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Technical Report Two

Building and Plant Energy Analysis Report

Army National Guard
Readiness Center Addition
Arlington, Va.

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10/11

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Executive Summary

The new trend in the building industry from design to completion is energy modeling. Through the use of such tools it is possible for the engineers on a project to obtain fairly accurate figures on operation costs, efficiencies, as well as emission statistics for a building still in the design phase. The most valuable point for the engineers and the owner to utilize such methods is early in the design process, during which time different systems can be considered and modeled to showcase the most economical and environmentally friendly way to proceed. The ArNG building is a hopeful LEED silver candidate and the use of such an analysis would be vital to obtain that goal.

This report is to demonstrate a clear understanding of building HVAC load and energy analysis procedures applicable to the Army National Guard Readiness Center Addition (ArNG). The actual designed system for the building was modeled in Trane TRACE 700 to get an estimate of the future performance as a whole. The above findings were to be compared to the design by the engineers on site, but due to security reasons these values were unavailable. However, the results from the TRACE model were analyzed to determine their accuracy. The ArNG building utilizes electricity and natural gas, from this an emissions breakdown was also performed.

After the energy analysis was performed it was found how similar each floor is in design. Though comparing the results with that of the original design could not happen, there is still the assumption that the model is fairly accurate. Every aspect which was considered came straight from the design documents and aside from discrepancies in software and the method of analysis, should procure an accurate model.

As for the total annual consumption for the ArNG building, it was found to be 4,664,299 kWh for electricity and 6,320,662 kBtu for gas. The majority of these values arise from space heating of the tower and lighting fixtures throughout the building. From the above energy consumption, it was determined that the ArNG building will require around $0.31/SF a year to operate. Tables are provided at the end of this report and effectively sum up the ArNG buildings performance.

Mechanical System Overview

The ArNG building houses a hydronic HVAC system consisting of a heating and chilled water 4 pipe system. This water is supplied to mechanical rooms on every floor containing AHU's as well as VAV terminals. There are a total of 17 AHU with one specified per tower level. The 3 underground levels hold the majority of the units and they range anywhere from 500 cfm to 4250 cfm. Typical size for the 5 tower levels is 1550 cfm.
There are two 400 ton centrifugal water-cooled chillers specified in conjunction with two cooling towers.

To create the energy model it was necessary to determine the block loads for the ArNG building. The following image (Figure 1) demonstrates the method used to group spaces together for block load calculations. These zones correspond to their own condition units and a grouped by similar occupancies. Only one floor is shown, however such blocking is typical throughout the remaining floors.

