Senior Thesis Capstone Project

Technical Assignment 2

Building and Plant Energy Analysis Report

Interdisciplinary Science and Engineering Building

University of Delaware
Newark, DE 19716

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Executive Summary

The fallowing building plant and energy analysis was conducted on the University of Delaware's newly designed Interdisciplinary Science and Engineering building (ISEB). The building will be built on university property, will be approximately 194,000 square feet, and is scheduled for completion in Fall 2013. The building will facilitate both research labs and educational/office spaces. Chilled water and steam, from campus utility plants, meet the building's heating and cooling requirements.

Trane's *TRACE 700* program was used for both the load calculations and energy simulation conducted in this report. The variation in load characteristics, ventilation rates, and energy recovery opportunities between lab and non-lab spaces makes running and analyzing the energy analysis for ISEB a complex process. After the TRACE load calculations were completed, they were compared to the loads presented in the design documents. The TRACE peak-cooling load was 4.2% higher than the design peak-cooling (chilled water) load and the TRACE peak-heating load was 14.6% lower than the design peak-heating (steam) load. These results are shown in table 1 below.

Table 1: Design vs. TRACE Calculated Loads

	Peak Cooling	Peak Heating
TRACE CALC	**1410 Tons**	**9,924 MBH**
Design Docs.	**1350 Tons**	**11,628 MBH**
Difference	**4.2%**	**14.6%**

The design engineers for ISEB had an energy simulation conducted and those results (shown in table 2 below) were compared against the TRACE energy simulation results. As previously stated, the complexity of the energy recovery and lab ventilation systems for this project made an energy simulation difficult but when compared against the mechanical engineers analysis the results were fairly close. The building electrical consumption calculated in TRACE was 8% higher than the value calculated by the design engineer. The chilled water consumption calculated by TRACE was 27% more while the steam consumption was 6% less. These two differences reflect the fact that the TRACE calculated cooling load was above the design cooling load value and the TRACE calculated heating load was below the design heat load value. The building's electric, chilled water, and steam consumption calculated by the TRACE energy analysis program resulted in a yearly energy bill of $1,268,803, which is 14% higher than the cost calculated by the design team. The TRACE energy analysis results and their variance from the simulation ran by the design engineer are show in table 3 below.

Table 2: Energy Simulation Results from Design Engineer

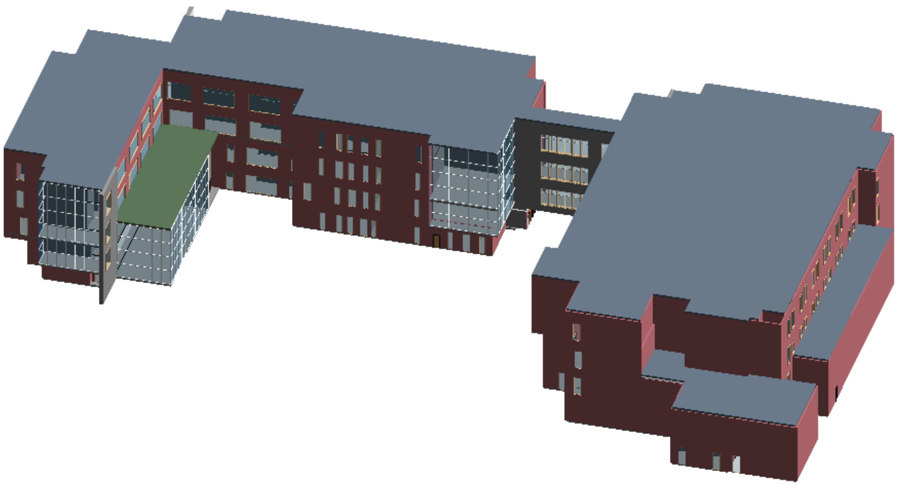
Electricity (kW-hr/yr)	Chilled Water (ton-hr/yr)	Steam (BTUH/yr)	Total Cost/Year
6,998,096	1,152,946	6,958	$1,085,495

