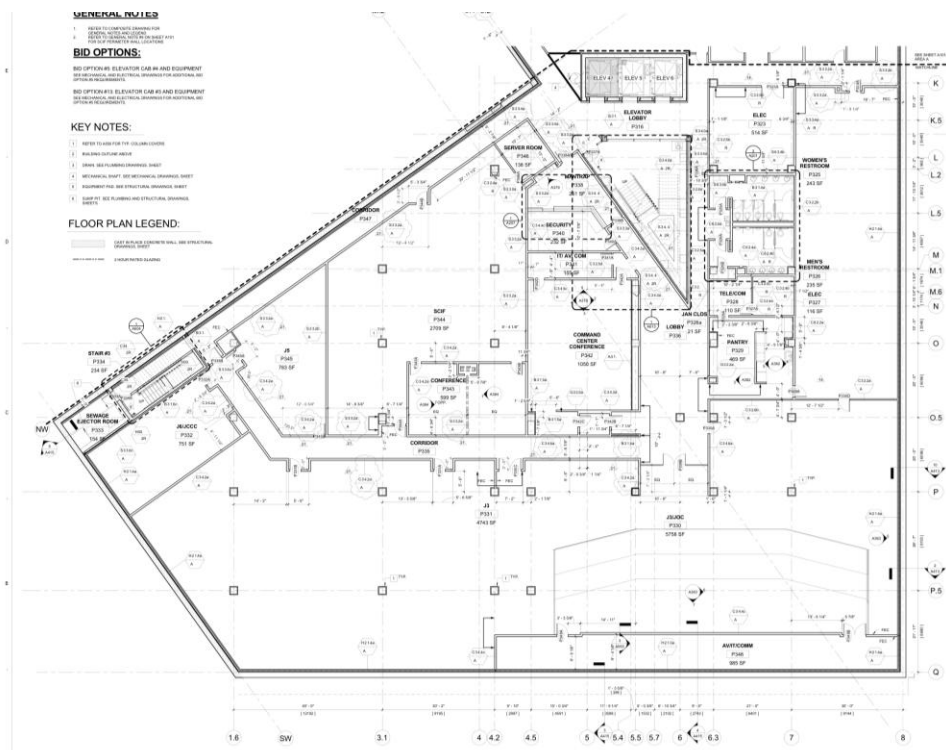

Figure 8

8.1 SCIF Specifications

As with any sensitive Government area, there are several specifications which must be followed. The idea of this type of area is as follows. A SCIF is an accredited area, room, group of rooms, buildings, or installation where SCI may be stored, used, discussed, and/or electronically processed. This space is accessible only to those individuals with proper clearance. The physical security protection for a SCIF is intended to prevent as well as detect visual, **acoustical**, technical, and physical access by unauthorized persons. One can see that this is to be a highly secured space which, in the case of the ArNG building, will be used during times of crisis.

Doors

Only a single primary entrance is acceptable for an SCIF, but emergency exits are an exception. All perimeter SCIF doors must be closed when not in use. These doors must be plumbed in their frames and firmly fixed to the surrounding wall. Door frames must be of sufficient strength to avoid improper alignment of door alarm sensors and improper door closure.

Door Construction Types: Selections of entrance and emergency exit doors is to be consistent with SCIF perimeter wall construction. Some acceptable types of doors are:

a. Solid wood core door, a minimum of 1 3/4 inches thick.

b. Sixteen gauge metal cladding over wood or composition materials, a minimum of 1 3/4 inches thick. The metal cladding shall be continuous and cover the entire front and back surface of the door.

c. Metal fire or acoustical protection doors, a minimum of 1 3/4 inches thick.

There are two entrances into the SCIF space of the ArNG building, these doors both have an STC rating of 55. As stated above, only one is desirable, but the exception of requiring a second exit for emergency purposes was necessary.

Walls

The ArNG building uses a permanent dry wall construction for this space, the criteria for this wall type is given as follows:

The walls, floor and ceiling will be permanently constructed and attached to each other. To provide visual evidence of attempted entry, all construction, to include above the false ceiling and below a raised floor, must be done in such a manner as to provide visual evidence of unauthorized Penetration.

The ArNG building specifies welded metal mesh applied to all the studs in the walls underneath the GWB. The idea being that if someone REALLY wanted to get in, they couldn't just drill a hole through a wall or break down a wall because of the mesh. This space is "technically" soundproofed due to increased layers of drywall on the walls, 4 total throughout this area.

8.2 SCIF Acoustical Specifications

Acoustical Isolation

The walls separating the SCIF space from other areas is to be sealed or insulted with nonhardening caulking. This will prevent persons located in adjacent passageways from overhearing SCI discussions or briefings from within the space, taking into account the normal ambient noise level.

> If this caulking and insulation is not sufficient to attenuate voices or sounds from within the SCIF, the next step is to raise the ambient noise level with the use of sound countermeasure devices, controlled sound generating source, or additional perimeter material installation.
>
> Air handling units and ducts will be equipped with silencers or sound countermeasure devices unless continuous duty blowers provide a practical, effective level of masking (blower noise) in each air path. The effective level of security may be determined by stationing personnel in adjacent spaces or passageways to determine if SCI can be overheard outside the space.

SCIF Sound Group

It is first important to understand the reasons for the acoustical protection and what it is used to stop. The acoustical protection measures and sound masking systems are designed to protect SCI against being inadvertently overheard by the casual passerby, not to protect against deliberate interception of audio. The SCIF's ability to keep sound from escaping its enclosed area will be rated using the Sound Transmission Class (STC). This is a single number rating used to determine the sound barrier performance of walls, ceilings, floors, windows, and doors.

According to the Architectural Graphics Standards (AGS), it describes various types of sound control, isolation requirements and office planning. The AGS established Sound Groups I through 4, of which Groups 3 and 4 are considered adequate for specific acoustical security requirements for SCIF construction.

> Sound Group I - STC of 30 or better. Loud speech can be understood fairly well. Normal speech cannot be easily understood.
>
> Sound Group 2 - STC of 40 or better. Loud speech can be heard, but is hardly intelligible. Normal speech can be heard only faintly if at all.
>
> Sound Group 3 - STC of 45 or better. Loud speech can be faintly heard but not understood. Normal speech is unintelligible.

Sound Group 4 - STC of 50 or better. Very loud sounds, such as loud singing, brass musical instruments or a radio at full volume, can be heard only faintly or not at all.

