Technical Report Two

Building, Plant Energy and Emission Analysis Report

10.25.2009

Defense Media Activity Building

Fort George G. Meade

Pavel Likhonin

Penn State University

Architectural Engineering

Mechanical Option

Faculty Advisor: Dr. Treado

Table of Contents

Contents

Executive Summary

Building energy modeling has become a necessary tool in the current building industry. It allows you to predict and estimate the cost of operation, efficiency, and the carbon footprint of the building. When energy modeling is done at the early stages of design, the owner can see benefits of different systems and their costs of operation. This early knowledge will better inform the owners to make better economical as well as environmentally friendly decisions. The DMA Building is no exception to this. DMA was originally modeled in eQuest by the engineer in order to satisfy LEED's energy requirements.

To better understand the DMA Building's performance, an energy model simulation was performed in Trane TRACE 700 and compared to the design. Both the design loads and energy consumption of the building were performed in this analysis. These estimated loads were then compared to the design and broken out by parts to see which systems of the building used the most energy. Building emissions were also calculated based on the building consumption of natural gas and electricity.

The performed energy analysis of the building was close to the design in a lot of the cases. Some of the discrepancies in this energy analysis were; lower heating load, higher fan and receptacle load than the design. The total annual consumption of electricity by the DMA Building is 13,945,268 kWh and 2,092 MBtu for Natural Gas. Based on the energy consumption of the building, the DMA Building will require \$5.03/ft^2 a year to operate. Most of that cost comes from the data center. Complete annual energy usage, monthly energy usage, cost, and building emissions are available in the last sections of this report.

Mechanical System Overview

The DMA Building is conditioned by (6) Air Handling Units, (10) Roof Top Units and APC high density cooling racks for the data center. The building was split up into 17 Zones for a block load calculation. These zones are directly related to their own air conditioning units. Each zone was then divided into blocks by occupancy. There are a total of 10 different occupancies used in the DMA Building. Table 1 shows the occupancy for each zone.

Table 1

Zone and Occupancy			
ZONE	**OCCUPANCY**	**ZONE**	**OCCUPANCY**
A	OFFICE	I	OFFICE-R
A	MECH	I	MEDIA
B	OFFICE	I	CONFERENCE
B	MECH	J	WAREHOUSE
C	DATA CENTER	K	STUDIO
D	CORRIDOR	L	STUDIO
D	MEDIA	M	STUDIO
E	MEDIA	O	WAREHOUSE
F	OFFICE	O	OFFICE
F	MECH	P	CORRIDOR
G	OFFICE	P	CONFERENCE
G	CONFERENCE	Q	OFFICE
H	EDITING	R	CONTROL
I	OFFICE		

The location of Zones A through R is shown in Figures 1, 2, and 3. Figure 1 is the ground floor, Figure 2 is the first floor, and Figure 3 shows the layout of zones on the second floor. The first floor has the largest area with the majority of the zones. Most of these areas are double-heighted which only leaves the eastern wing of the building for the second floor occupancy.