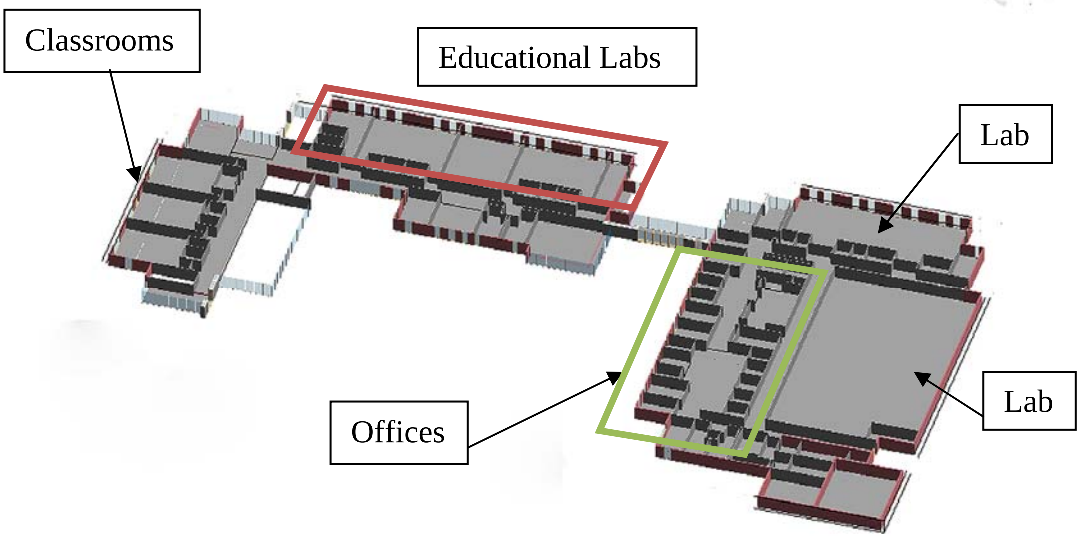
Table 3: TRACE Energy Simulation Results

Electricity (kW-hr/yr)	**Chilled Water (ton-hr/yr)**	**Steam (BTUH/yr)**	**Total Cost/Year**
7,601,151	**1,589,141**	**6,562**	**$1,268,803**
+ 8%	**+ 27%**	**- 6%**	**+14%**

Building Overview

ISEB is a unique building due to its mixed use. It contains strictly controlled laboratory spaces with stringent environmental requirements, as well as classrooms and office areas that deal with large occupant fluctuations. All of the educational related spaces, as well as the office spaces, are supplied by any one of the three recirculating type AHU's. The lab and lab support spaces require 100% outdoor air and are supplied by any one of the seven 100% outdoor air AHU's. Each wing of the building contains both lab and non-lab spaces. (Typical floor show below)





Load Calculation Procedure

Design Conditions:

The site for ISEB is located on the University of Delaware's campus, which resides in Newark, DE. The nearest location that ASHRAE Handbook of funamentals has design conditions recorded for is Wilmington, DE. These conditions are reported in Table 4 below.

Table 4: Design Outdoor Air Conditions

ASHRAE HOF 2009 CH.14 APPENDIX	
Wilmington, DE	dB Temp
0.4% Cooling	93.1 ^{o}F
99.6% Heating	11.7 ^{o}F

The indoor design conditions needed to be determined and specified for each space. For this building the engineer has specified two indoor condition types, lab and non-lab. These conditions were found in the design documents and are shown below in table 5.

Table 5:Indoor Air Design Conditions

Indoor Design Conditions		
	Winter	Summer
Lab Spaces	72 ^{o}F	72 ^{o}F
Non Lab Spaces	70 ^{o}F	75 ^{o}F

Space Types and Loads:

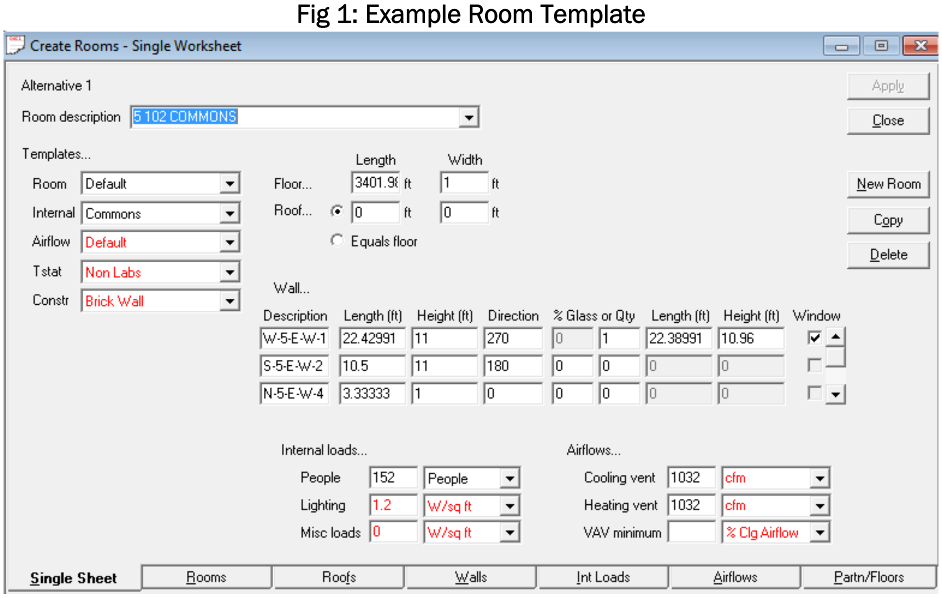
After examining the use and occupancy density of each space throughout ISEB, sixteen space types were determined. Each space type was given a specific lighting and equipment load density on a watt per square foot basis. ASHRAE standard 90.1, table 9.6.1, was used to determine lighting power densities for each space type. Equipment power densities were found in the energy simulation report obtained from the design engineer. These assumptions are summarized in table 6 below.

Table 6: Lighting and Equipment Power Densities

	Lighting	Equipment
Space Type	watts/SF	watts/SF
Classroom	1.4	-
Office	1.1	2
Lab	1.4	6
Lab Support	1.4	20
Imaging	1.4	25
Clean Room	1.4	20
Corridor	0.5	-
Restroom	0.9	-
Entry	0.6	-
Storage	0.8	-
Mech. Room	1.5	15
Telecom/Elec.	1.5	20
Common Area	1.2	-
Conference	1.3	-
Food Prep	1.2	20
Stair	0.6	-

Design occupancies, cooling airflows, heating airflows, and ventilation airflows for each space were input individually to increase the accuracy of the load calculations. An example room template is shown in figure 1 below.

Fig 1: Example Room Template



Construction:

For simplicity, a typical wall construction was determined from the construction documents and used for all walls of the model. The u-values for each building assembly are show in table 7 below.

Table 7: Building Construction

Assembly	U Value (Btu/h-ft^2-^{o}F)	Shading Coeff.
Brick Wall	0.104	-
Roof	0.048	-
Floor	0.08	-
Windows	0.29	0.23
Typical Door	0.20	-

Schedules:

Occupancy, lighting, and miscellaneous load schedules were made for both lab and non-lab space types in order to increase the accuracy of the load calculations and to accommodate the mixed use of the building. Sample occupancy schedules are shown below in tables 8 and 9. (All schedules may be found in appendix A)

Table 8: Example Occupancy Schedule

Educational Occupancy Weekday		
From	To	% Peak
Midnight	6:00am	5
6:00am	7:00am	35
7:00am	10:00am	100
10:00am	3:00pm	90
3:00pm	5:00pm	100
5:00pm	6:00pm	90
6:00pm	7:00pm	70
7:00pm	8:00pm	55
8:00pm	9:00pm	35
9:00pm	Midnight	5

Table 9: Example Occupancy Schedule

Research Occupancy		
From	To	% Peak
Midnight	6:00am	40
6:00am	7:00am	45
7:00am	10:00am	100
10:00am	2:00pm	80
2:00pm	4:00pm	100
4:00pm	5:00pm	80
5:00pm	6:00pm	55
6:00pm	7:00pm	45
7:00pm	Midnight	40

Results:

Table 10: Load Calculation Results

System	ft^2 / Ton	BTUH / ft^2	SUPPLY CFM / ft^2	OA CFM / ft^2
AHU-1	222	54	1.88	0.56
AHU-2	426	35	1.72	0.26
AHU-3	134	89	1.28	1.28
AHU-4	134	124	1.38	1.38
AHU-5	58	205	1.56	1.56
AHU-6	48	250	3.61	3.61
AHU-7	39	307	4.64	4.64
AHU-8	43	277	3.96	3.96
AHU-9	72	164	1.25	1.25
AHU-10	426	28	0.96	0.16
FCU's	171	70	1.45	0

The load calculation results, illustrated in table 10 above, show how diverse the spaces in ISEB are. Zones served by AHU's 1, 2, and 10 have ft^2/Ton and BTUH/ ft^2 values that are within the expected range for classroom and office space types (using engineering rules of thumb).