These STC values were determined desirable based on STC Ratings were obtained from Architectural Acoustics by Marshall Long for the calculation of the different of wall types.10

With the ArNG building and its SCIF space, it is desired to have an STC of 50 or better, placing it in Group 4. It is also stipulated that if the SCIF is compartmentalized, the dividing walls must meet Group 3 requirements.

Sound Masking and Stand-Off Distance

If standard construction practices can not meet the above sound groups of 3 or 4, sound masking should then be applied. Protection against interception of SCI discussions may include use of sound masking devices, structural enhancements, or SCIF perimeter placement.

Masking of sound which emanates from an SCIF area is commonly done by a sound masking system. A sound masking system may utilize a noise generator, tape, disc or record player as a noise source and an amplifier and speakers or transducers for distribution.

Placement of Speakers and Transducers

To be effective, the masking device must produce sound at a higher volume on the exterior of the SCIF than the voice conversations within the SCIF. Speakers/transducers should be placed close to or mounted on any paths which would allow audio to leave the area. These paths may include doors, windows, common perimeter walls, vents/ducts, and any other means by which voice can leave the area.

For common walls, the speakers/transducers should be placed so the sound optimizes acoustical protection.

For doors and windows, the speakers/transducers should be close to the aperture of the window or door and the sound projected in a direction facing away from conversations.

Once the speakers or transducers are optimally placed, the system volume must be set and fixed. The level for each speaker should be determined by listening to conversations occurring within the SCIF and the masking sound and adjusting the level until conversations are unintelligible from outside the SCIF.

8.3 Analysis and Results

There a few methods to increase the STC of a wall. This mainly involves adding mass, increasing or adding air space, and adding absorptive material within the partition.

The ArNG building has no specified sound masking equipment and relies on the wall. The welded mesh core wall with 4 layers of GWB is more than enough to sound poof the space. This is a clear example of adding mass. But could less layers be used in conjunction with sound masking to save money.

According to Marshall Long, the wall construction for the ArNG building should provide an STC of 56 or more. Figure 9 shows this wall construction.

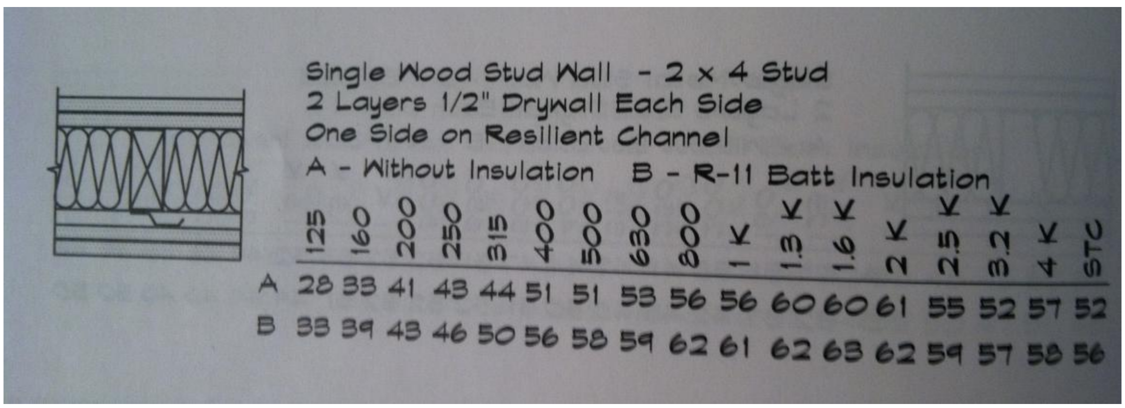

Figure 9

Figure 10 shows the benefits of using the before mentioned caulking material to prevent flanking noise.

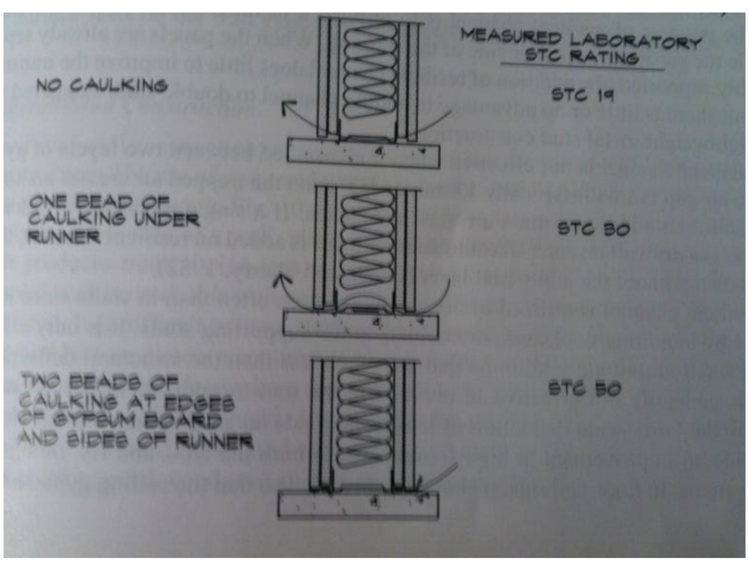

Figure 10

Using RS Mean data is was possible to determine the cost of the proposed wall system for the SCIF area. This space has a wall surface area of 2,420 SF. Using this information, the proposed wall costs approximately $12.02/SF. This isn't unreasonable when acoustical panel walls can run upwards of $20/SF.

By using only a single sheet of 5/8" GWB on both the interior and exterior, along with resilient channels, the wall STC would be around 44. This is right around the Sound Group 3 level and would fit well in this situation if it wasn't desirable to be in group 4. This wall type would cost approximately $7.18/SF. This is a considerable savings of around $30,000. In conjunction with this lower STC wal,l a sound masking system could be cheaply placed. Such a unit can cover over 6,000 SF and would cost considerably less than 30,000 dollars in savings.

With this in mind, I would recommend installing the wall as designed. This is a very sensitive area and not one which should take shortcuts on design. The higher STC wall will ensure no sound exfiltrations.

9.0 Final Conclusion and Discussion of Results

With the analysis of the proposed mechanical system in mind, it would be hard to decided between one or the other. The cost estimates and payback were not unreasonable, though it was surprising to see how little can be saved from making substantial changes. Though a 9 yr payback period would be unreasonable in the long run, the actual energy savings and cost savings were not of a substantial result.

First cost calculations were difficult for lack of information. This building is for Government purposes, and as a result has some documentation which can not be procured.

This type of building is a perfect candidate for DOAS and there leave further room for improvement which wasn't touched in the scope of this paper. Reduced duct sizes, decreased maintenance, increased IAQ are all positives for implementing this type of system.