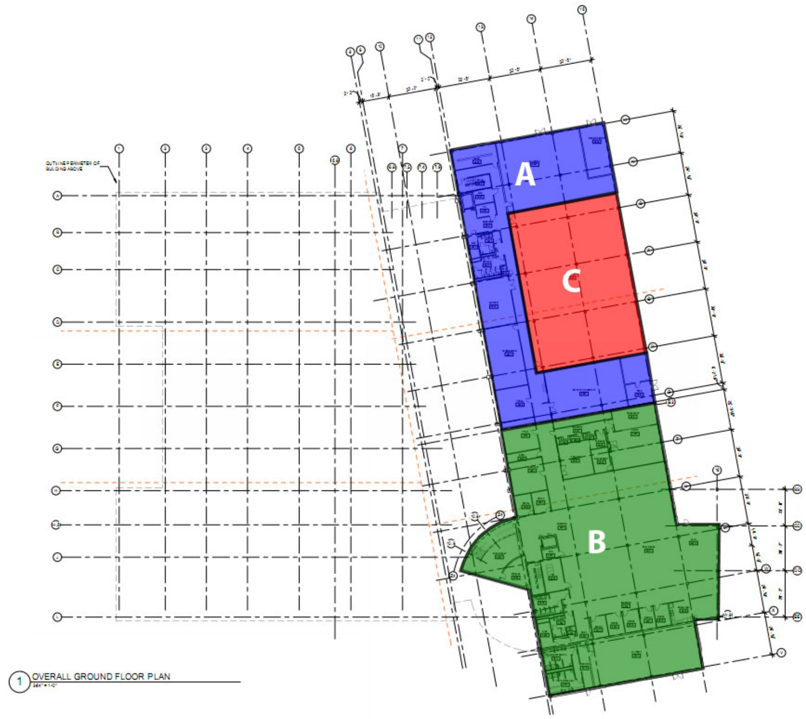


Figure 1

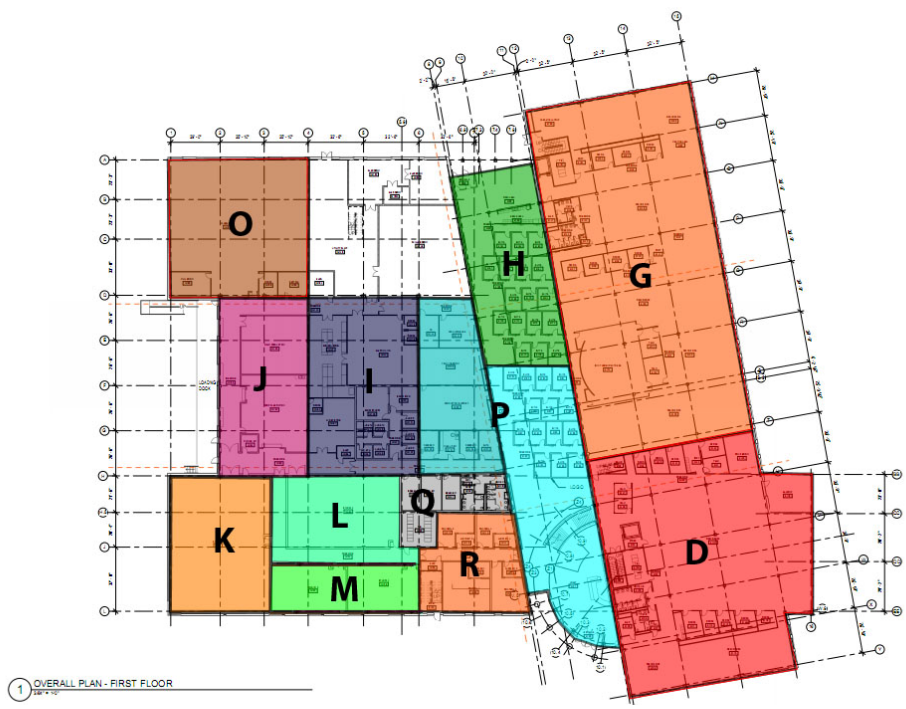


Figure 2

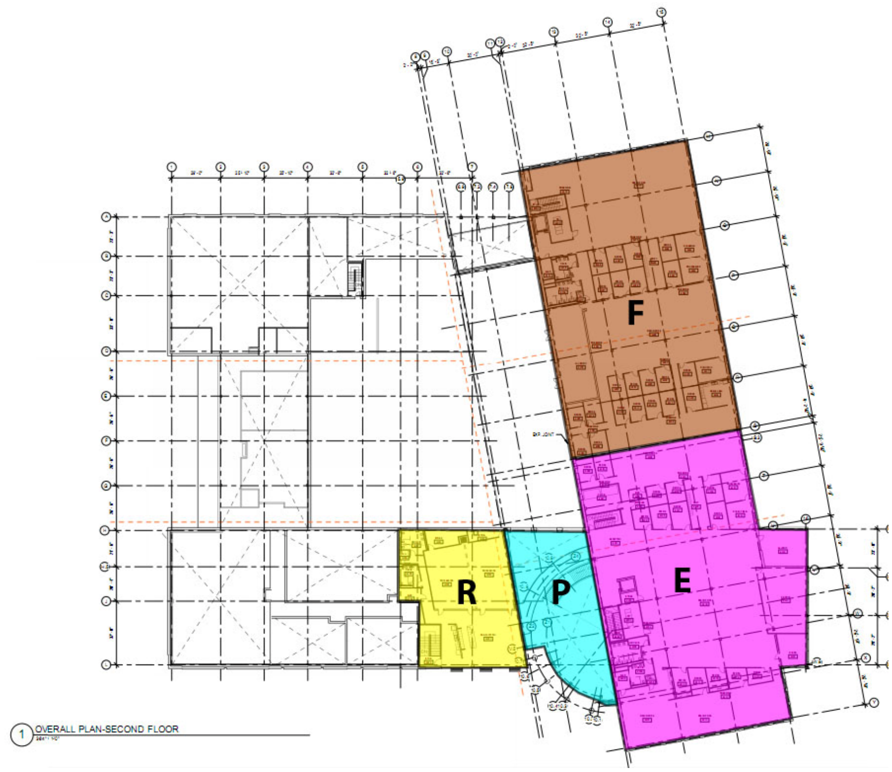


Figure 3

Design Load Estimation

Assumptions

Trane TRACE 700 was used to calculate the design cooling and heating loads for the DMA Building. TRACE uses an 8760 hour analysis for building energy consumption, design loads, and performance. A Block Load simulation was done to estimate the loads on this building. This approach takes all the similar rooms in a zone and lumps them together to estimate the total load for that zone. The information used to construct the building model was obtained from HOK and HSMM|AECOM.

Infiltration

Infiltration for the DMA Building was assumed to be 0.3 air changes per hour. That is achieved by slight pressurization with an assumption of average construction.

Design Air Conditions

Fort George G. Meade is located just outside of Baltimore, MD so the design conditions for Baltimore were used in the building model. The design outdoor air conditions for Baltimore, MD were obtained from ASHRAE Fundamentals 2005. The coldest month was January and the hottest month was July. These values are shown in Table 2 below.

Table 2

ASHRAE Design Conditions for Baltimore, MD		
Summer		Winter
DB (F)	MCWB (F)	DB (F)
93.6	75	12.3

The indoor air design conditions for the DMA Building were obtained from the designer. These values can be seen in Table 3 below.

Table 3

Indoor Conditions	
Cooling Setpoint	75 F
Heating Setpoint	68 F
Relative Humidity	50%

Loads and Schedules

Internal loads of the building were based on the type of space and the function. Occupancy load was based on moderate office activity in the majority of the rooms. Lighting loads and miscellaneous loads were provided by the engineer. Table 4 shows internal loads based on occupancy and space. A sample of the software input of internal loads can be found in the Appendix.

Table 4

	Office		Conference		Control Room		Corridor		Editing Suites	
	Sensible	Latent	Sensible	Latent	Sensible	Latent	Sensible	Latent	Sensible	Latent
Lighting (W/SF)	1		1		1		1		1	
Misc (W/SF)	1.5		1.5		8		0		8.5	
People (Btu/hr)	250	200	245	155	250	200	0	0	250	200
People (SF/Person)	143		20		143		0		143	
	Equip Room/ Data Center		Media		Storage/Mech		Studio		Warehouse	
	Sensible	Latent	Sensible	Latent	Sensible	Latent	Sensible	Latent	Sensible	Latent
Lighting (W/SF)	1		1		1		1		1	
Misc (W/SF)	15		3.5		0		3.5		0	
People (Btu/hr)	0	0	250	200	0	0	0	0	250	200
People (SF/Person)	0		143		0		0		0	

The lighting schedule was based on a typical office space provided by the TRACE software. The core hours of the building use 100% of the lights and the rest are varied. This schedule was applied to the majority of the spaces. Some of the spaces in the DMA Building are occupied 24 hours a day. Studios and Media spaces were assumed to be occupied 24 hours a day. The lighting schedule used in the energy model can be seen in Table 5 below. A sample of the modeling software interface for schedules can be found in the Appendix.