The large ventilation air requirements, process loads, and high hood densities that characterize the lab spaces in this building explain the abnormally low ft^2/Ton and high BTUH/ ft^2 values for zones served by AHU's 3 through 9.

The spaces served by the fan coil units are characteristically smaller spaces (electrical rooms, telecom rooms, vestibules, and lobbies) that contain high loads due to telecom or electrical equipment and/or large amounts of glazing. This accounts for the relatively low ft^2/Ton and high BTUH/ ft^2 values.

Energy Analysis

All of the internal loads, supply and ventilation rates, construction types, and schedules used for the load calculations were used for this energy analysis. (Schedules and example templates can be found in appendix A).

Systems:

All of the systems in this energy simulation were modeled as VAV systems with reheat. The fan static pressure and energy consumption values from the fan schedule found in the design documents was input for each air handling unit.

Plants:

The cooling plant in this simulation was modeled as "*purchased chilled water"* to best represent the buildings use of chilled water supplied by the campus chilled water utility plant. The heating plant in this simulation was modeled as "*purchased steam*" to best represent the buildings use of steam provided from the campus steam plant. Pump energy use was input based on the chilled and hot water pump schedules in the design documents.

Fuel Costs:

Fuel costs were obtained from the energy analysis report conducted by the design engineers. The rates, illustrated in figure 12 below, were based on EIA averages for Maryland and were calculated using the formulas on page 14 of *Treatment of District or Campus Thermal Energy in LEED V2 and LEED 2009 – Design & Construction* dated August 13, 2010.

Table 11: Utility Rates used in TRACE Simulation

Unit	Cost
Electricity	**$ 0.1184 / kW-hr**
Chilled Water	**$ 0.828 / Therm**
Steam	**$ 2.34 / Therm**

Results:

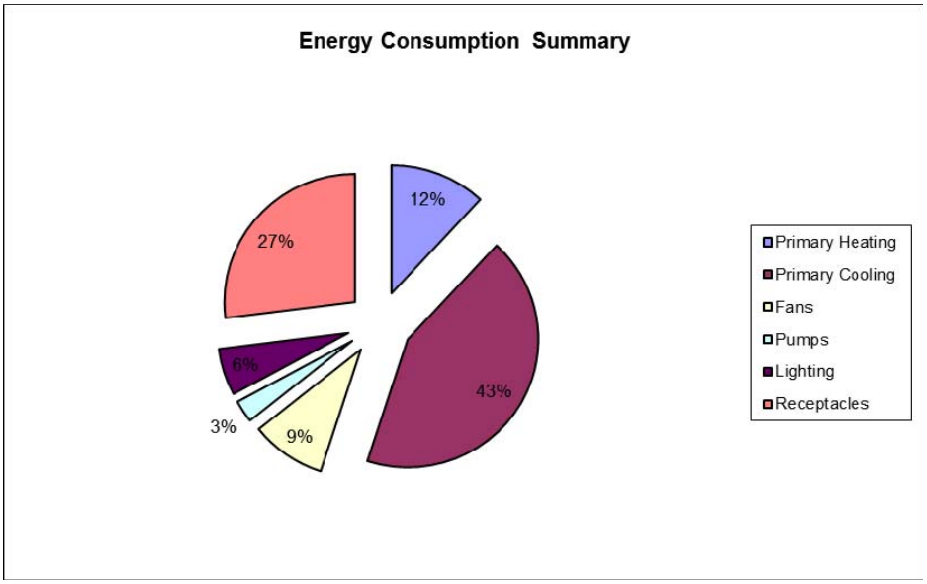
The results obtained from the TRACE energy simulation are reasonable. When compared to the energy analysis conducted by the design engineer, the TRACE energy model was within an acceptable range of variance in all categories. A comparison between the two energy models is shown below in table 12.

Table 12: Total Building Energy Consumption

Simulation	Electricity (kW-hr/yr)	Chilled Water (ton-hr/yr)	Steam (BTUH/yr)	Total Cost/Year
TRACE	**7,601,151**	**1,589,141**	**6,562**	**$1,268,803**
Design Engineer	6,998,096	1,152,946	6,958	$1,085,495
Difference	+ 8%	+ 27%	- 6%	+14%

The total energy consumption of ISEB was broken down into end use fractions. As expected, the primary heating and cooling consumed the majority of the buildings energy, due to the vast amount of ventilation air required by the building. These results are show in figure 2 below.