In the end the VAV system as design would be the likely choice. It is the economical choice in most situations and without further comparisons, it would be difficult to back up DOAS further.

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Appendix A: Tabulations

Building:	Army National Guard Readiness Center Addition										
System Tag/Name:	Level 1P(AHU-1P-A1,A2,Ba,B2,B3)										
Operating Condition Description:											
Units (select from pull-down list)	IP										
Inputs for System	**Name**	**Units**			**System**						
Floor area served by system	As	sf			42342						
Population of area served by system (including diversity)	Ps	P	100% diversity		575						
Design primary supply fan airflow rate	Vpsd	cfm			32,340						
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf			0.06						
OA req'd per person for system area (Weighted average)	Rps	cfm/p			5.7						
Inputs for Potentially Critical zones											
Zone Name			*Zone title turns purple italic for critical zone(s)*			Corridor	Prefunction	Training	Large Conf.	IT/COMM	Men Locker	Women Lock
Zone Tag						P132	P133	P135	P136	P137	P138	P139
Space type			Select from pull-down list			Corridors	Lobbies/prefunction	Gym, stadium (play area)	Conference/meeting	Telephone/data entry	Health club/weight rooms	Health club/weight rooms
Floor Area of zone	Az	sf				625	1700	589	1867	100	492	566
Design population of zone	Pz	P	(default value listed; may be overridden)			0	51	17.67	93.35	6	4.92	5.66
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm				300	400	600	600	375	300	300
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?			Select from pull-down list or leave blank if N/A									
Local recirc. air % representative of ave system return air	Er											
Inputs for Operating Condition Analyzed											
Percent of total design airflow rate at conditioned analyzed	Ds	%			100%	100%	100%	100%	100%	100%	100%	100%
Air distribution type at conditioned analyzed			Select from pull-down list			CS	CS	CS	CS	CS	CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez					1.00	1.00	1.00	1.00	1.00	1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep											
Results											
Ventilation System Efficiency	Ev				#VALUE!							
Outdoor air intake required for system	Vot	cfm			#VALUE!							
Outdoor air per unit floor area	Vot/As	cfm/sf			#VALUE!							
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p			#VALUE!							
Outdoor air as a % of design primary supply air	Ypd	cfm			#VALUE!							
Detailed Calculations											
Initial Calculations for the System as a whole											
Primary supply air flow to system at conditioned analyzed	Vps	cfm	= VpdDs	=	32340							
UncorrectedOA requirement for system	Vou	cfm	= Rps Ps + Ras As	=	5984							
Uncorrected OA req'd as a fraction of primary SA	Xs		= Vou / Vps	=	0.19							
Initial Calculations for individual zones											
OA rate per unit area for zone	Raz	cfm/sf				0.06	0.06	0.30	0.06	0.06	0.06	0.06
OA rate per person	Rpz	cfm/p				0.00	7.50	0.00	5.00	5.00	20.00	20.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm	Critical zone needs more ventilation			300	400	600	600	375	300	300
Unused OA req'd to breathing zone	Vbz	cfm	= Rpz Pz + Raz Az	=		37.5	484.5	176.7	578.8	36.0	127.9	147.2
Unused OA requirement for zone	Voz	cfm	= Vbz/Ez	=		38	485	177	579	36	128	147
Fraction of zone supply not directly recirc. from zone	Fa		= Ep + (1-Ep)Er	=		1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		= Ep	=		1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		= 1-(1-Ez)(1-Ep)(1-Er)	=		1.00	1.00	1.00	1.00	1.00	1.00	1.00
Unused OA fraction required in supply air to zone	Zd		= Voz / Vdz	=		0.13	1.21	0.29	0.96	0.10	0.43	0.49
Unused OA fraction required in primary air to zone	Zp		= Voz / Vpz	=		0.13	1.21	0.29	0.96	0.10	0.43	0.49
System Ventilation Efficiency					Critical zo							
Zone Ventilation Efficiency (App A Method)	Evz		= (Fa + FbXs - FcZ) / Fa	=		1.06	-0.03	0.89	0.22	1.09	0.76	0.69
System Ventilation Efficiency (App A Method)	Ev		= min (Evz)	=	(0.27)							
Ventilation System Efficiency (Table 6.3 Method)	Ev		= Value from Table 6.3	=	n/a							
Minimum outdoor air intake airflow											
Outdoor Air Intake Flow required to System	Vot	cfm	= Vou / Ev	=	No Solutic							
OA intake req'd as a fraction of primary SA	Y		= Vot / Vps	=	Would nee							
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	= Vou / Ev	=	n/a							
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		= Vot / Vps	=	n/a							
OA Temp at which Min OA provides all cooling											
OAT below which OA Intake flow is @ minimum		Deg F	= {(Tp-dTsf)-(1-Y)*(Tr+dTrf	=	#VALUE!							