Level 3P Block Loading Example

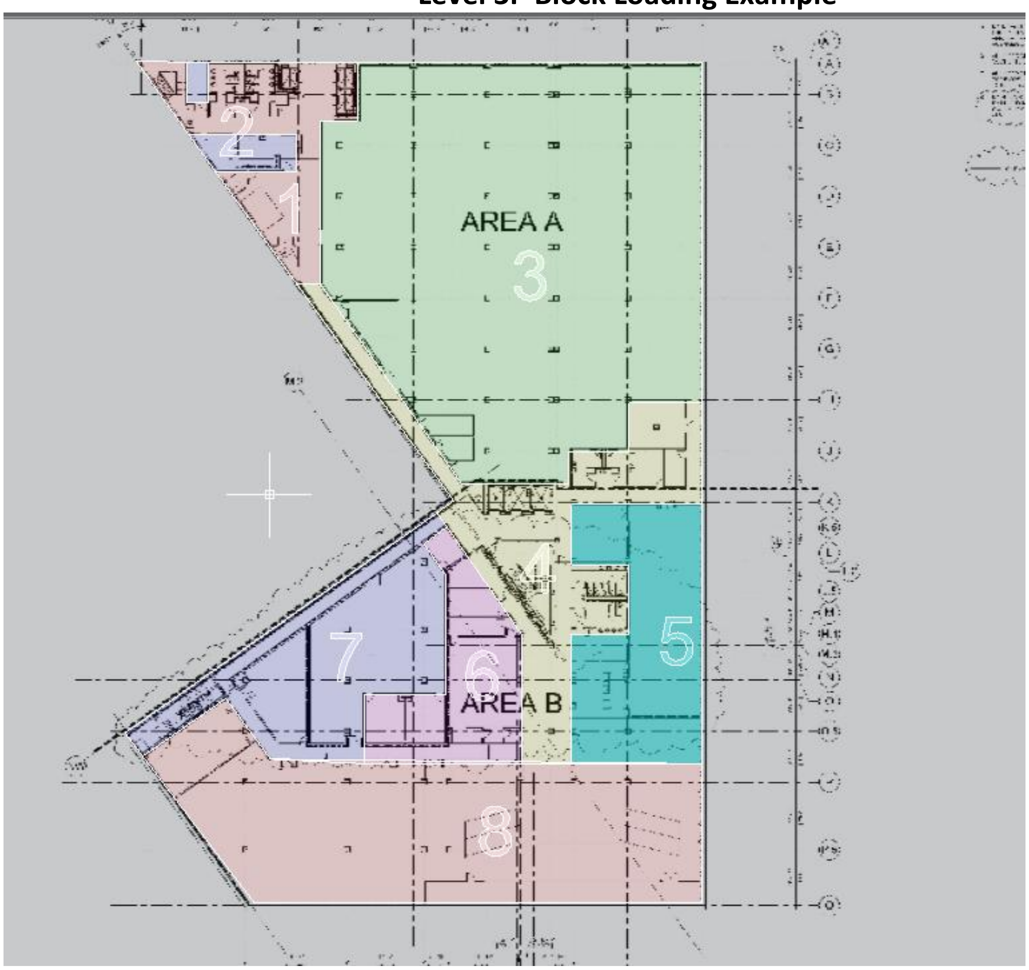

Figure 1

The ArNG building is a multiuse administrative facility with several occupancy types. Table 1 states such occupancies along with their corresponding zone given above. Again this is for only a single floor, but such spaces are typical throughout the building.

ArNG Zone and Occupancy Breakdown	
Zone	**Occupancy**
1	Corridor
1	Mechanical
2	Electrical/Data
3	Office
3	Conference
4	Corridor
4	Prefunction
4	Lobby
4	Mechanical
5	Office
5	Media
6	Conference
6	Media
7	Office
8	Office
8	Conference

Table 1

Design Load Estimation

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

Assumptions

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

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 2 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 2

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 3 below.

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

Table 3

Loads/Schedules

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 4 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 4

It is important for the energy model to follow some standard schedules for lighting as well as occupancy. Such schedules better analyze the full impact of the above loads on the various spaces. It is unreasonable to state that each space will be used 24 hours a day at full capacity. As a result, Table 5 shows the breakdown of light usage and occupancy as a percentage during various hours of the day.

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

Table 5

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 6

Conclusion

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

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

Annual Energy Consumption and Operating Costs

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

Assumptions

To generate the most accurate representation of the building which is to be built, the following analysis was based entirely off of the efficiencies and equipment specified by the engineers on the project.

The power company specified is Dominion Virginia Power. This company however cannot supply the rates specified for the ArNG building. As a result, standard rates for Arlington, Va. were used and can be found in Table 7 below.

Utility Costs/Rates

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

Table 7

These values should provide an accurate measurement for the remainder of the ArNG building analysis. They are however not the exact utility costs specified by Dominion because they were unavailable.

A Standard schedule of rates was established to showcase the peak, mid-peak, and off-peak hours for usage. This is shown in Table 8.

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

Table 8

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 9.

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 9

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 10 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 10

Along with the above monthly breakdown, it is more pertinent to see a visual representation of the monthly energy consumption. Figure 2 below clearly shows the peaks for summer and winter heating/cooling respectively.