Fig. 2: Total Building Energy Consumption Breakdown



Steam and chilled water consumption rates obtained from the TRACE energy simulation were tabulated and broken down by consumption per month. In concurrence with the building's heating and cooling load profiles, the steam load peaked from October to April while the chilled water consumption peaked from May until September. These results are show below in figures 3 and 4.

Fig. 3: Steam Consumption

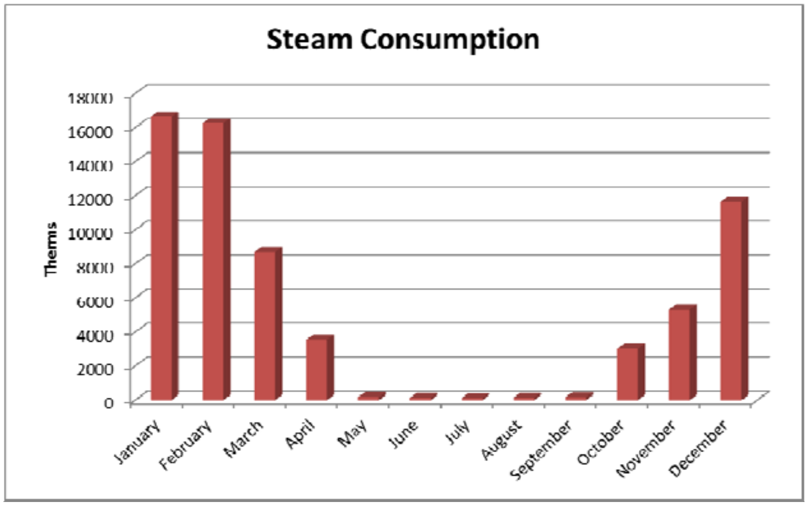
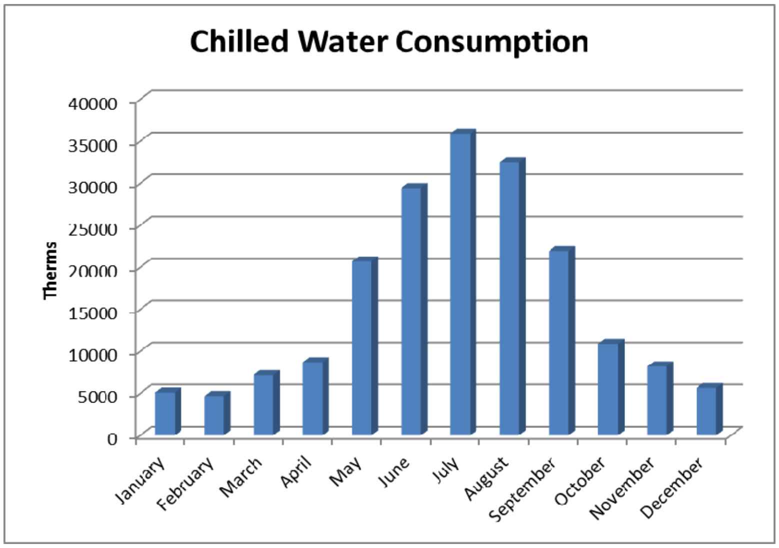


