Georgetown University New Science Center

Building and Plant Energy Analysis Report

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GEORGETOWN UNIVERSITY NEW SCIENCE CENTER

Building and Plant Energy Analysis Report

Executive Summary

Energy analysis is a critical part of the modern design process for mechanical systems in buildings. Heating and cooling systems are designed to provide a comfortable environment for building occupants and to provide optimal energy efficiency to minimize environmental impacts and utility costs to the owner. This report analyzes the design load requirements and the annual energy consumption and operating costs of the New Science Center's heating and cooling system.

The systems analyzed for this report include the primary Dedicated Outdoor Air System consisting of four air handling units and the chilled beam system. Not included in the analysis are the steam and hot water unit heaters used in the loading dock, mechanical penthouse, and emergency stair spaces.

Trane TRACE 700 is the energy software used to estimate the design loads, energy consumption, and operating costs of the New Science Center's mechanical system design. The first part of this report describes the assumptions made within the TRACE energy model. The second part contains detailed results and discussion of the analysis performed.

The results revealed the annual electric energy consumption of the building to be 524,639 kWh. The annual chilled water load was found to be 31,251 therms and the annual steam load was 5,245 therms.

The costs of energy to meet these loads are split up by fuel type. At the district steam and chilled water plant, natural gas is the assumed fuel type used for the steam boiler, and purchased electricity is assumed for the chiller. As modeled, the annual natural gas consumption is 6,295 therms with an annual cost of $8,561. The annual electricity consumption is 776,517 kWh at an annual cost of $88,284.

Contents

Cooling and Heating System Overview

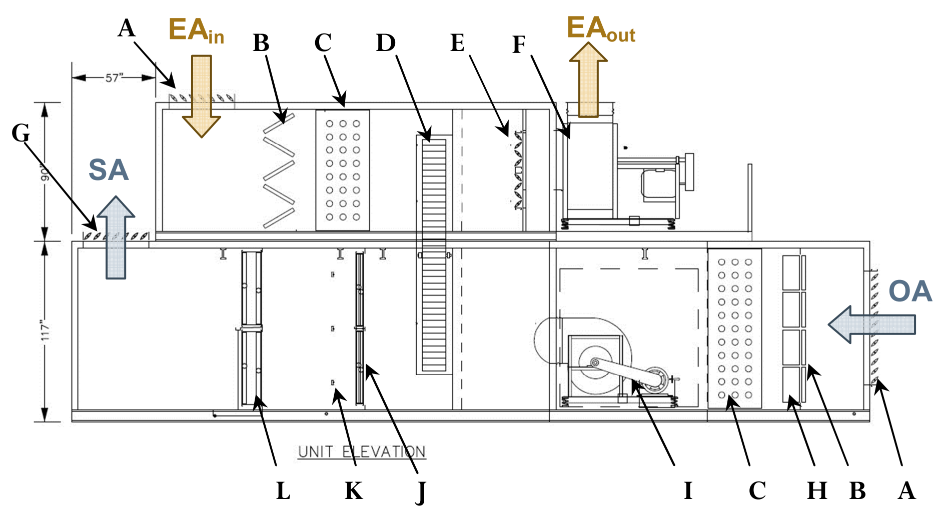
The New Science Center is conditioned by (4) Air Handling Units, an active chilled beam system, and steam and hot water unit heaters. The AHUs supply 100% outdoor air to all occupied spaces within the building. The chilled beams are used in offices, physics and biology labs (not used in chemistry labs), conference rooms, computer labs, and some of the lounges. Steam and hot water unit heaters (not included in this energy analysis) are used in emergency stairwells, entrance vestibules, the loading dock, and the mechanical penthouse.

Steam and chilled water for the systems are supplied by the Georgetown University district utility plant. The plant uses gas/oil fired high pressure boilers and electric motor driven chillers. Detailed data and specs of the plant are unavailable.

The four air handling units in the mechanical penthouse each contain two parallel variable speed fans, heating and cooling coils, and an enthalpy recovery wheel. Each supplies a maximum 54,000 cfm to a common plenum that distributes to the rest of the building. The Building Automation System cycles the units based on the load and ventilation requirements of the building.

FIGURE 1

Typical Air Handling Unit Detail



- **A** - Inlet air dampers
- **B** - Pre-filters
- **C** - Sound attenuator
- **D** - Enthalpy wheel
- **E** - Fan isolation damper
- **F** - Exhaust fan
- **G** - Discharge dampers
- **H** - Final filters
- **I** - Supply fan
- **J** - HW coil
- **K** - Steam humidifier
- **L** - Cooling coil

The chilled beam system is supported by a 200 ton water source heat pump recovery unit, and district steam and chilled water. The water source heat pump transfers heat from the return chilled water to the hot water supply of the chilled beams. Any additional load needed after the heat pump, is supplied by two redundant shell-tube heat exchangers and district chilled water.