Table 5

Lighting Schedule	
Time	Lights
Midnight-6am	0
6am-7am	10
7am-8am	50
8am-5pm	100
5pm-6pm	50
6pm-7pm	10
7pm-Midnight	0

Typical office occupancy schedule is shown below in Table 6. This was also applied to the majority of the spaces in the DMA building while Studios and Media spaces are occupied 24 hours a day.

Table 6

Occupancy Schedule	
Time	People
Midnight-7am	0
7am-8am	30
8am-5pm	100
5pm-6pm	30
6pm-7pm	1
7pm-Midnight	0

Design vs. Computed Block Loads

The entire building was modeled and simulated in Trane TRACE 700. For the purpose of this report, (6) main air handlers will be discussed and compared to the original design because the rest of the building follows the same trend. Table 7 below summarizes the space cooling SF/ton, heating Btuh/SF, total supply air CFM/SF, and ventilation supply as a percentage for the designed vs. modeled zones. The rest of the zones share a similar pattern as seen from the total building energy consumption later in the report when compared to the design.

Table 7

Comparison of Loads and Ventilation Indices									
AREA	Zone	Cooling SF/ton		Heating Btuh/SF		Supply CFM/SF		Ventilation %OA	
(SF)	(AHU)	Design	Modeled	Design	Modeled	Design	Modeled	Design	Modeled
12672	A	513.66	583.65	13.63	13.36	0.95	0.53	13.09	22
16000	B	623.30	554.54	8.08	13.84	0.78	0.57	19.10	21.2
19532	D	430.79	360.67	14.33	19.72	0.90	1.04	14.67	38.9
19748	E	428.28	352.84	15.16	19.12	0.85	1.2	12.69	11.6
16648	F	510.05	446.64	11.83	17.2	0.74	0.7	11.82	18.4
18363	G	516.98	385.09	12.84	19.12	0.86	0.74	11.38	21.6

When comparing the design versus modeled cooling loads, there is a slight deviation from space to space. There is no significant trend of the modeled loads being mostly smaller or larger than the design. Some of spaces, such as Zone A, have a higher modeled square foot per ton while others, like Zone B, have a lower square foot per ton value. This deviation may come from slightly different areas used for the model. Another difference for this deviation is the modeling technique and the use of different software. The final design analysis for the DMA Building was done in eQuest with a room by room model. eQuest uses a different interface than TRACE so there is an expectation for getting differences in loads. The biggest contribution to this deviation of loads is probably the use of block loads instead of a room by room building analysis which was done by the designer.

Heating loads for the model were generally higher than the designer's loads. This is an interesting observation for the main AHU's because the total heating use of the model was lower than the design. The other areas of the building such as warehouses and mechanical rooms had much lower heating values than the design which lowered the heating energy use. The data center also had a much lower heating value because it was assumed to be on 100% of the time. The data center produces a lot of heat by itself and will need to be cooled year round.

The total modeled CFM was lower than the design which made the percentage of the outside air higher. This lower CFM is directly related to a slightly lower cooling load in the model. Total CFM is usually calculated from the cooling design and a smaller cooling load would yield a lower supply of air into the space.

In general, the modeled building was relatively close to the design. The biggest difference between the modeled building and the design is the modeling method used. The designed building calculated loads room by room, while the modeled building used block loads, where multiple rooms with same functions were combined.

Annual Energy Consumption and Operating Costs

The annual energy consumption was calculated using the same TRACE model that was used for load calculations. For comparison purposes, LEED submittal for EA Credit 1 will be used. Actual utility bills are not available because the DMA Building will only finish construction in 2011. The engineers performed energy consumption and operating cost analysis in eQuest. Using the values from the eQuest model, the LEED submittal was created by the engineers.

The model that was originally used for this analysis was provided by HSMM|AECOM for reference purposes. The model provided, however, was corrupt and couldn't be used. Several attempts were made to access the eQuest model from different computers with different settings and processors with no success.

Assumptions

All of the equipment was modeled with the efficiencies and EER's specified by the engineers. A sample window of equipment inputs for performance characteristics can be seen in the Appendix. Supply and exhaust fans were also modeled for this building assuming energy usage based on horsepower listed in the design documents (also listed in Technical Report One). Another assumption used is that the Data Center is operated 24 hours a day, 7 days a week.

Baltimore Gas and Electric rates were used for this calculation as well as the rates mentioned in EA Credit 1. Table 8 below, shows the rates used for the DMA Building.

Table 8

Baltimore Gas and Electric Rates		
Electricity	Demand Charge ($/kW)	3.95
Electricity	Peak (cents/kWh)	11.551
Electricity	Mid-Peak (cents/kWh)	9.265
Electricity	Off-Peak (cents/kWh)	8.824
Gas	Up to first 10000 therms ($/therm)	0.1975
Gas	Above 10000 therms ($/therm)	0.0948

Using the Baltimore Gas and Electric Rates gave an unreasonable cost for electricity and natural gas. When using the rates that were provided by the engineer, the costs per year were more reasonable. The rates used by the engineer were a flat rate of 6.59 Cents per kWh and $8.07 per MBtu. Both rates were used and reported in this analysis. Two separate yearly costs were computed based on the different rates, but the rates provided by the engineers were used for monthly analysis.

The Schedule of Peak, Mid-peak, and Off-peak hours was obtained from Baltimore Gas and Electric. This schedule is seen in Table 9 below.

Table 9

Schedule of Rates		
Start Time	End Time	Rate
11 p.m.	7 a.m.	Off-peak
7 a.m.	10 a.m.	Mid-peak
10 a.m.	8 p.m.	Peak
8 p.m.	11 p.m.	Mid-peak

Annual Energy Consumption

A designed and baseline energy figures were available from the LEED submission for EA Credit 1. Table 10 below shows the total energy consumption per year split up based on different types of loads in the building. Here you can see the comparison between the modeled (block loads), designed, and ASHRAE 90.1 baseline building energy usage per year. Data center energy consumption was added in after the model was created. This value was provided by the engineers based on the energy consumption of the cooling racks.