Building:	Army National Guard Readiness Center Addition										
System Tag/Name:	Level 1P(AHU-1P-A1,A2,Ba,B2,B3)										
Operating Condition Description:											
Units (select from pull-down list)	IP										
Inputs for System	**Name**	**Units**		**System**							
Floor area served by system	As	sf		42342							
Population of area served by system (including diversity)	Ps	P	100% diversity	575							
Design primary supply fan airflow rate	Vpsd	cfm		32,340							
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf		0.06							
OA req'd per person for system area (Weighted average)	Rps	cfm/p		5.7							
Inputs for Potentially Critical zones											
Zone Name	Zone title turns purple italic for critical zone(s)				Elec.	Jan. Closet	Elev. Lobby	Corridor	IT/COMM	Pantry/Copy	Corridor
Zone Tag					P101	P104	P105	P106	P107	P108	P110
Space type		Select from pull-down list			Electrical equipment rooms	Stages, studios	Lobbies	Corridors	Telephone/data entry	Break rooms	Corridors
Floor Area of zone	Az	sf			112	66	340	340	151	331	460
Design population of zone	Pz	P	(default value listed; may be overridden)		0	4.62	51	0	9.06	8.275	0
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm			575	75	300	100	375	520	150
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?		Select from pull-down list or leave blank if N/A									
Local recirc. air % representative of ave system return air	Er										
Inputs for Operating Condition Analyzed											
Percent of total design airflow rate at conditioned analyzed	Ds	%		100%	100%	100%	100%	100%	100%	100%	100%
Air distribution type at conditioned analyzed		Select from pull-down list			CS	CS	CS	CS	CS	CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez				1.00	1.00	1.00	1.00	1.00	1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep										
Results											
Ventilation System Efficiency	Ev			#VALUE!	Critical zone needs more ventilation						
Outdoor air intake required for system	Vot	cfm		#VALUE!							
Outdoor air per unit floor area	Vot/As	cfm/sf		#VALUE!							
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p		#VALUE!							
Outdoor air as a % of design primary supply air	Ypd	cfm		#VALUE!	#VALUE!						
Detailed Calculations											
Initial Calculations for the System as a whole											
Primary supply air flow to system at conditioned analyzed	Vps	cfm	= VpdDs	= 32340							
UncorrectedOA requirement for system	Vou	cfm	= Rps Ps + Ras As	= 5984							
Uncorrected OA req'd as a fraction of primary SA	Xs		= Vou / Vps	= 0.19							
Initial Calculations for individual zones											
OA rate per unit area for zone	Raz	cfm/sf			0.06	0.06	0.06	0.06	0.06	0.06	0.06
OA rate per person	Rpz	cfm/p			0.00	10.00	5.00	0.00	5.00	5.00	0.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm	Critical zone needs more ventilation		575	75	300	100	375	520	150
Unused OA req'd to breathing zone	Vbz	cfm	= Rpz Pz + Raz Az	=	6.7	50.2	275.4	20.4	54.4	61.2	27.6
Unused OA requirement for zone	Voz	cfm	= Vbz/Ez	=	7	50	275	20	54	61	28
Fraction of zone supply not directly recirc. from zone	Fa		= Ep + (1-Ep)Er	=	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		= Ep	=	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		= 1-(1-Ez)(1-Ep)(1-Er)	=	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Unused OA fraction required in supply air to zone	Zd		= Voz / Vdz	=	0.01	0.67	0.92	0.20	0.14	0.12	0.18
Unused OA fraction required in primary air to zone	Zp		= Voz / Vpz	=	0.01	0.67	0.92	0.20	0.14	0.12	0.18
System Ventilation Efficiency				Critical zone needs over 100% OA in zone SA							
Zone Ventilation Efficiency (App A Method)	Evz		= (Fa + FbXs - FcZ) / Fa	=	1.17	0.52	0.27	0.98	1.04	1.07	1.00
System Ventilation Efficiency (App A Method)	Ev		= min (Evz)	= (0.27)							
Ventilation System Efficiency (Table 6.3 Method)	Ev		= Value from Table 6.3	= n/a							
Minimum outdoor air intake airflow											
Outdoor Air Intake Flow required to System	Vot	cfm	= Vou / Ev	= **No Solution**							
OA intake req'd as a fraction of primary SA	Y		= Vot / Vps	= **Would need over 100% OA intake**							
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	= Vou / Ev	= n/a							
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		= Vot / Vps	= n/a							
OA Temp at which Min OA provides all cooling											
OAT below which OA Intake flow is @ minimum		Deg F	= {(Tp-dTsf)-(1-Y)*(Tr+dTrf	= #VALUE!							

Building:	Army National Guard Readiness Center Addition											
System Tag/Name:	Level 1P(AHU-1P-A1,A2,Ba,B2,B3)											
Operating Condition Description:												
Units (select from pull-down list)	IP											
Inputs for System	**Name**	**Units**		**System**								
Floor area served by system	As	sf		42342								
Population of area served by system (including diversity)	Ps	P	100% diversity	575								
Design primary supply fan airflow rate	Vpsd	cfm		32,340								
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf		0.06								
OA req'd per person for system area (Weighted average)	Rps	cfm/p		5.7								
Inputs for Potentially Critical zones					ntially Critical Zones							
Zone Name			*Zone title turns purple italic for critical zone(s)*		Elec.	Security off.	Elev. Lobby	Open Office	Elec.	IT/COMM	Pantry/Copy	
Zone Tag					P119	P120	P123	P125	P129	P130	P131	
Space type			Select from pull-down list		Electrical equipment rooms	Guard stations	Lobbies	Office space	Electrical equipment rooms	Telephone/data entry	Break rooms	
Floor Area of zone	Az	sf			112	161	378	11852	118	110	433	
Design population of zone	Pz	P	(default value listed; may be overridden)		0	2.415	56.7	59.26	0	6.6	10.825	
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm			575	200	300	7192	930	375	1550	
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?			Select from pull-down list or leave blank if N/A									
Local recirc. air % representative of ave system return air	Er											
Inputs for Operating Condition Analyzed												
Percent of total design airflow rate at conditioned analyzed	Ds	%		100%	100%	100%	100%	100%	100%	100%	100%	
Air distribution type at conditioned analyzed			Select from pull-down list		CS	CS	CS	CS	CS	CS	CS	
Zone air distribution effectiveness at conditioned analyzed	Ez				1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Primary air fraction of supply air at conditioned analyzed	Ep											
Results												
Ventilation System Efficiency	Ev			#VALUE!								
Outdoor air intake required for system	Vot	cfm		#VALUE!								
Outdoor air per unit floor area	Vot/As	cfm/sf		#VALUE!								
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p		#VALUE!								
Outdoor air as a % of design primary supply air	Ypd	cfm		#VALUE!								
Detailed Calculations												
Initial Calculations for the System as a whole												
Primary supply air flow to system at conditioned analyzed	Vps	cfm	= VpdDs	= 32340								
UncorrectedOA requirement for system	Vou	cfm	= Rps Ps + Ras As	= 5984								
Uncorrected OA req'd as a fraction of primary SA	Xs		= Vou / Vps	= 0.19								
Initial Calculations for individual zones												
OA rate per unit area for zone	Raz	cfm/sf			0.06	0.06	0.06	0.06	0.06	0.06	0.06	
OA rate per person	Rpz	cfm/p			0.00	5.00	5.00	5.00	0.00	5.00	5.00	
Total supply air to zone (at condition being analyzed)	Vdz	cfm	Critical zone needs more ventilation		575	200	300	7192	930	375	1550	
Unused OA req'd to breathing zone	Vbz	cfm	= Rpz Pz + Raz Az	=	6.7	21.7	306.2	1007.4	7.1	39.6	80.1	
Unused OA requirement for zone	Voz	cfm	= Vbz/Ez	=	7	22	306	1007	7	40	80	
Fraction of zone supply not directly recirc. from zone	Fa		= Ep + (1-Ep)Er	=	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Fraction of zone supply from fully mixed primary air	Fb		= Ep	=	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Fraction of zone OA not directly recirc. from zone	Fc		= 1-(1-Ez)(1-Ep)(1-Er)	=	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Unused OA fraction required in supply air to zone	Zd		= Voz / Vdz	=	0.01	0.11	**1.02**	0.14	0.01	0.11	0.05	
Unused OA fraction required in primary air to zone	Zp		= Voz / Vpz	=	0.01	0.11	**1.02**	0.14	0.01	0.11	0.05	
System Ventilation Efficiency				Critical zo								
Zone Ventilation Efficiency (App A Method)	Evz		= (Fa + FbXs - FcZ) / Fa	=	1.17	1.08	0.16	1.04	1.18	1.08	1.13	
System Ventilation Efficiency (App A Method)	Ev		= min (Evz)	= (0.27)								
Ventilation System Efficiency (Table 6.3 Method)	Ev		= Value from Table 6.3	= n/a								
Minimum outdoor air intake airflow												
Outdoor Air Intake Flow required to System	Vot	cfm	= Vou / Ev	= No Solutic								
OA intake req'd as a fraction of primary SA	Y		= Vot / Vps	= Would nee								
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	= Vou / Ev	= n/a								
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		= Vot / Vps	= n/a								
OA Temp at which Min OA provides all cooling												
OAT below which OA Intake flow is @ minimum		Deg F	= {(Tp-dTsf)-(1-Y)*(Tr+dTrf	= #VALUE!								