Design Load Estimation

Assumptions

All assumptions that follow are defined by this report's preparer, Kevin Edstrom. The energy model and assumptions from the design engineer were unavailable for reference for this report.

Indoor/Outdoor Air Design Conditions:

Outdoor air design conditions are based on ASHRAE Fundamentals 2009 weather information. These are summarized in Table 1 below.

TABLE 1

ASHRAE Weather Data for Washington, DC*		
	DB Temp [°F]	WB Temp [°F]
Summer Design (0.4%)	93.5	75.1
Winter Design (99.6%)	10.7	-

* Washington DC Dulles International Airport

Indoor air design setpoints were provided in the contract documents as summarized in Table 2 below.

TABLE 2

Indoor Design Setpoints [°F]	
Office, Circulation Spaces & Toilet Rooms	
Occupied cooling	75
Occupied heating	70
Unoccupied cooling	78
Unoccupied heating	65
Laboratory and Lab Equipment Spaces	
Occupied cooling	74
Occupied heating	72
Unoccupied cooling	78
Unoccupied heating	68

Block Loads:

Similar spaces were lumped into block loads for the energy model. All rooms were assigned to one of nine zones based on the type of space. Each zone was modeled in the analysis as a single room, taking into account the exterior wall and glazing profiles for each. Zones descriptions and total floor areas are described in Table 3.

Table 3

Zones		
Designation	**Description**	**Total Area [SF]**
A	Computer lab	2,859
B	Conference	2,677
C	Corridor	16,754
D	Lab - Physics/Biology	30,371
E	Lab - Chemistry	11,450
F	Lounge/Lobby	7,761
G	Office	11,301
H	Recitation	4,120
I	Storage	12,401

Each zone was assigned a unique template for internal loads, airflow, thermostat, and construction.

Internal loads and schedules

People and equipment loads were defined by the TRACE libraries for each template. These values are summarized in Table 4 below. The lighting power densities were taken from ASHRAE Standard 90.1 (Table 9.6.1). Note that equipment loads were based on assumed usage and occupancy of the spaces. These may vary greatly based on the types of equipment used by the university, especially in lab spaces.

Table 4

Internal Loads Templates						
Template	Zones assigned	occ density [sq ft/person]	sensible/latent per person [Btu/h]	workstations	lighting [W/sq ft]	miscellaneous [W/sq ft]
Computer labs	A	33.3	250/200	1 per person	1.1	0.5
Conference rooms	B	20	245/155	3	1.3	0.22
Corridors	C	250	250/200	0	0.5	0
Labs	D, E	33.3	250/250	1 per person	1.4	0.22
Lounges/Lobby	F	50	245/155	0	1.2	0
Offices	G	143	250/200	1 per person	1.1	0.5
Recitation	H	20	250/200	.4 per person	1.4	0.22
Storage	I	0	-	0	0.5	0

Internal load schedules were established for people loads, lighting loads, and miscellaneous loads. The schedules used are shown in Figures 2 through 4 on the following page.