Fig. 4: Chilled Water Consumption

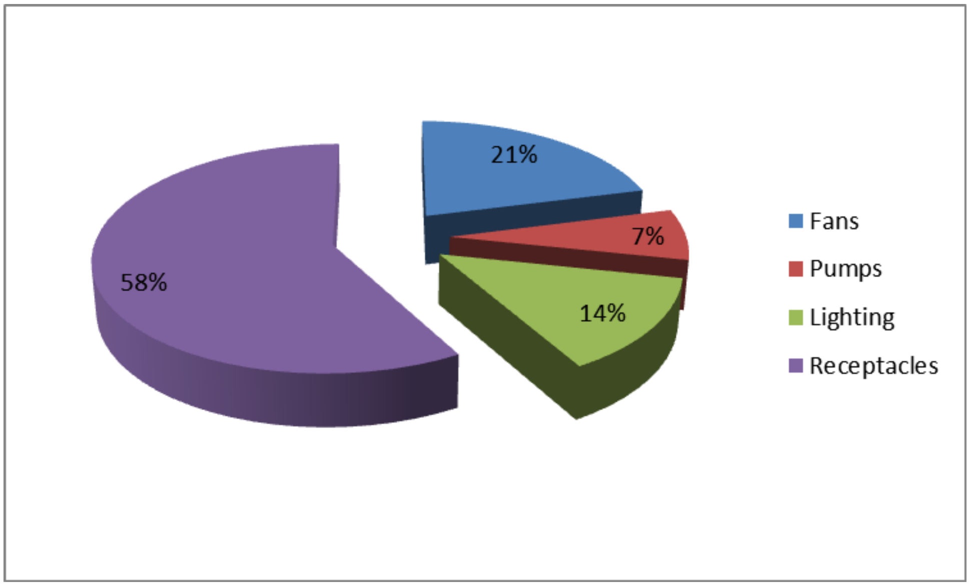


The TRACE simulated building electrical consumption was broken down by component and tabulated in table 13 below. When this was done receptacle loads dominated the profile at 58%. The lack of compressor and boiler electrical use due to the fact that there is no on site boiler or chiller is an explanation for the relatively high percentage of receptacle loads. These results are illustrated in figure 5 below.

Table 13: Electrical Load Distribution

Source	% Total
Fans	21
Pumps	7
Lighting	13
Receptacles	58

Fig. 5: Electrical Load Distribution



The total cost of operation per square foot of usable space was calculated in the TRACE energy simulation to be $7.53/ft^2. Due to the fact that when this report was conducted ISEB was still under construction, the accuracy of this calculation could not be determined. It should be noted that the total operational cost used to determine this value (depicted in table 14 below) was within 8% of that calculated in the design engineer's simulation.

Table 14: Total Cost of Operation per Year

$ / ft^2
7.53

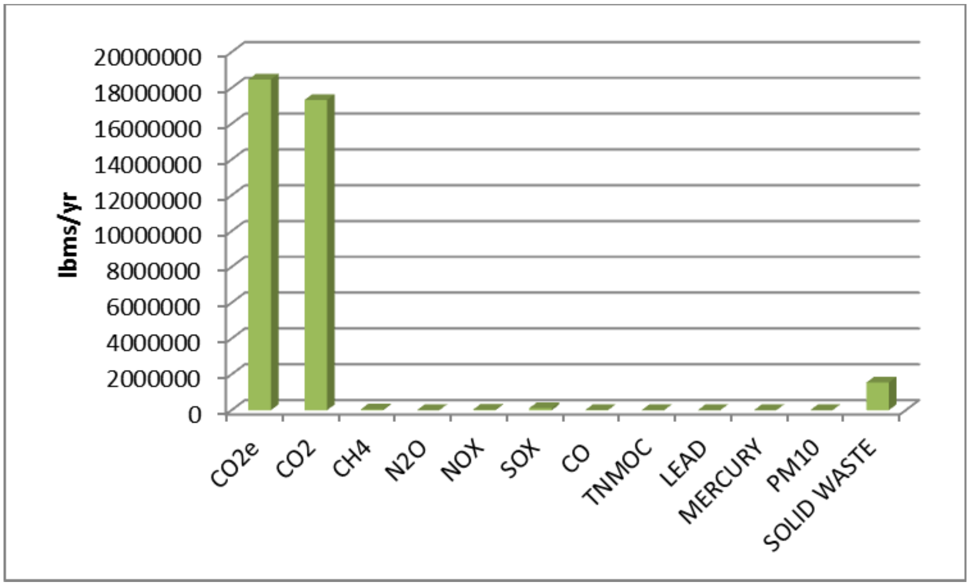
Emissions:

Because chilled water and steam are delivered to the building and no on-site combustion occurs, only the electricity delivered to the building was used to calculate the building's annual emissions footprint. Each pollutant's lb/kWh value was obtained from *Regional Grid emission Factors 2007*, table B10. The results of the emissions calculations are shown in table 15 and in figure 6 below.