	Name	Units				System				
Building:	Army National Guard Readiness Center Addition									
System Tag/Name:	Level 2T(AHU-2T-A1)									
Operating Condition Description:										
Units (select from pull-down list)	IP									
Inputs for System	**Name**	**Units**				**System**				
Floor area served by system	As	sf				15,772				
Population of area served by system (including diversity)	Ps	P		100% diversity		212				
Design primary supply fan airflow rate	Vpsd	cfm				11,645				
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf				0.06				
OA req'd per person for system area (Weighted average)	Rps	cfm/p				5.0				
Inputs for Potentially Critical zones										
Zone Name	Zone title turns purple italic for critical zone(s)						Conference	PA Studio	Storage	Open Office
Zone Tag							T220	T222	T223	T224
Space type		Select from pull-down list					Conference/meeting	Computer (not printing)	Storage rooms	Office space
Floor Area of zone	Az	sf					405	378	249	9560
Design population of zone	Pz	P		(default value listed; may be overridden)			20.25	1.512	0	47.8
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm					500	500	75	5850
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?		Select from pull-down list or leave blank if N/A								
Local recirc. air % representative of ave system return air	Er						75%	75%	75%	75%
Inputs for Operating Condition Analyzed										
Percent of total design airflow rate at conditioned analyzed	Ds	%				100%	100%	100%	100%	100%
Air distribution type at conditioned analyzed		Select from pull-down list					CS	CS	CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez						1.00	1.00	1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep									
Results										
Ventilation System Efficiency	Ev					0.28				
Outdoor air intake required for system	Vot	cfm				7938				
Outdoor air per unit floor area	Vot/As	cfm/sf				0.50				
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p				37.4				
Outdoor air as a % of design primary supply air	Ypd	cfm				68%				
Detailed Calculations										
Initial Calculations for the System as a whole										
Primary supply air flow to system at conditioned analyzed	Vps	cfm	=	VpdDs	=	11645				
UncorrectedOA requirement for system	Vou	cfm	=	Rps Ps + Ras As	=	2045				
Uncorrected OA req'd as a fraction of primary SA	Xs		=	Vou / Vps	=	0.18				
Initial Calculations for individual zones										
OA rate per unit area for zone	Raz	cfm/sf					0.06	0.06	0.12	0.06
OA rate per person	Rpz	cfm/p					5.00	5.00	0.00	5.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm					500	500	75	5850
Unused OA req'd to breathing zone	Vbz	cfm	=	Rpz Pz + Raz Az	=		125.6	30.2	29.9	812.6
Unused OA requirement for zone	Voz	cfm	=	Vbz/Ez	=		126	30	30	813
Fraction of zone supply not directly recirc. from zone	Fa		=	Ep + (1-Ep)Er	=		1.00	1.00	1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		=	Ep	=		1.00	1.00	1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		=	1-(1-Ez)(1-Ep)(1-Er)	=		1.00	1.00	1.00	1.00
Unused OA fraction required in supply air to zone	Zd		=	Voz / Vdz	=		0.25	0.06	0.40	0.14
Unused OA fraction required in primary air to zone	Zp		=	Voz / Vpz	=		0.25	0.06	0.40	0.14
System Ventilation Efficiency										
Zone Ventilation Efficiency (App A Method)	Evz		=	(Fa + FbXs - FcZ) / Fa	=		0.92	1.12	0.78	1.04
System Ventilation Efficiency (App A Method)	Ev		=	min (Evz)	=	0.28				
Ventilation System Efficiency (Table 6.3 Method)	Ev		=	Value from Table 6.3	=	n/a				
Minimum outdoor air intake airflow										
Outdoor Air Intake Flow required to System	Vot	cfm	=	Vou / Ev	=	7938				
OA intake req'd as a fraction of primary SA	Y		=	Vot / Vps	=	0.68				
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	=	Vou / Ev	=	n/a				
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		=	Vot / Vps	=	n/a				
OA Temp at which Min OA provides all cooling										
OAT below which OA intake flow is @ minimum		Deg F	=	{(Tp-dTsf)-(1-Y)*(Tr+dTrf	=	47				