Figure 2

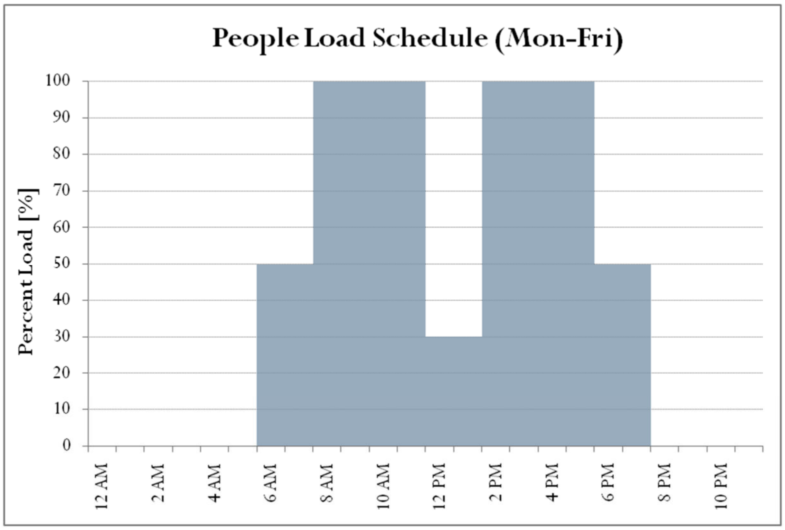


Figure 3

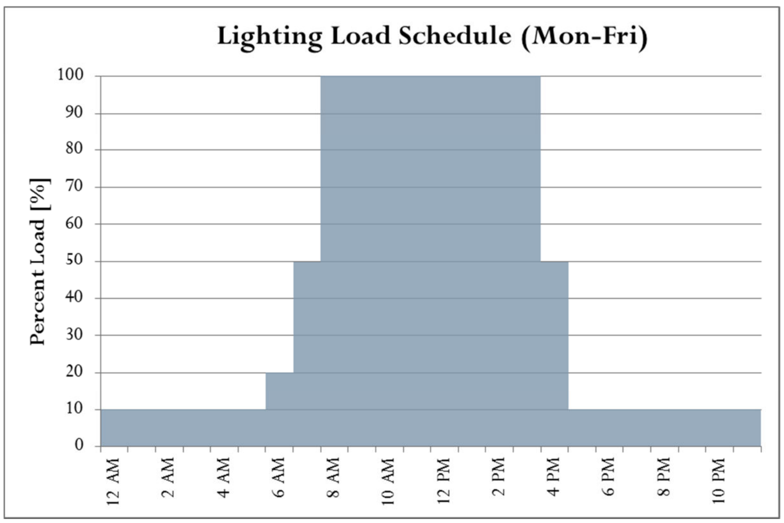
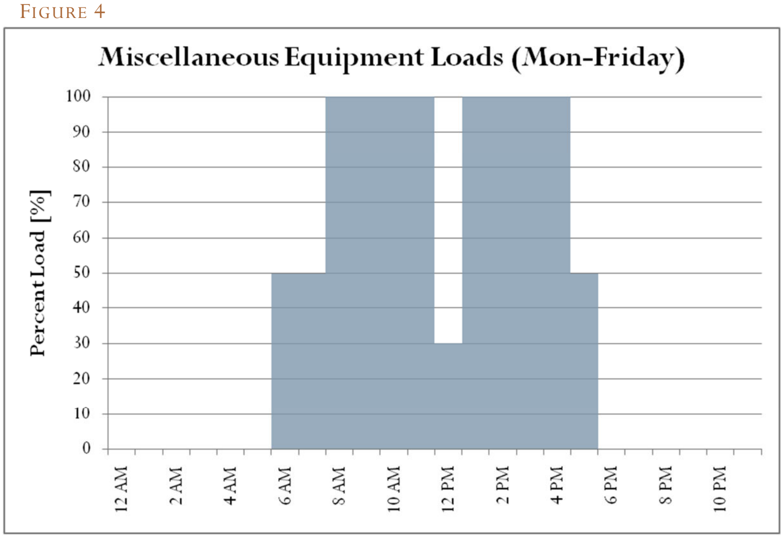


Figure 4



Airflow

Airflows for all templates of this system were set at minimum ventilation requirements according to ASHRAE Standard 62.1. OA ventilation rates are not specified in the contract documents. Labs were assumed to be 100% airflow exhaust. Infiltration was assumed to be 0.3 air changes per hour with a pressurized, average construction.

Thermostat

Thermostat settings in the TRACE model were assigned setpoints found in the contract documents. There are two templates for these settings: one for labs and lab equipment spaces, and one for all other spaces. These settings are summarized in Table 5 below.

Table 5

Thermostat Templates	
Space	[°F]
Labs and Lab Equipment Spaces	
Cooling dry bulb	74
Heating dry bulb	72
Cooling driftpoint	78
Heating driftpoint	68
Offices, Circulation Spaces, Toilets	
Cooling dry bulb	75
Heating dry bulb	70
Cooling driftpoint	78
Heating driftpoint	65

Construction

Construction materials were assigned based on the contract documents. There were three façade types used throughout the building. Table 6 is a schedule of exterior walls used for each zone. Table 7 shows the construction and corresponding U-Values associated with each façade type. Glazing U-values were found in the contract documents. All spaces are set at 14.5' floor to floor height with a 4.5' plenum space.