Table 10

Annual Energy Consumption			
	Modeled	**Designed**	**Baseline**
Space Heating	1,937 (MBtu)	3,173 (MBtu)	4,433 (Mbtu)
Space Cooling	1,044,978 (kWh)	1,280,000 (kWh)	2,945,750 (kWh)
Lighting	705,581 (kWh)	834,000 (kWh)	932000 (kWh)
Pumps	154,484 (kWh)	366,000 (kWh)	388,000 (kWh)
Fans	834,583 (kWh)	291,000 (kWh)	701,500 (kWh)
Heat Rejection	8,760 (kWh)	7,000 (kWh)	4,000 (kWh)
Receptacle	1,832,882 (kWh)	826,000 (kWh)	826,000 (kWh)
Data Center	9,364,000 (kWh)	9,364,000 (kWh)	9,364,000 (kWh)
Water Heating	155 (Mbtu)	155 (Mbtu)	155 (Mbtu)

From this analysis, the biggest consumer of energy is the data center followed by space cooling. Several large differences can be seen in the Modeled versus Designed buildings. Space heating is lower by 30% in the modeled as compared to the designed. Several attempts were made to raise the space heating value with very little success. After spending hours on the phone with Trane and a whole day trying to close the gap between the designed and modeled buildings, 30% difference between the loads was the best scenario. The file somehow got corrupted and raising infiltration or the setpoint temperature only lowered the consumption for space heating.

Space cooling was also lower than the Designed, but much closer to the design value than Space Heating. Lighting was also a little bit lower as well as the pumps. Fans on the other hand were much higher energy consumers than the design as well as receptacles. The reason for high receptacle consumption is the type of function of this building. DMA is a media building with television studios, media centers, editing suites, control rooms, and offices. All of the DMA equipment was modeled as a receptacle load.

Figure 4 below shows the calculated/modeled percentage of energy use in the DMA Building. The data center is consuming 42% of the building's total energy.

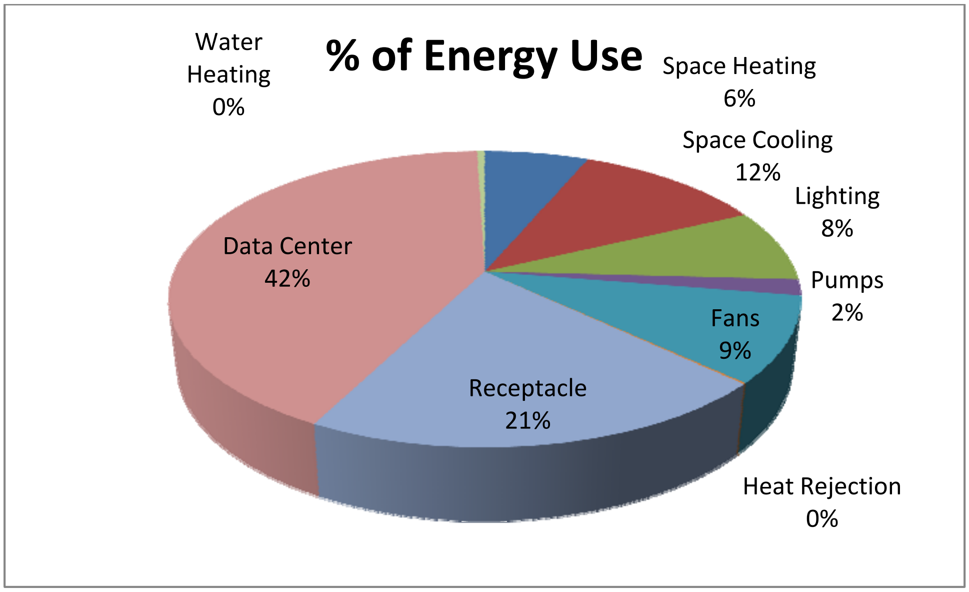


Figure 4

In addition to an annual consumption, monthly consumption was also computed with Trane TRACE 700. Table 11 shows the monthly consumption based on Peak, Mid-Peak, and Off-Peak hours for both natural gas and electricity.

Table 11

Monthly Energy Consumption												
Electric	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
On-Peak	173,817	156,484	184,873	178,873	196,423	200,688	204,045	209,045	188,896	188,099	179,185	174,730
Off-Peak	99,583	89,881	101,132	99,492	107,920	107,511	113,707	111,445	105,909	103,226	98,615	100,377
Mid-Peak	89,028	80,461	92,354	90,148	99,172	100,406	104,955	104,273	95,811	94,422	89,582	89,603
Data Center	780,333	780,333	780,333	780,333	780,333	780,333	780,333	780,333	780,333	780,333	780,333	780,333
Total	1,142,761	1,107,159	1,158,692	1,148,846	1,183,848	1,188,938	1,203,040	1,205,096	1,170,949	1,166,080	1,147,715	1,145,043
Gas												
On-Peak	383,200	350,100	225,000	140,500	71,100	43,700	34,700	46,000	66,800	151,200	180,100	289,400

The total consumption of electricity is highest in the summer while natural gas consumption is highest in the winter. Natural gas is used to heat the building and electricity is used to cool it. Figure 5 shows the modeled energy consumption graphically by month.

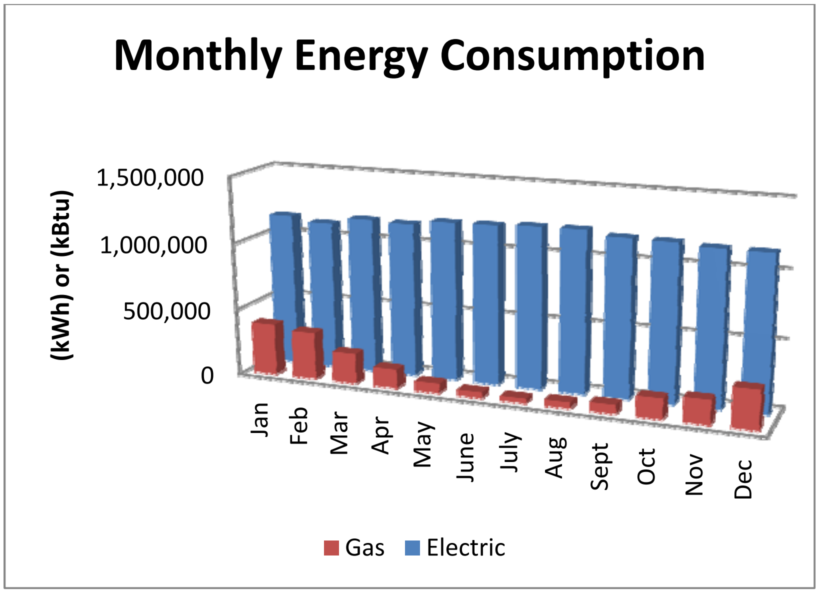


Figure 5

Energy Costs

Two separate energy costs were calculated for this report. One calculation was done using Baltimore Gas and Electric rates and the second using the designer's rates. Table 12 used BGE rates while Table while Table 13 used the designer's rates.