Building:	Army National Guard Readiness Center Addition										
System Tag/Name:	Level 1P(AHU-1P-A1,A2,Ba,B2,B3)										
Operating Condition Description:											
Units (select from pull-down list)	IP										
Inputs for System	**Name**	**Units**		**System**							
Floor area served by system	As	sf		42342							
Population of area served by system (including diversity)	Ps	P	100% diversity	575							
Design primary supply fan airflow rate	Vpsd	cfm		32,340							
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf		0.06							
OA req'd per person for system area (Weighted average)	Rps	cfm/p		5.7							
Inputs for Potentially Critical zones											Pote
Zone Name			*Zone title turns purple italic for critical zone(s)*		Conference	Conference	Corridor	Telecom	Siprnet	*Elev.Lobby*	Open Office
Zone Tag					P111	P112	P113	P114	P115	P116	P117
Space type			Select from pull-down list		Conference/meeting	Conference/meeting	Corridors	Telephone/data entry	Computer (not printing)	Lobbies	Office space
Floor Area of zone	Az	sf			243	115	660	164	123	360	18408
Design population of zone	Pz	P	(default value listed; may be overridden)		12.15	5.75	0	9.84	0.492	54	92.04
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm			300	150	300	375	375	200	13648
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?			Select from pull-down list or leave blank if N/A								
Local recirc. air % representative of ave system return air	Er										
Inputs for Operating Condition Analyzed											
Percent of total design airflow rate at conditioned analyzed	Ds	%		100%	100%	100%	100%	100%	100%	100%	100%
Air distribution type at conditioned analyzed			Select from pull-down list		CS	CS	CS	CS	CS	CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez				1.00	1.00	1.00	1.00	1.00	1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep										
Results											
Ventilation System Efficiency	Ev			#VALUE!							
Outdoor air intake required for system	Vot	cfm		#VALUE!							
Outdoor air per unit floor area	Vot/As	cfm/sf		#VALUE!							
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p		#VALUE!							
Outdoor air as a % of design primary supply air	Ypd	cfm		#VALUE!							
Detailed Calculations											
Initial Calculations for the System as a whole											
Primary supply air flow to system at conditioned analyzed	Vps	cfm	= VpdDs =	32340							
UncorrectedOA requirement for system	Vou	cfm	= Rps Ps + Ras As =	5984							
Uncorrected OA req'd as a fraction of primary SA	Xs		= Vou / Vps =	0.19							
Initial Calculations for individual zones											
OA rate per unit area for zone	Raz	cfm/sf			0.06	0.06	0.06	0.06	0.06	0.06	0.06
OA rate per person	Rpz	cfm/p			5.00	5.00	0.00	5.00	5.00	5.00	5.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm	Critical zone needs more ventilation		300	150	300	375	375	200	13648
Unused OA req'd to breathing zone	Vbz	cfm	= Rpz Pz + Raz Az =		75.3	35.7	39.6	59.0	9.8	291.6	1564.7
Unused OA requirement for zone	Voz	cfm	= Vbz/Ez =		75	36	40	59	10	292	1565
Fraction of zone supply not directly recirc. from zone	Fa		= Ep + (1-Ep)Er =		1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		= Ep =		1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		= 1-(1-Ez)(1-Ep)(1-Er) =		1.00	1.00	1.00	1.00	1.00	1.00	1.00
Unused OA fraction required in supply air to zone	Zd		= Voz / Vdz =		0.25	0.24	0.13	0.16	0.03	1.46	0.11
Unused OA fraction required in primary air to zone	Zp		= Voz / Vpz =		0.25	0.24	0.13	0.16	0.03	1.46	0.11
System Ventilation Efficiency				Critical zo							
Zone Ventilation Efficiency (App A Method)	Evz		= (Fa + FbXs - FcZ) / Fa =		0.93	0.95	1.05	1.03	1.16	-0.27	1.07
System Ventilation Efficiency (App A Method)	Ev		= min (Evz) =	(0.27)							
Ventilation System Efficiency (Table 6.3 Method)	Ev		= Value from Table 6.3 =	n/a							
Minimum outdoor air intake airflow											
Outdoor Air Intake Flow required to System	Vot	cfm	= Vou / Ev =	No Solutic							
OA intake req'd as a fraction of primary SA	Y		= Vot / Vps =	Would nee							
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	= Vou / Ev =	n/a							
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		= Vot / Vps =	n/a							
OA Temp at which Min OA provides all cooling											
OAT below which OA Intake flow is @ minimum		Deg F	= {(Tp-dTsf)-(1-Y)*(Tr+dTrf =	#VALUE!							

	Name	Units			System	T211	T212	T213	T214	T216	T218	T217
Building:	Army National Guard Readiness Center Addition											
System Tag/Name:	Level 2T(AHU-2T-A1)											
Operating Condition Description:												
Units (select from pull-down list)	IP											
Inputs for System	**Name**	**Units**			**System**							
Floor area served by system	As	sf			15,772							
Population of area served by system (including diversity)	Ps	P	100% diversity		212							
Design primary supply fan airflow rate	Vpsd	cfm			11,645							
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf			0.06							
OA req'd per person for system area (Weighted average)	Rps	cfm/p			5.0							
Inputs for Potentially Critical zones						**Potentially Critical Zones**						
Zone Name			*Zone title turns purple italic for critical zone(s)*			Conference	Conference	Corridor	IT/COMM	Elec.	Simnet	Lobby
Zone Tag						T211	T212	T213	T214	T216	T218	T217
Space type			Select from pull-down list			Conference/meeting	Conference/meeting	Corridors	Telephone/data entry	Electrical equipment rooms	Computer lab	Lobbies
Floor Area of zone	Az	sf				256	114	420	186	35	79	285
Design population of zone	Pz	P	(default value listed; may be overridden)			12.8	5.7	0	11.16	0	1.975	42.75
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm				300	150	700	375	375	375	300
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?			Select from pull-down list or leave blank if N/A									
Local recirc. air % representative of ave system return air	Er					[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Inputs for Operating Condition Analyzed												
Percent of total design airflow rate at conditioned analyzed	Ds	%			100%	100%	100%	100%	100%	100%	100%	100%
Air distribution type at conditioned analyzed			Select from pull-down list			CS	CS	CS	CS	CS	CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez					1.00	1.00	1.00	1.00	1.00	1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep											
Results												
Ventilation System Efficiency	Ev				0.28							
Outdoor air intake required for system	Vot	cfm			7938							
Outdoor air per unit floor area	Vot/As	cfm/sf			0.50							
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p			37.4							
Outdoor air as a % of design primary supply air	Ypd	cfm			68%							
Detailed Calculations												
Initial Calculations for the System as a whole												
Primary supply air flow to system at conditioned analyzed	Vps	cfm	= VpdDs	=	11645							
UncorrectedOA requirement for system	Vou	cfm	= Rps Ps + Ras As	=	2045							
Uncorrected OA req'd as a fraction of primary SA	Xs		= Vou / Vps	=	0.18							
Initial Calculations for individual zones												
OA rate per unit area for zone	Raz	cfm/sf				0.06	0.06	0.06	0.06	0.06	0.12	0.06
OA rate per person	Rpz	cfm/p				5.00	5.00	0.00	5.00	0.00	10.00	5.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm				300	150	700	375	375	375	300
Unused OA req'd to breathing zone	Vbz	cfm	= Rpz Pz + Raz Az	=		79.4	35.3	25.2	67.0	2.1	29.2	230.9
Unused OA requirement for zone	Voz	cfm	= Vbz/Ez	=		79	35	25	67	2	29	231
Fraction of zone supply not directly recirc. from zone	Fa		= Ep + (1-Ep)Er	=		1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		= Ep	=		1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		= 1-(1-Ez)(1-Ep)(1-Er)	=		1.00	1.00	1.00	1.00	1.00	1.00	1.00
Unused OA fraction required in supply air to zone	Zd		= Voz / Vdz	=		0.26	0.24	0.04	0.18	0.01	0.08	0.77
Unused OA fraction required in primary air to zone	Zp		= Voz / Vpz	=		0.26	0.24	0.04	0.18	0.01	0.08	0.77
System Ventilation Efficiency												
Zone Ventilation Efficiency (App A Method)	Evz		= (Fa + FbXs - FcZ) / Fa	=		0.91	0.94	1.14	1.00	1.17	1.10	0.41
System Ventilation Efficiency (App A Method)	Ev		= min (Evz)	=	0.28							
Ventilation System Efficiency (Table 6.3 Method)	Ev		= Value from Table 6.3	=	n/a							
Minimum outdoor air intake airflow												
Outdoor Air Intake Flow required to System	Vot	cfm	= Vou / Ev	=	7938							
OA intake req'd as a fraction of primary SA	Y		= Vot / Vps	=	0.68							
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	= Vou / Ev	=	n/a							
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		= Vot / Vps	=	n/a							
OA Temp at which Min OA provides all cooling												
OAT below which OA intake flow is @ minimum		Deg F	= {(Tp-dTsf)-(1-Y)*(Tr+dTrf	=	47							