Table 6

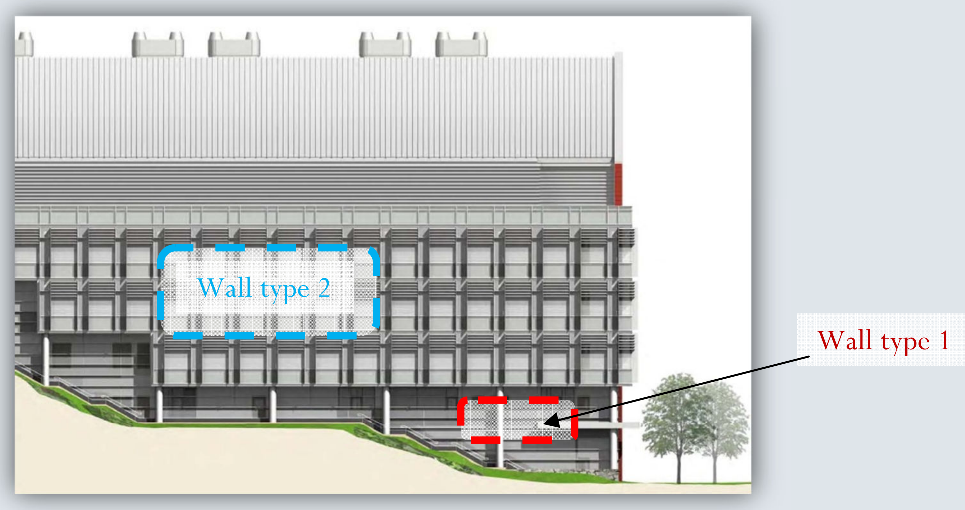
Block Exterior Walls			
Block Type	Linear ft.	Direction facing	Wall type*
Conference	60	east	1
Corridors	303	west	1
	120	south	1
Labs – Physics & Bio	175	south	3
	489	east	3
Labs – Chem	336	east	3
Lounges	171	west	2
	60	south	2
Offices	470	west	2
Recitation	22	east	3

* See Table 7

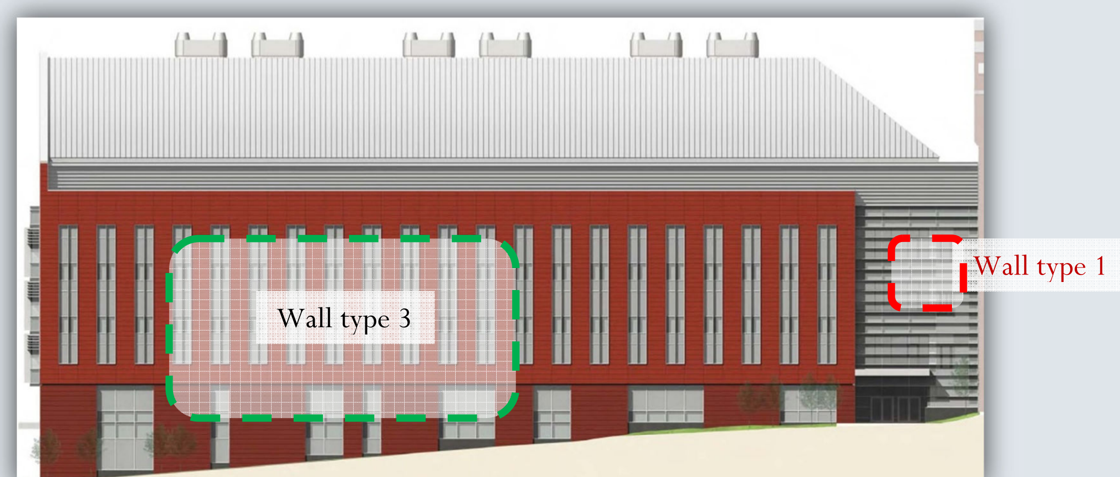
TABLE 7

Exterior Wall Type Properties and Locations			
	Description	Wall U-Value	Glazing U-value/shading coefficient
Type 1	Low E glass curtainwall	-	0.25/0.43
Type 2	Aluminum panels and low E glass	.130123	0.25/0.43
Type 3	Terra cotta	.0601104	0.25/0.43

West Elevation:



East Elevation:



Note that wall type 2 has shading devices running horizontally across the top of each floor. These were accounted for by adding custom shading libraries to TRACE and assigning them to these rooms. Custom shading libraries were also used for all glazing to account for the smaller, vertical and horizontal shading between each window panel.

Systems, Plants, and Economics

Two separate system and plant scenarios were used in the TRACE model for the analysis. The first was used for the annual energy consumption analysis in the next section of this report. The second was used for the economic analysis.

To provide a representative energy consumption analysis, the first model is set up using purchased steam and chilled water in the heating and cooling plants. This will give us representative steam and chilled water loads to be acquired from the Georgetown University district utility plant. Since economic information regarding the plant was unavailable, the 2nd model was set up using an air-cooled chiller for cooling, and a gas fired hot water boiler for heating. The second model will better represent the amount of fuel consumed in generating the energy of the steam and chilled water loads. Economic information for electricity was acquired from Pepco, a Washington, DC power provider. Gas economic data for the DC area was acquired from the U.S. Energy Information Administration's website.