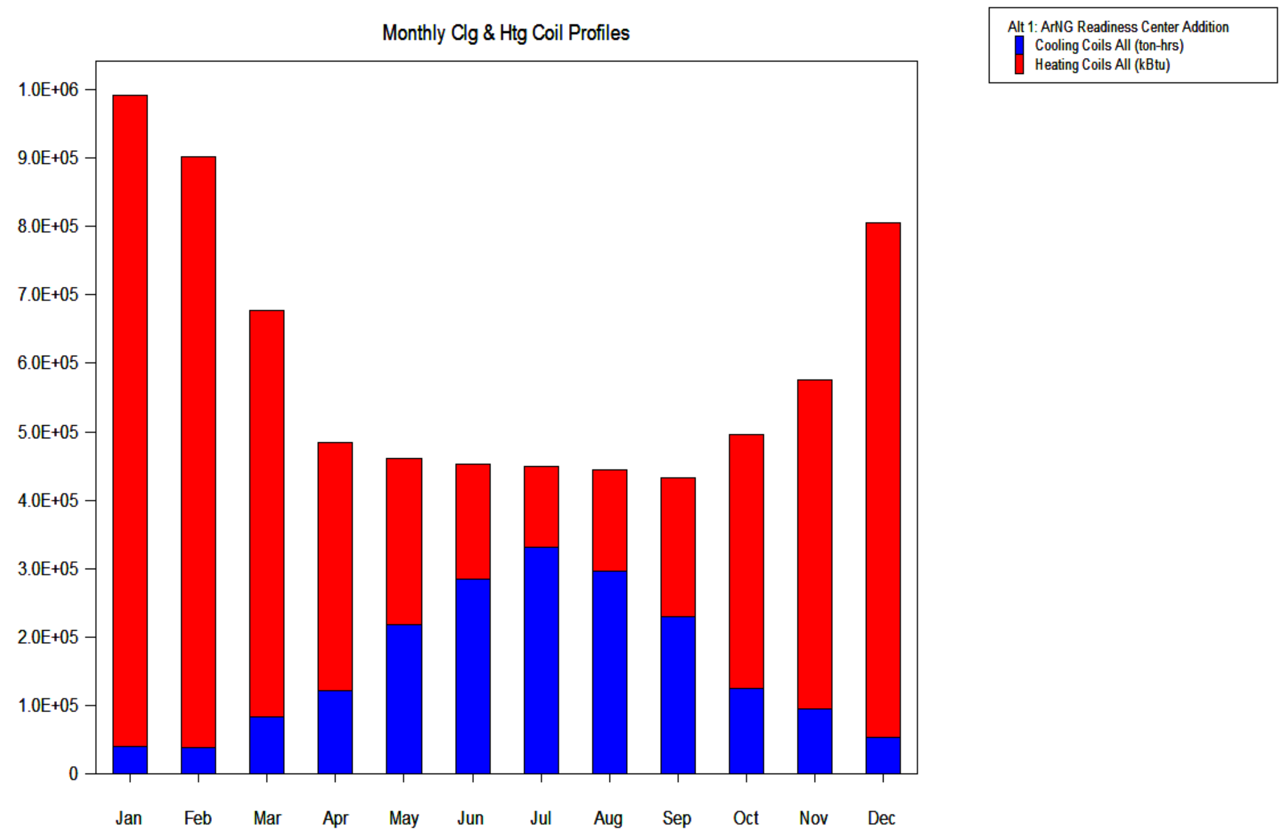

Figure 2

Energy Costs

As was described in the beginning of this section, standard utility costs were specified for the ArNG building cost analysis. These values are speculated to be higher than those which Dominion Virginia Power is supplying; however it should provide a good base analysis. Table 11 and Figure 3 below state the monthly utility costs for electricity and natural gas. It is no surprise that electricity costs peak in the summer while natural gas peaks in the winter.