Table 12

Energy Use and Cost					
	(kWh)	(Mbtu)	Percentage of Energy	Cost	Percentage of Cost
Space Heating		1,937	6.4	$ 3,972.83	0.2
Space Cooling	1,044,978		11.6	$ 130,155.66	7.5
Lighting	705,581		7.9	$ 87,882.58	5.0
Pumps	154,484		1.7	$ 19,241.52	1.1
Fans	834,583		9.3	$ 103,950.23	6.0
Heat Rejection	8,760		0.1	$ 1,091.09	0.1
Receptacle	1,832,882		20.5	$ 228,291.85	13.1
Data Center	9,364,000		42.0	$ 1,166,318.88	67.0
Water Heating		155	0.5	$ 361.17	0.0
Total	13,945,268	2,092	100.0	$ 1,741,265.80	100

Table 13

Energy Use and Cost					
	(kWh)	(Mbtu)	Percentage of Energy	Cost	Percentage of Cost
Space Heating		1,937	6.4	$ 15,631.00	1.7
Space Cooling	1,044,978		11.6	$ 68,864.05	7.4
Lighting	705,581		7.9	$ 46,497.79	5.0
Pumps	154,484		1.7	$ 10,180.50	1.1
Fans	834,583		9.3	$ 54,999.02	5.9
Heat Rejection	8,760		0.1	$ 577.28	0.1
Receptacle	1,832,882		20.5	$ 120,786.92	12.9
Data Center	9,364,000		42.0	$ 617,087.60	65.9
Water Heating		155	0.5	$ 1,250.00	0.1
Total	13,945,268	2,092	100.0	$ 935,874.16	100

When analyzing the data, one can see that something must have been missing from the Baltimore Gas and Electric rates which wasn't accounted for in the calculation. The electricity cost is very high and the cost of natural gas is very low. For this report, the designer's values will be used for further evaluation of the DMA Building. The DMA Building will require $5.03 a square foot per year to operate.

Figure 6 shows the percentage of cost associated with energy usage. The highest percentage of cots is the Data Center followed by receptacle loads.

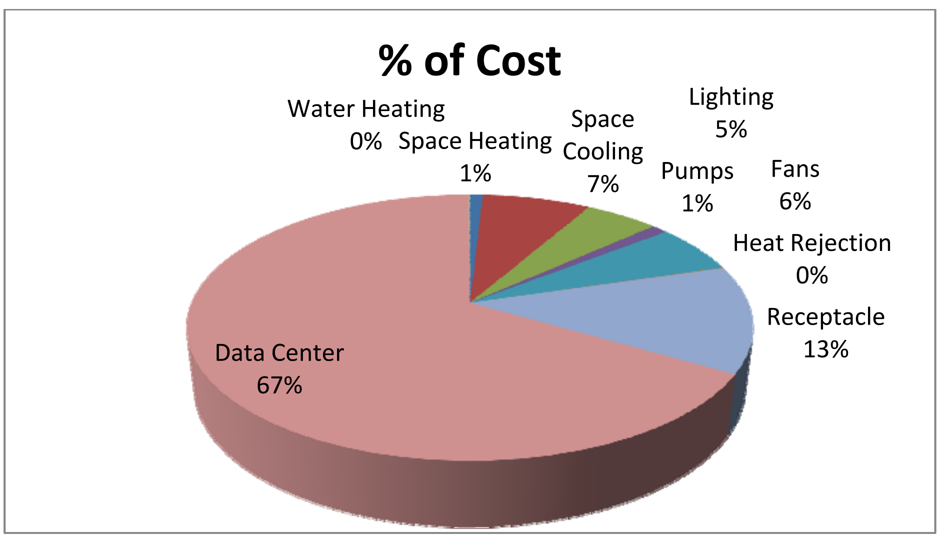
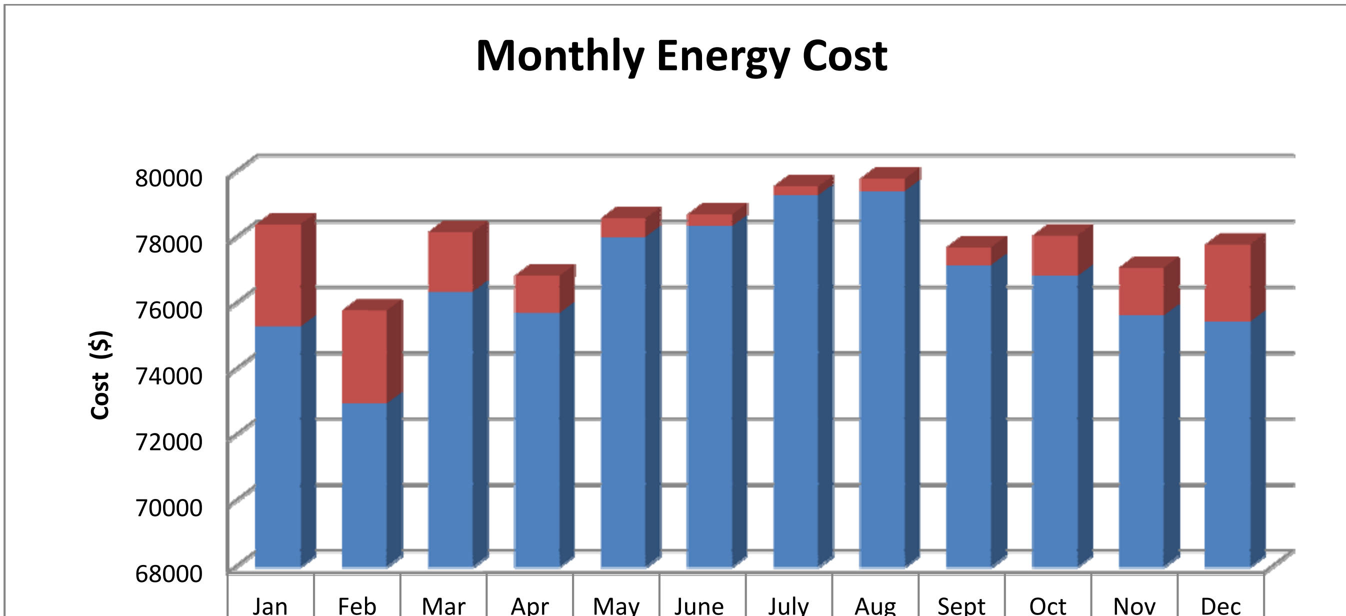