Table 15: Pollutant Emissions Due to Electrical Consumption

Pollutant	lb / kWh	kWh/year	lb Pollutant / year
CO2e	2.43E+00	7,601,151	18470797
CO2	2.28E+00	7,601,151	17330627
CH4	5.94E-03	7,601,151	45151
N2O	4.56E-05	7,601,151	347
NOX	3.92E-03	7,601,151	29797
SOX	1.53E-02	7,601,151	116298
CO	1.85E-03	7,601,151	14062
TNMOC	7.93E-05	7,601,151	603
LEAD	1.42E-07	7,601,151	1
MERCURY	4.91E-08	7,601,151	0
PM10	1.27E-04	7,601,151	965
SOLID WASTE	2.03E-01	7,601,151	1543036

Fig. 6: Building Emissions Due to Electrical Consumption



Conclusion

The University of Delaware's new Interdisciplinary Science and Engineering Building contains a mixture of space uses and types. The coexistence of both lab and non-lab space types can make calculating accurate loads and modeling the energy consumption difficult. The load calculations and energy simulation conducted with Trane's TRACE 700 program gave reasonable results. The assumptions made and data used for this report resulted in final values very similar to those calculated by the design engineers. Although relatively similar results were obtained between this report and the design engineers results, both the load calculation and energy simulation conducted through TRACE resulted in consistently higher load and energy use values.

References

ASHRAE Standard 62.1-2007

ASHRAE Standard 90.1-2007

ASHRAE Handbook of Fundementals–2009

Mechanical & Electrical Equipment for Builders, tenth edition

Mueller Associates

Thomas Syvertsen

EMO Energy Solutions

Regional Grid emission Factors 2007

Appendix A

Schedules:

Educational Occupancy Weekday		
From	**To**	**% Peak**
Midnight	6:00am	5
6:00am	7:00am	35
7:00am	10:00am	100
10:00am	3:00pm	90
3:00pm	5:00pm	100
5:00pm	6:00pm	90
6:00pm	7:00pm	70
7:00pm	8:00pm	55
8:00pm	9:00pm	35
9:00pm	Midnight	5

Educational Occupancy Weekend		
From	**To**	**% Peak**
Midnight	9:00am	0
9:00am	9:00pm	45
9:00pm	Midnight	0

Research Occupancy		
From	**To**	**% Peak**
Midnight	6:00am	40
6:00am	7:00am	45
7:00am	10:00am	100
10:00am	2:00pm	80
2:00pm	4:00pm	100
4:00pm	5:00pm	80
5:00pm	6:00pm	55
6:00pm	7:00pm	45
7:00pm	Midnight	40

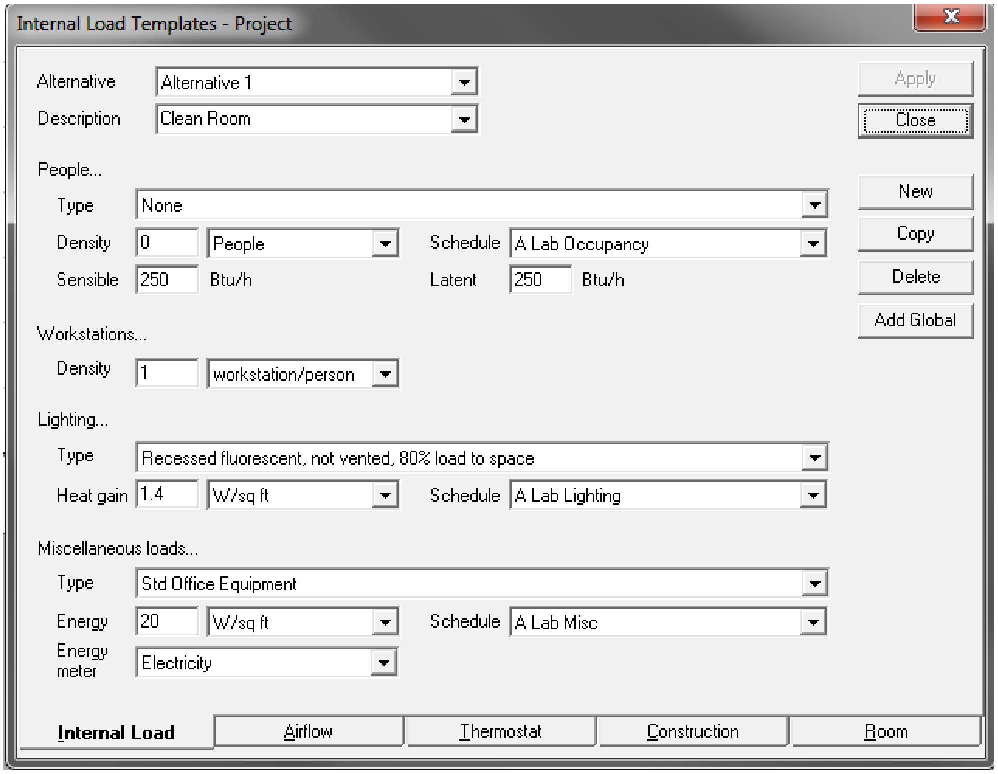
Educational Lighting		
From	**To**	**% Peak**
Midnight	6:00am	15
6:00am	7:00am	30
7:00am	8:00am	45
8:00am	Noon	100
Noon	1:00pm	70
1:00pm	2:00pm	90
2:00pm	5:00pm	100
5:00pm	6:00pm	90
6:00pm	7:00pm	70
7:00pm	8:00pm	55
8:00pm	9:00pm	45
9:00pm	Midnight	15