Annual Energy Consumption and Operating Costs

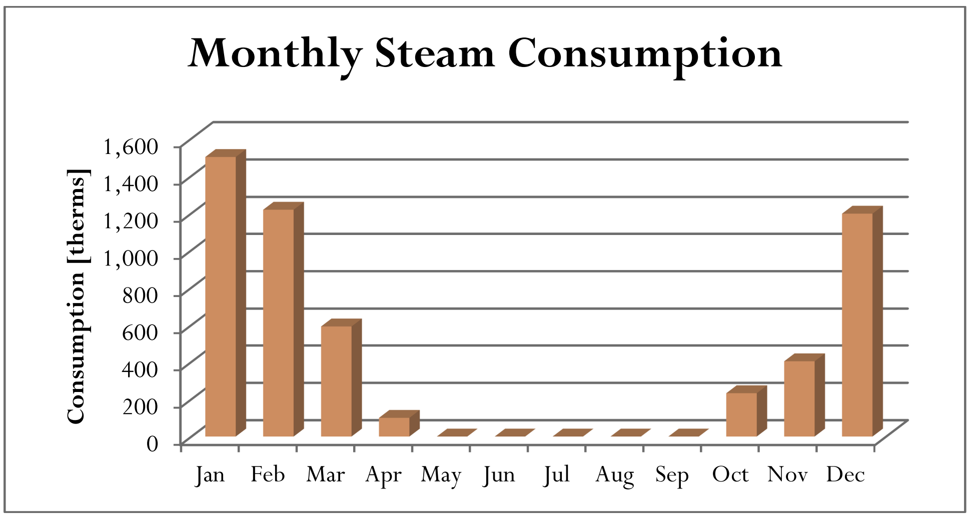
The annual energy consumption was estimated using the Trane TRACE assumptions described in the previous section of this report. Energy consumption for the New Science Center requires three energy sources: district steam, district chilled water, and electricity. The model used for the analysis does not take into account the semester schedule of Georgetown University. Realistically, these loads may vary greatly from this analysis depending on the use and schedule of the occupants.

Annual Energy Consumption

Steam

The steam demanded by the heating system is shown in Figure 5. The steam is converted to HW that is distributed to the heating coils. This model assumes that there is no heat lost through the shell-and-tube heat exchangers. The annual steam consumption is 5,245 therms.

FIGURE 5



Chilled Water

Figure 6 below shows the monthly chilled water required by the cooling loads. The annual consumption is 31,251 therms. A comparison of the monthly steam and chilled water loads on the district plant are shown in Figure 7.

FIGURE 6

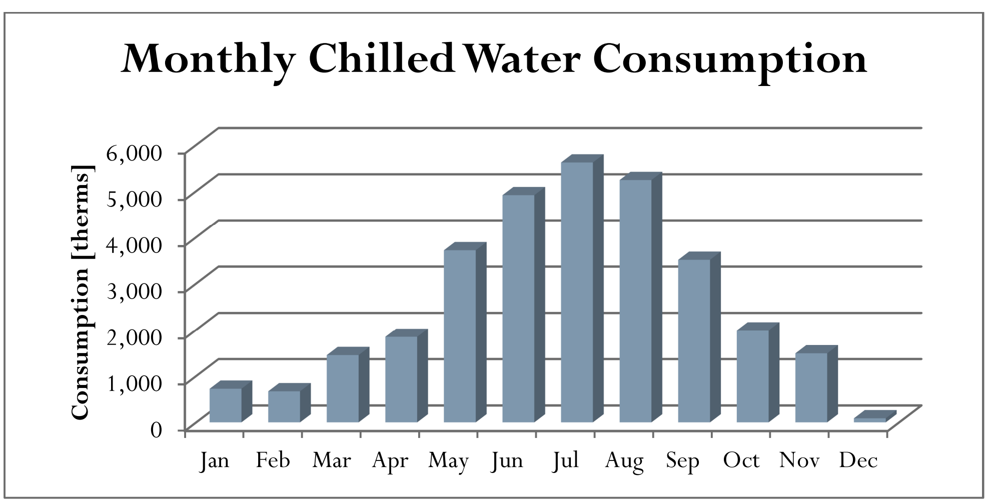
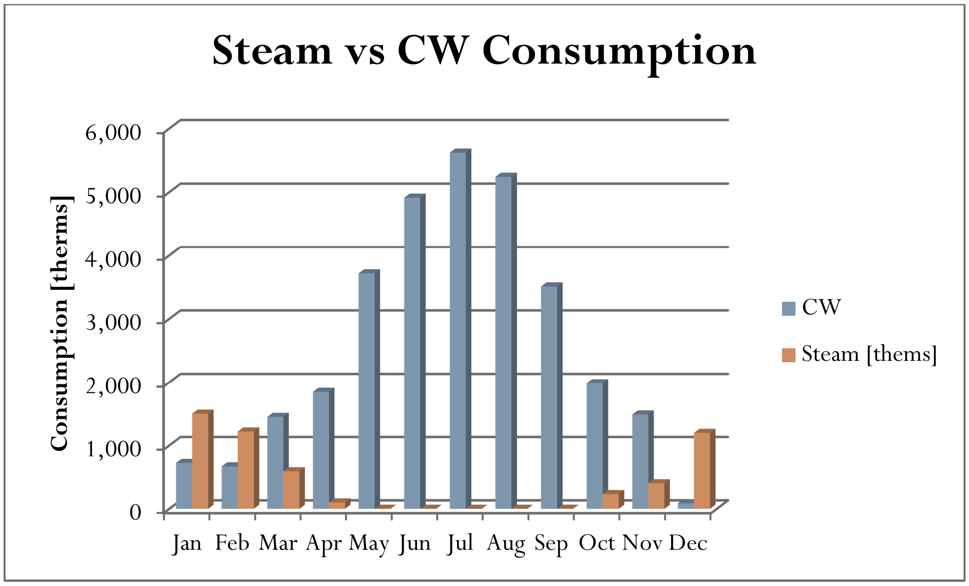