Monthly Utility Costs												
	January	**Febuary**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Electricity ($)	4244	4361	4900	5221	5848	6679	7027	6751	6208	5238	5047	4525
Natural Gas ($)	2985	2707	1866	1140	763	530	367	462	636	1168	1510	2357

Table 11

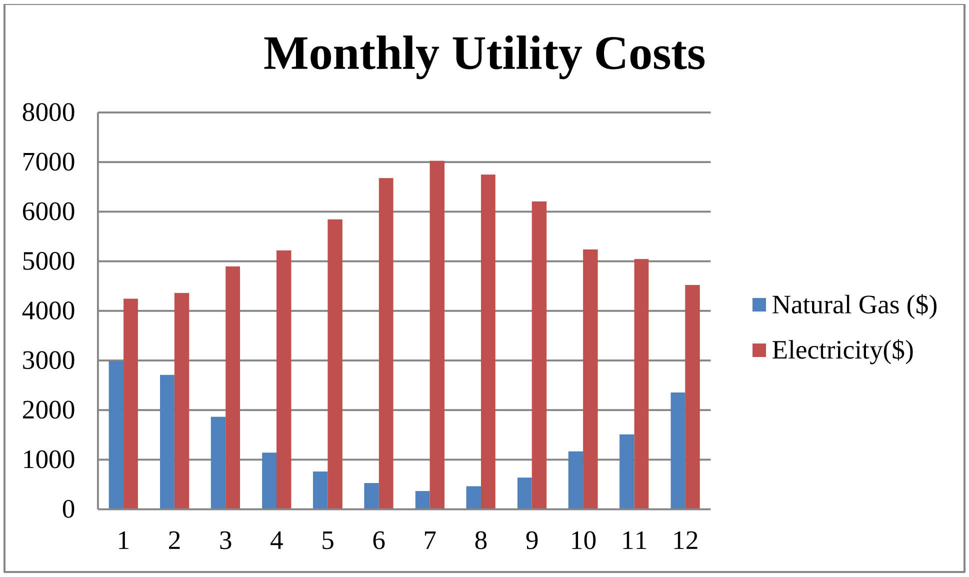

Figure 3

Table 12 and Figure 4 compiles the total utility costs combining both costs from electricity and natural gas. The figure clearly shows that in July is the largest and most costly energy demand mainly for cooling purposes. January is on the other end of the scale, peaking for winter demands. From this we see that April and October require the least amount of energy. All of this can be attributed to seasonal changes as expected.

Total Monthly Utility Costs												
	January	Febuary	March	April	May	June	July	August	September	October	November	December
Total(elec+gas)$	7229	7068	6766	6361	6611	7209	7394	7213	6844	6406	6557	6882