Figure 6

The reason for the high percentage of cost for the data center is the cost of electricity compared to natural gas as well as the data center being the highest consumer of energy in the DMA Building.

A monthly cost was also calculated using Trane TRACE. The highest monthly cost was in August with $79,787 while the lowest monthly cost was in February with $75,787. Figure 7 shows the total cost per month.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Gas	3092.4	2825.3	1815.8	1133.8	573.78	352.66	280.03	371.22	539.08	1220.2	1453.4	2335.5
Electric	75308	72962	76358	75709	78016	78351	79280	79416	77166	76845	75634	75458

Figure 7

Annual Carbon Footprint

Values for the emission calculation were taken from "Regional Grid Emission Factors 2007" Table B-10. Table B-10 is for Total Emission Factors for Delivered Electricity for Maryland. The emission for boilers was also obtained from the Regional Grid Emission Factors 2007 Table 8. After computing the total energy consumption of the building, a total carbon footprint can be approximated using the values given. Table 14 below provides emissions of the building from electricity separated into several different categories such as CO_2, NOx, SOx, and others. CO_{2e} is the CO_2 equivalent of all the emissions.

Table 14

Combustion Emission Factors for Generated Electricity			
	(lb/kWh)	(kWh/year)	lb/year
CO2e	1.82	13,945,268	25,380,388
CO_2	1.71	13,945,268	23,846,408
CH_4	4.02E-03	13,945,268	56,060
N_2O	3.54E-05	13,945,268	494
NO_X	3.10E-03	13,945,268	43,230
SO_X	1.11E-02	13,945,268	154,792
CO	1.19E-03	13,945,268	16,595
TNMOC	7.74E-05	13,945,268	1,079
Lead	1.16E-07	13,945,268	2
Mercury	3.56E-08	13,945,268	0
PM20	9.25E-05	13,945,268	1,290
Solid Waste	1.69E-01	13,945,268	2,356,750

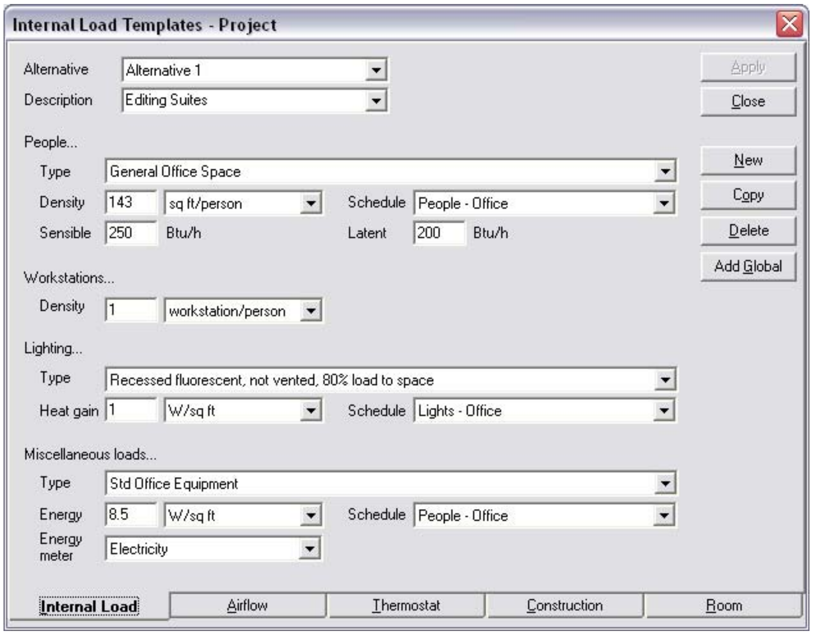
Table 15 provides the DMA Building's emissions from boilers. The boilers in the DMA Building use natural gas and the following table describes the emissions associated with burning of natural gas. The emissions from electricity are much higher because the majority of the energy used by the building comes from electricity. In addition to that fact is the low efficiency of getting that energy to the building. Usually only about 30% of the original utility energy gets delivered to the building as opposed to a 98% efficient boiler which uses energy in its raw form.

Table 15

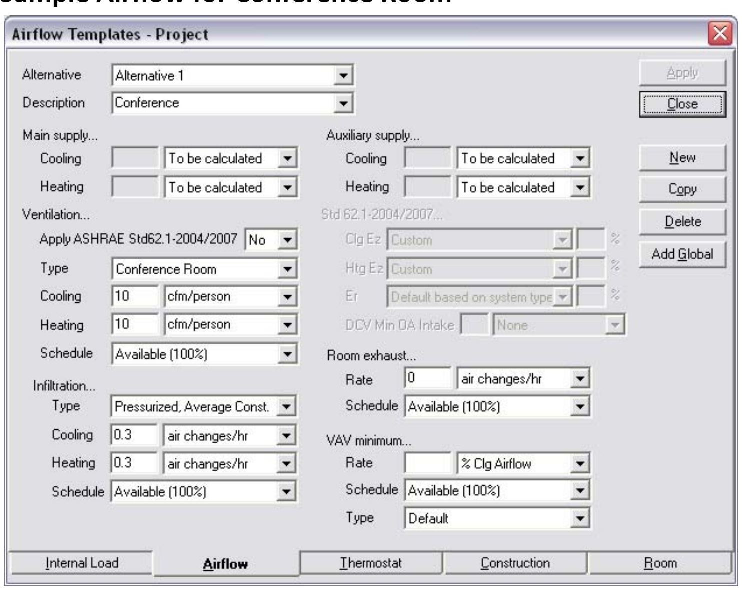
Combustion Emission Factors for Natural Gas Boiler				
	(lb/1000 CF)	(Mbtu/year)	(Btu/CF)	lb/year
CO2e	1.23E+02	2092	1010	254,768
CO_2	1.22E+02	2092	1010	252,697
CH_4	2.50E-03	2092	1010	5
N_2O	2.50E-03	2092	1010	5
NO_X	1.11E-01	2092	1010	230
SO_X	6.32E-04	2092	1010	1
CO	9.33E-04	2092	1010	2
VOC	6.13E-03	2092	1010	13
Lead	5.00E-07	2092	1010	0
Mercury	2.60E-07	2092	1010	0
PM10	8.40E-03	2092	1010	17