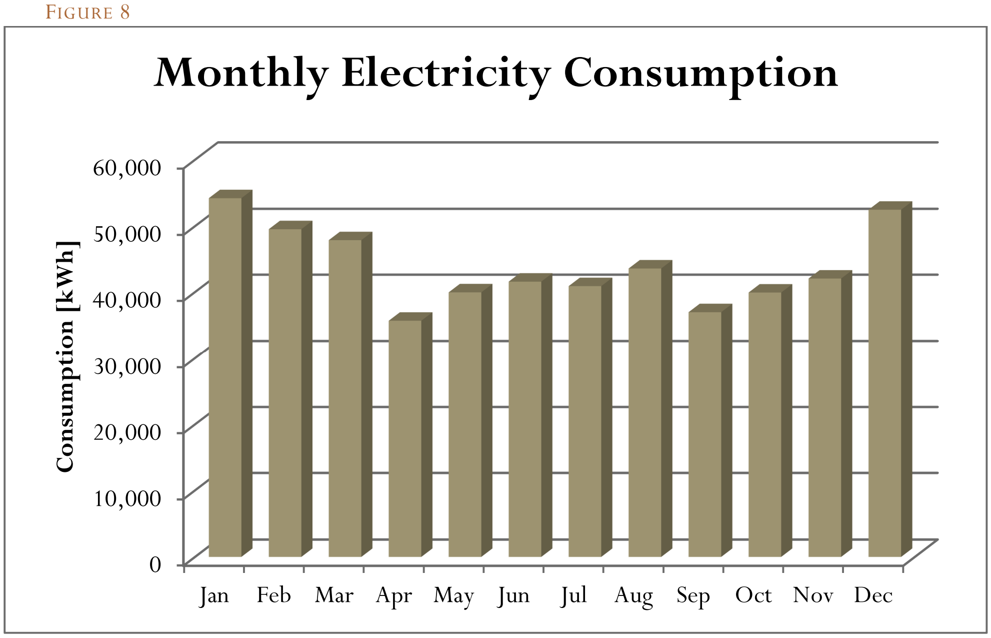
FIGURE 7



Electricity

Figure 8 shows the monthly energy consumption of the whole building. The total annual load of the building is 524,639 kWh according to this analysis. This does not include the energy required by the chilled water plant to provide the chilled water for the cooling load.