Table 12

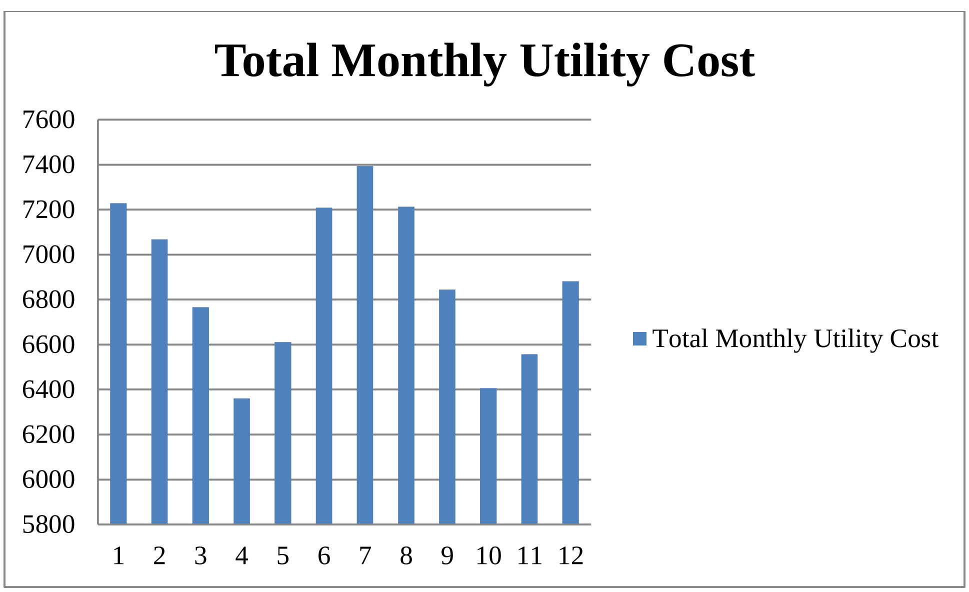

Figure 4

After all the data was analyzed it was finally determined that the ArNG building cost/yr for Electricity yielded $66,150 and Natural gas yielded $16,150 with a cost/SF of 0.31 respectively. After reviewing other buildings of this size and function it was found that these values seem somewhat low. It would be interesting to compare such values with those of the design.

Emissions

The ArNG Trace model produced the following emissions in its analysis:

Co2 23,551,152 lbm/yr
So2 61,904 gm/yr
Nox 32,881 gm/yr

To perform such calculations, emission values were taken from the "Regional Grid Emission Factors 2007" pdf. Table 8 was used for boiler emissions while Table B-10 was used for delivered electricity for Virginia. These tables are provided in Appendix A. Table 13 provides the findings for the carbon footprint of the ArNG building.

			From Electricity			From Natural Gas	Total
Pollutant	**Pollutans (lbs/kWh)**	**kWh/yr**	**Pollutant (lbs/yr)**	**Pollutant (lbs/1000ft^3)**	**Gas (1000 ft^3/yr)**	**Pollutant (lbs/yr)**	**Emissions**
CO2e	1.4	5,144,965	7202951	123	6,636,695,100	8.16313E+11	8.16321E+11
CO2	1.33	5,144,965	6842803.45	122	6,636,695,100	8.09677E+11	8.09684E+11
CH4	0.00252	5,144,965	12965.3118	0.0025	6,636,695,100	16591737.75	16604703.06
N2O	0.0000281	5,144,965	144.5735165	0.0025	6,636,695,100	16591737.75	16591882.32
Nox	0.00267	5,144,965	13737.05655	0.111	6,636,695,100	736673156.1	736686893.2
Sox	0.00804	5,144,965	41365.5186	0.000632	6,636,695,100	4194391.303	4235756.822
CO	0.000974	5,144,965	5011.19591	0.0933	6,636,695,100	619203652.8	619208664
TNMOC	0.0000877	5,144,965	451.2134305	0.00613	6,636,695,100	40682940.96	40683392.18
Lead	0.000000102	5,144,965	0.52478643	0.0000005	6,636,695,100	3318.34755	3318.872336
Mercury	3.24E-08	5,144,965	0.166696866	0.00000026	6,636,695,100	1725.540726	1725.707423
PM10	0.0000725	5,144,965	373.0099625	0.0084	6,636,695,100	55748238.84	55748611.85
Solid Waste	0.0147	5,144,965	75630.9855				75630.9855

Table 13

Most emissions should be due to the inefficiency of the process of providing electricity to the site. It can be seen above how this isn't true in which the boilers are producing an overwhelming large amount of pollutants. This can either be due to an error in specification in the Trace program or poor efficiency on the use of the natural gas.

Conclusion

The ArNG building is a fairly typical administrative building for office use. Due to a large variety of equipment for data and communication purposes there are large demands on the building. Though a direct comparison could not be made, the building does seem to follow some trends of similar type buildings with some exceptions. It is important to note that such values, even the design, are approximate values which could easily change during implementation of the actual systems.

Appendix A

Tables used for emissions calculations taken from the "Regional Grid Emission Factors 2007" pdf and specified for Virginia.

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

Table B-10

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	