Appendix

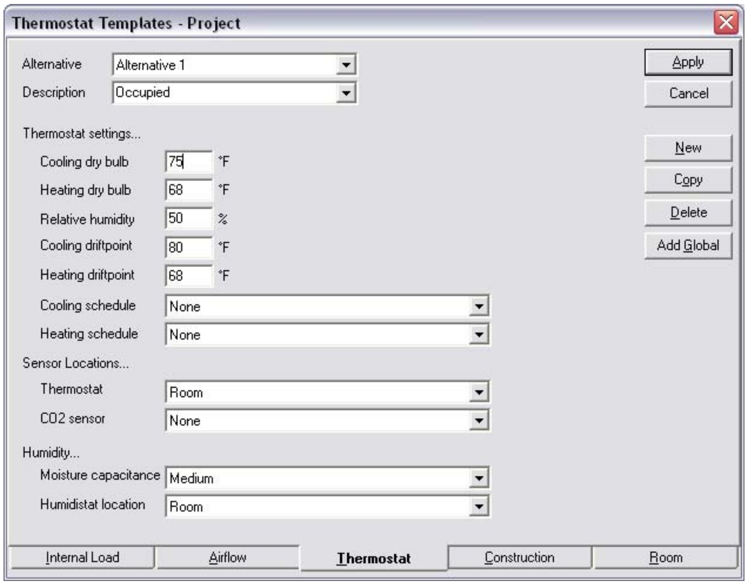
Sample of Internal Loads



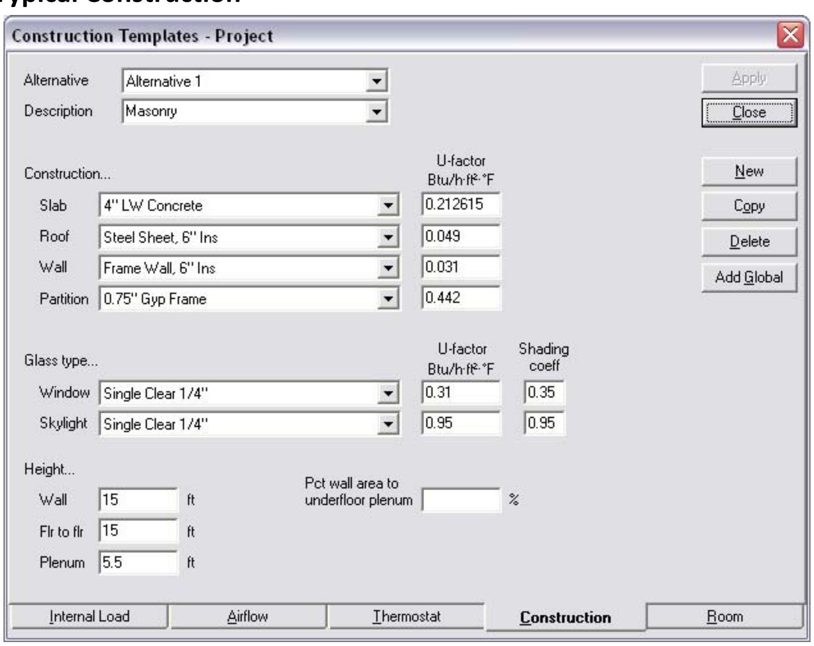
Sample Airflow for Conference Room



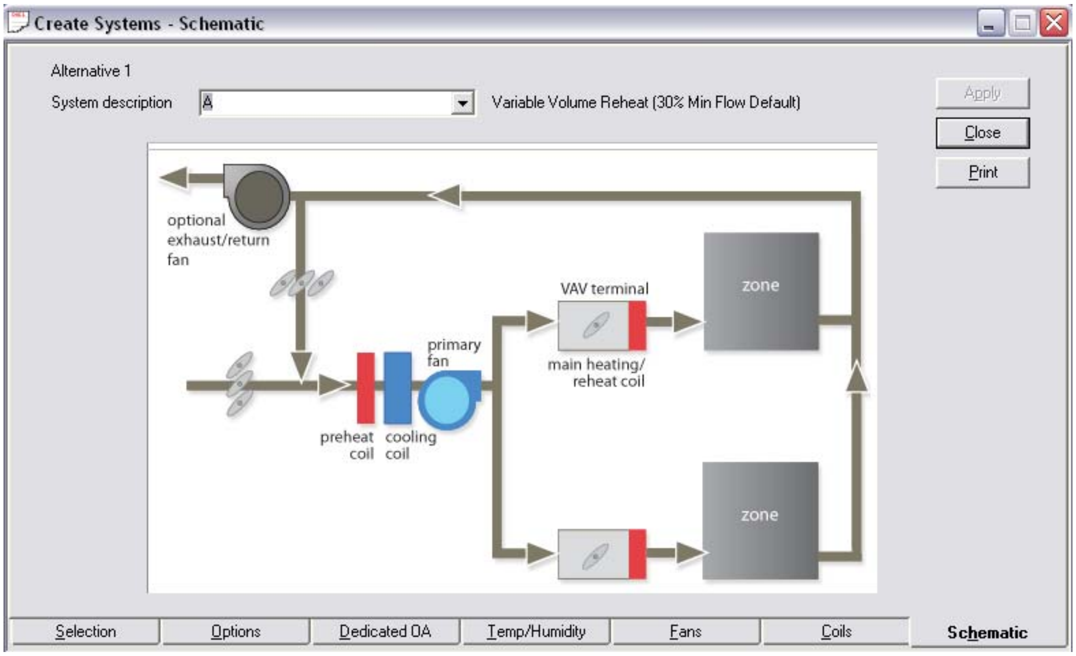
Thermostat Settings