Building:			Army National Guard Readiness Center Addition		
System Tag/Name:			Level 1P(AHU-1P-A1,A2,Ba,B2,B3)		
Operating Condition Description:					
Units (select from pull-down list)			IP		

	Name	Units		System	
Inputs for System					
Floor area served by system	As	sf		42342	
Population of area served by system (including diversity)	Ps	P	100% diversity	575	
Design primary supply fan airflow rate	Vpsd	cfm		32,340	
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf		0.06	
OA req'd per person for system area (Weighted average)	Rps	cfm/p		5.7	
Inputs for Potentially Critical zones					
Zone Name			*Zone title turns purple italic for critical zone(s)*		Fitness Cen.
Zone Tag					P141
Space type			Select from pull-down list		Health club/weight rooms
Floor Area of zone	Az	sf			1366
Design population of zone	Pz	P	(default value listed; may be overridden)		13.66
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm			900
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?			Select from pull-down list or leave blank if N/A		
Local recirc. air % representative of ave system return air	Er				
Inputs for Operating Condition Analyzed					
Percent of total design airflow rate at conditioned analyzed	Ds	%		100%	100%
Air distribution type at conditioned analyzed			Select from pull-down list		CS
Zone air distribution effectiveness at conditioned analyzed	Ez				1.00
Primary air fraction of supply air at conditioned analyzed	Ep				
Results					
Ventilation System Efficiency	Ev			#VALUE!	
Outdoor air intake required for system	Vot	cfm		#VALUE!	
Outdoor air per unit floor area	Vot/As	cfm/sf		#VALUE!	
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p		#VALUE!	
Outdoor air as a % of design primary supply air	Ypd	cfm		#VALUE!	
Detailed Calculations					
Initial Calculations for the System as a whole					
Primary supply air flow to system at conditioned analyzed	Vps	cfm	= VpdDs	= 32340	
UncorrectedOA requirement for system	Vou	cfm	= Rps Ps + Ras As	= 5984	
Uncorrected OA req'd as a fraction of primary SA	Xs		= Vou / Vps	= 0.19	
Initial Calculations for individual zones					
OA rate per unit area for zone	Raz	cfm/sf			0.06
OA rate per person	Rpz	cfm/p			20.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm	**Critical zone needs more ventilation**		900
Unused OA req'd to breathing zone	Vbz	cfm	= Rpz Pz + Raz Az	=	355.2
Unused OA requirement for zone	Voz	cfm	= Vbz/Ez	=	355
Fraction of zone supply not directly recirc. from zone	Fa		= Ep + (1-Ep)Er	=	1.00
Fraction of zone supply from fully mixed primary air	Fb		= Ep	=	1.00
Fraction of zone OA not directly recirc. from zone	Fc		= 1-(1-Ez)(1-Ep)(1-Er)	=	1.00
Unused OA fraction required in supply air to zone	Zd		= Voz / Vdz	=	0.39
Unused OA fraction required in primary air to zone	Zp		= Voz / Vpz	=	0.39
System Ventilation Efficiency				**Critical zo**	
Zone Ventilation Efficiency (App A Method)	Evz		= (Fa + FbXs - FcZ) / Fa	=	0.79
System Ventilation Efficiency (App A Method)	Ev		= min (Evz)	= **(0.27)**	
Ventilation System Efficiency (Table 6.3 Method)	Ev		= Value from Table 6.3	= n/a	
Minimum outdoor air intake airflow					
Outdoor Air Intake Flow required to System	Vot	cfm	= Vou / Ev	= **No Solutic**	
OA intake req'd as a fraction of primary SA	Y		= Vot / Vps	= **Would nee**	
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	= Vou / Ev	= n/a	
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		= Vot / Vps	= n/a	
OA Temp at which Min OA provides all cooling					
OAT below which OA Intake flow is @ minimum		Deg F	= {(Tp-dTsf)-(1-Y)*(Tr+dTrf	= #VALUE!	

Table B-10 (page 2) Total Emission Factors for Delivered Electricity by State (lb of pollutant per kWh of electricity)