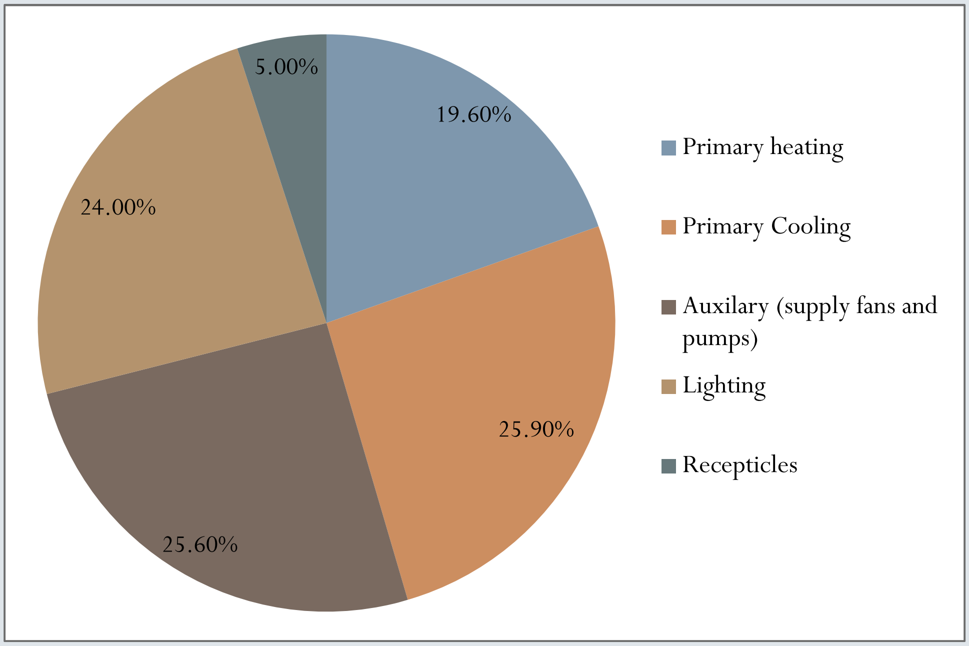
FIGURE 8



The electric energy distribution of the New Science Center's subsystems is shown in Figure 9. These percentages may be different from the actual system design due to semester and break schedules, and due to special equipment used within the labs.

FIGURE 9

Electric Energy Subsystem Distribution



Annual Operating Costs

The operating costs were calculated using a separate TRACE model as described in the previous section. This was done in order to provide an estimate of actual operating costs of the building's energy consumption with the absence of economic data of the district utility plant. This model assumes a gas fired boiler and electric motor driven chillers are used to meet the heating and cooling loads of the building.

Electric utility costs were acquired from Pepco, an electric provider in Washington, DC. The annual electric utility costs were estimated to be $88,284. See Table 8 for a detailed breakdown of these loads and costs.

TABLE 8

Electric Utility Costs							
			Unit Costs		Cost		
Month	Consumption [kWh]	Demand [kW]	[$/kWh]	[$/kW]	Consumption	Demand	Total
Jan	59,370	270	0.10906	0.4531	$6,475	$268	$6,743
Feb	54,263	271	0.10906	0.4531	$5,918	$269	$6,187
Mar	58,576	290	0.10906	0.4531	$6,388	$277	$6,666
Apr	48,819	293	0.10906	0.4531	$5,324	$279	$5,603
May	68,249	371	0.10906	0.4531	$7,443	$314	$7,758
Jun	81,481	443	0.10906	0.4531	$8,886	$347	$9,233
Jul	88,972	462	0.10906	0.4531	$9,703	$356	$10,059
Aug	86,956	441	0.10906	0.4531	$9,483	$346	$9,829
Sep	63,752	404	0.10906	0.4531	$6,953	$329	$7,282
Oct	54,054	303	0.10906	0.4531	$5,895	$283	$6,179
Nov	52,827	276	0.10906	0.4531	$5,761	$271	$6,033
Dec	59,198	244	0.10906	0.4531	$6,456	$257	$6,713
TOTAL	776,517	462					**$88,284**

Total gas utility costs are $8,561, as calculated in the Table 9 below. The unit costs were taken from the U.S. Energy Information Administration's website for average large commercial cost data in Washington, DC.

TABLE 9

Gas Utility Costs			
Month	Consumption [therms]	[$/therm]	Total Cost
Jan	1,802	1.36	$2,451
Feb	1,463	1.36	$1,990
Mar	710	1.36	$966
Apr	120	1.36	$163
May	0	1.36	$0
Jun	0	1.36	$0
Jul	0	1.36	$0
Aug	0	1.36	$0
Sep	0	1.36	$0
Oct	279	1.36	$379
Nov	483	1.36	$657
Dec	1,438	1.36	$1,956
TOTAL	6,295		**$8,561**

The total energy costs of the building are summarized in Table 10. In Table 11, the broken out annual costs and costs per SF values are given for specific sub-systems. Please note that these numbers are based off many assumptions and do not represent the actual costs to Georgetown University. Actual energy consumption and costs are not available.