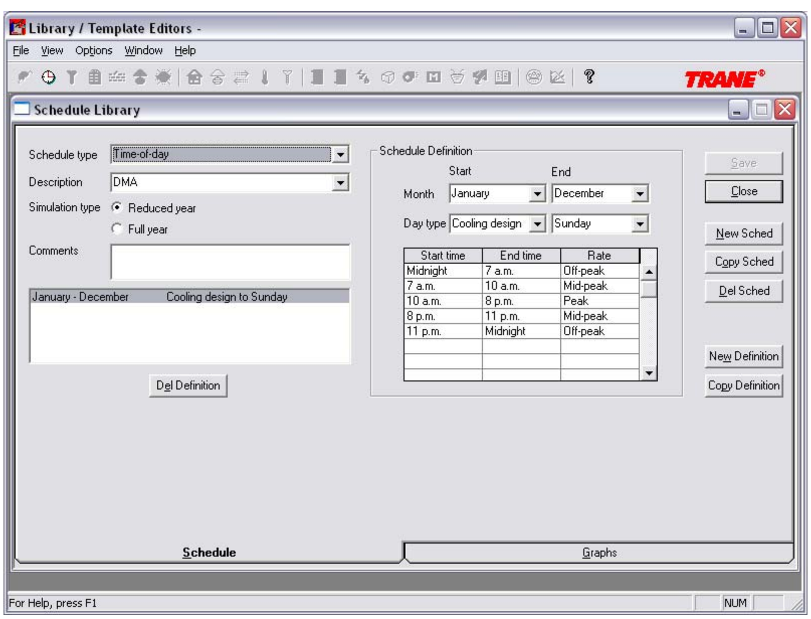
Typical Construction



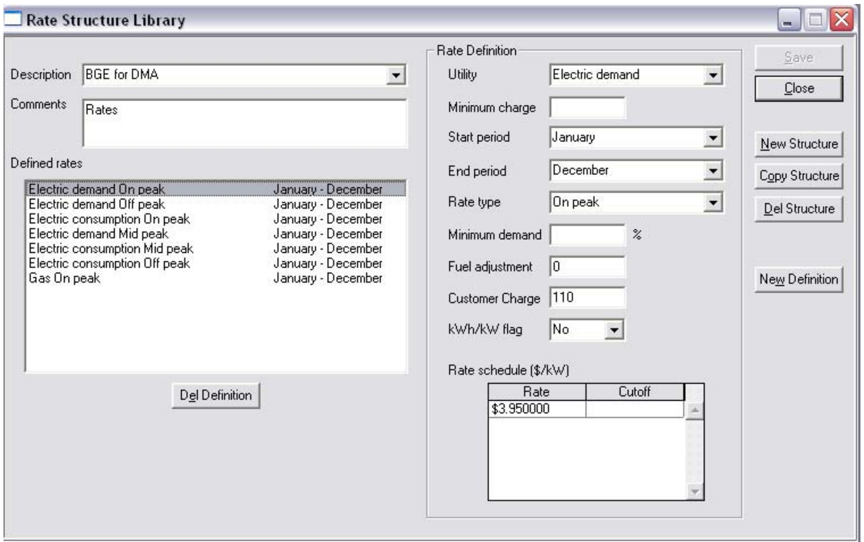
System A Sample Schematic



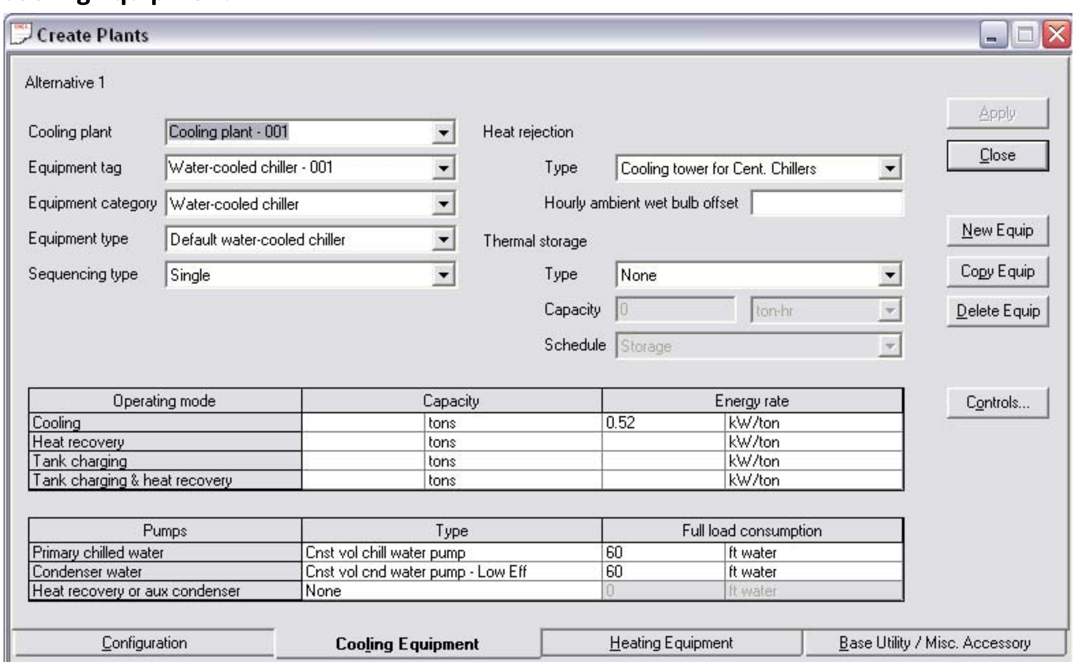
Schedules



Rate structures



Cooling Equipment



Heating Equipment