Pollutant (lb)	MT	NC	ND	NE	NH	NJ	NM	NV	NY	OH	OK	OR	PA
CO_{2e}	1.99E+00	1.47E+00	2.68E+00	1.81E+00	8.60E-01	9.31E-01	2.43E+00	1.88E+00	1.03E+00	2.20E+00	2.08E+00	4.85E-01	1.55E+00
CO_2	1.87E+00	1.41E+00	2.61E+00	1.71E+00	8.05E-01	8.61E-01	2.29E+00	1.76E+00	9.61E-01	2.10E+00	1.93E+00	4.40E-01	1.48E+00
CH_4	4.17E-03	2.37E-03	2.41E-03	3.70E-03	2.19E-03	2.79E-03	5.38E-03	4.81E-03	2.59E-03	3.71E-03	5.67E-03	1.83E-03	2.70E-03
N_2O	5.29E-05	3.11E-05	5.92E-05	4.94E-05	1.53E-05	1.76E-05	6.50E-05	3.75E-05	1.68E-05	4.73E-05	5.09E-05	1.04E-05	3.22E-05
NO_X	3.33E-03	2.83E-03	3.71E-03	3.09E-03	1.44E-03	1.32E-03	4.00E-03	2.89E-03	1.72E-03	4.14E-03	3.02E-03	5.21E-04	2.91E-03
SO_X	5.88E-03	8.26E-03	1.00E-02	4.79E-03	5.47E-03	6.34E-03	7.30E-03	1.21E-02	6.23E-03	1.19E-02	8.88E-03	3.03E-03	8.88E-03
CO	7.40E-04	4.31E-04	1.07E-03	6.09E-04	1.13E-03	6.69E-04	8.66E-04	7.39E-04	1.75E-03	6.38E-04	8.67E-04	2.72E-04	6.01E-04
TNMOC	6.02E-05	5.25E-05	5.34E-05	5.23E-05	8.62E-05	6.92E-05	7.27E-05	6.23E-05	6.38E-05	5.41E-05	8.01E-05	3.90E-05	5.46E-05
Lead	1.99E-07	1.16E-07	4.23E-07	1.87E-07	4.57E-08	4.27E-08	2.37E-07	1.09E-07	5.59E-08	1.76E-07	1.61E-07	2.05E-08	1.17E-07
Mercury	4.08E-08	2.40E-08	7.52E-08	3.73E-08	2.60E-08	1.44E-08	4.75E-08	2.27E-08	3.99E-08	3.59E-08	3.27E-08	4.59E-09	2.70E-08
PM10	1.14E-04	6.55E-05	3.03E-04	1.01E-04	5.47E-05	5.14E-05	1.36E-04	8.97E-05	6.87E-05	9.87E-05	1.16E-04	2.87E-05	7.14E-05
Solid Waste	3.01E-01	1.78E-01	3.33E-01	2.88E-01	5.65E-02	6.23E-02	3.65E-01	1.68E-01	6.18E-02	2.71E-01	2.49E-01	3.25E-02	1.78E-01

Pollutant (lb)	RI	SC	SD	TN	TX	UT	VA	VT	WA	WI	WV	WY	
CO_{2e}	1.18E+00	1.00E+00	1.45E+00	1.46E+00	1.99E+00	2.62E+00	1.40E+00	1.88E-02	4.11E-01	2.03E+00	2.41E+00	2.67E+00	
CO_2	1.04E+00	9.57E-01	1.36E+00	1.40E+00	1.85E+00	2.51E+00	1.33E+00	1.78E-02	3.82E-01	1.92E+00	2.31E+00	2.52E+00	
CH_4	5.65E-03	1.72E-03	3.02E-03	2.43E-03	5.80E-03	4.21E-03	2.52E-03	2.25E-05	1.13E-03	4.13E-03	3.85E-03	5.42E-03	
N_2O	2.04E-05	2.12E-05	3.91E-05	3.28E-05	4.37E-05	5.53E-05	2.81E-05	1.70E-06	1.05E-05	5.32E-05	5.08E-05	7.30E-05	
NO_X	7.91E-04	1.90E-03	2.45E-03	2.77E-03	2.42E-03	5.00E-03	2.67E-03	1.38E-04	6.13E-04	3.51E-03	4.62E-03	4.58E-03	
SO_X	9.90E-03	5.73E-03	3.97E-03	7.32E-03	1.05E-02	1.47E-02	8.04E-03	1.13E-04	1.70E-03	6.60E-03	1.35E-02	7.05E-03	
CO	8.52E-04	3.22E-04	5.26E-04	4.14E-04	9.77E-04	6.89E-04	9.74E-04	5.90E-05	1.80E-04	7.13E-04	6.50E-04	9.00E-04	
TNMOC	9.92E-05	4.89E-05	4.12E-05	4.17E-05	8.22E-05	5.78E-05	8.77E-05	1.02E-04	3.74E-05	8.26E-05	5.26E-05	7.43E-05	
Lead	6.87E-09	7.66E-08	1.47E-07	1.24E-07	1.49E-07	2.08E-07	1.02E-07	6.33E-10	3.21E-08	1.97E-07	1.92E-07	2.77E-07	
Mercury	4.09E-09	1.62E-08	3.01E-08	2.50E-08	2.96E-08	4.15E-08	3.24E-08	1.03E-09	6.62E-09	4.01E-08	3.87E-08	5.54E-08	
PM10	7.02E-05	4.61E-05	8.12E-05	6.75E-05	1.37E-04	1.14E-04	7.25E-05	7.67E-06	2.46E-05	1.11E-04	1.05E-04	1.49E-04	
Solid Waste	1.31E-02	1.17E-01	2.26E-01	1.91E-01	1.82E-01	3.20E-01	1.47E-01	2.83E-04	4.96E-02	3.03E-01	2.95E-01	4.26E-01	

Table 8 Emission Factors for On-Site Combustion in a Commercial Boiler (lb of pollutant per unit of fuel)

Pollutant (lb)	Commercial Boiler					
	Bituminous Coal *	Lignite Coal **	Natural Gas	Residual Fuel Oil	Distillate Fuel Oil	LPG
	1000 lb	1000 lb	1000 ft^3 ***	1000 gal	1000 gal	1000 gal
CO_{2e}	2.74E+03	2.30E+03	1.23E+02	2.56E+04	2.28E+04	1.35E+04
CO_2	2.63E+03	2.30E+03	1.22E+02	2.55E+04	2.28E+04	1.32E+04
CH_4	1.15E-01	2.00E-02	2.50E-03	2.31E-01	2.32E-01	2.17E-01
N_2O	3.68E-01	ND †	2.50E-03	1.18E-01	1.19E-01	9.77E-01
NO_X	5.75E+00	5.97E+00	1.11E-01	6.41E+00	2.15E+01	1.57E+01
SO_X	1.66E+00	1.29E+01	6.32E-04	4.00E+01	3.41E+01	0.00E+00
CO	2.89E+00	4.05E-03	9.33E-02	5.34E+00	5.41E+00	2.17E+00
VOC	ND †	ND †	6.13E-03	3.63E-01	2.17E-01	3.80E-01
Lead	1.79E-03	6.86E-02	5.00E-07	1.51E-06	ND †	ND †
Mercury	6.54E-04	6.54E-04	2.60E-07	1.13E-07	ND †	ND †
PM10	2.00E+00	ND †	8.40E-03	4.64E+00	1.88E+00	4.89E-01

* from the U.S. LCI data module: Bituminous Coal Combustion in an Industrial Boiler (NREL 2005)
** from the U.S. LCI data module: Lignite Coal Combustion in an Industrial Boiler (NREL 2005)
*** Gas volume at 60°F and 14.70 psia.
† no data available