TABLE 10

Total Energy Costs			
Month	Electric	Gas	Total
Jan	$6,743	$2,451	$9,194
Feb	$6,187	$1,990	$8,177
Mar	$6,666	$966	$7,632
Apr	$5,603	$163	$5,766
May	$7,758	$0	$7,758
Jun	$9,233	$0	$9,233
Jul	$10,059	$0	$10,059
Aug	$9,829	$0	$9,829
Sep	$7,282	$0	$7,282
Oct	$6,179	$379	$6,558
Nov	$6,033	$657	$6,690
Dec	$6,713	$1,956	$8,669
TOTAL	$88,284	$8,561	**$96,845**

TABLE 11

Operating Cost Breakdown		
	Annual cost	[$/SF]
Primary Heating	$12,975.20	0.13
Primary Cooling	$22,865.56	0.23
Supply Fans	$12,889.46	0.13
Pumps	$9,799.52	0.10
Lighting	$21,188.16	0.21
Receptacles	$4,414.20	0.04
Total	$96,845.00	0.97

Annual Emissions

Energy emissions were determined using emission factors from a report published by the National Renewable Energy Laboratory (Deru and Torcellini). The calculated emissions can be found on the following page in Tables 12 and 13. The emission factors were multiplied by the total electric load and natural gas load to estimate the total pollutant emitted per year from the New Science Center based on the TRACE simulation.

TABLE 12

Annual Delivered Electricity Emissions			
Pollutant	Elec load [kWh]	Lb of pollutant per kWh	Pollutant emitted [lb]
CO2	776,517	1.16E+00	900,759.72
CH4	776,517	3.59E-03	2,787.70
N2O	776,517	3.87E-05	30.05
Nox	776,517	3.00E-03	2,329.55
Sox	776,517	8.57E-03	6,654.75
CO	776,517	8.54E-04	663.15
TNMOC	776,517	7.26E-05	56.38
Lead	776,517	1.39E-07	0.11
Mercury	776,517	3.36E-08	0.03
PM10	776,517	9.26E-05	71.91
Solid Waste	776,517	2.05E-01	159,185.99

TABLE 13

Annual Delivered Natural Gas Emissions				
Pollutant	Gas load [therms]	Lb of pollutant per 1000 CF	Lb of pollutant per therm	Pollutant emitted [lb]
CO2	6,295	1.16E+01	1.13E+03	7,103,307.39
CH4	6,295	7.04E-01	6.85E+01	431,097.28
N2O	6,295	2.35E-04	2.29E-02	143.90
NOX	6,295	1.64E-02	1.60E+00	10,042.61
SOX	6,295	1.22E+00	1.19E+02	747,071.98
CO	6,295	1.36E-02	1.32E+00	8,328.02
TNMOC	6,295	4.56E-05	4.44E-03	27.92
Lead	6,295	2.41E-07	2.34E-05	0.15
Mercury	6,295	5.51E-08	5.36E-06	0.03
PM10	6,295	8.17E-04	7.95E-02	500.29
PM-unspecified	6,295	1.42E-03	1.38E-01	869.54
Solid Waste	6,295	1.60E+00	1.56E+02	979,766.54

Conclusions

The energy modeling process can become very complicated with complex systems. For the system analyzed for the New Science Center, there were many assumptions and some system simplifications that were made to complete the TRACE model. The results that were produced seem reasonable; however there are too many factors to consider it very accurate.

The monthly estimated consumption data of the steam and chilled water show a realistic relationship to each other throughout the year. In the winter months the chilled water load dips down while the steam rises and in the summer vice versa. This is due to outdoor air temperature changes during these times of year. The electricity loads from the analysis would realistically be lower in the summer months since most students would be on summer break.

The electricity costs in the simulation results show a noticeable drop during the fall and spring months. I this is most likely caused by the heating and cooling loads being minimal during these months, therefore less equipement is needed to condition the outdoor air entering the building.

To build a more representative model, some of the additional information would be needed from the client, Georgetown University. The people and equipment loads and schedules would need to be looked into more thoroughly. For more accurate operating costs, more information would be needed relating to the district utilities plant used for steam and chilled water.

For a lab building using chilled beams, a VAV- DOAS, a water source heat pump energy recovery unit, and various other energy saving strategies and technologies, a more detailed system analysis would need to be performed by experienced engineers. However, the complexity of this system allows it to minimize energy costs and the carbon footprint of the New Science Center.

References

2009 ASHRAE Handbook—Fundamentals.

ASHRAE Standard 62.1-2007.

ASHRAE Standard 90.1-2007.

Deru, M., and P. Torcellini. *Source Energy and Emission Factors for Energy Use in Buildings*. Tech. 2007.

Pepco. <http://www.pepco.com/>.

U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. <http://www.eia.gov/>.

Appendix A – List of Figures and Tables

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