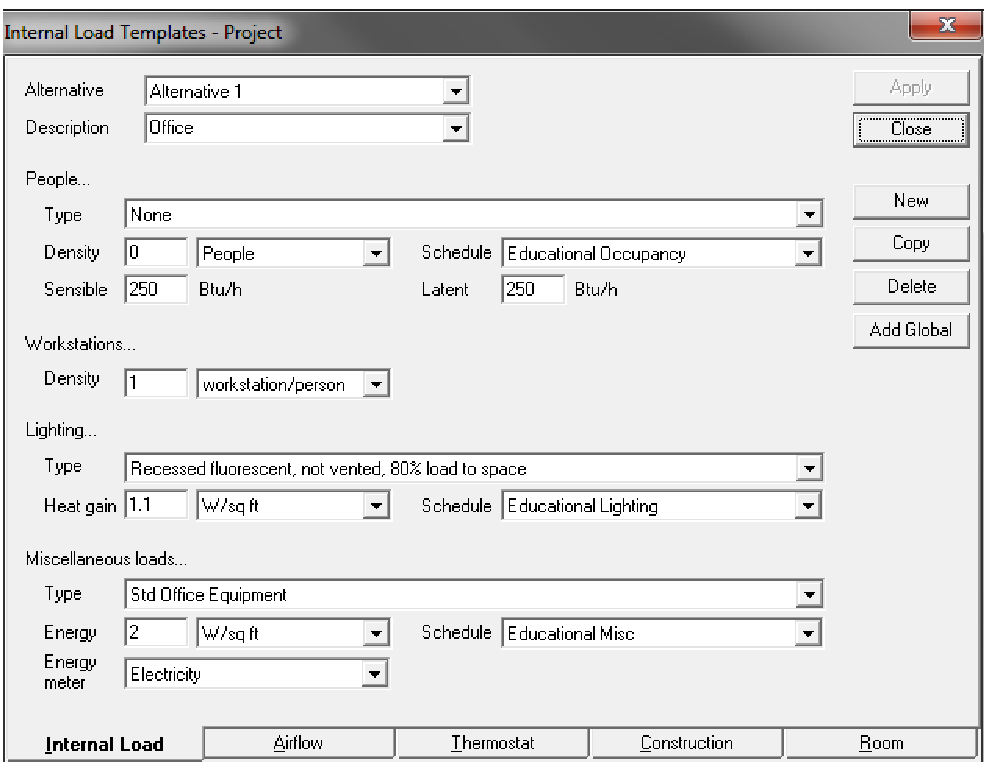
Research Lighting		
From	**To**	**% Peak**
Midnight	6:00am	40
6:00am	7:00am	45
7:00am	8:00am	80
8:00am	11:00am	100
11:00am	Noon	90
Noon	1:00pm	80
1:00pm	2:00pm	90
2:00pm	4:00pm	100
4:00pm	5:00pm	80
5:00pm	6:00pm	50
6:00pm	Midnight	40

Educational Misc.		
From	**To**	**% Peak**
Midnight	6:00am	70
6:00am	7:00am	85
7:00am	8:00am	95
8:00am	11:00am	100
11:00am	Noon	95
Noon	1:00pm	90
1:00pm	2:00pm	95
2:00pm	4:00pm	100
4:00pm	5:00pm	90
5:00pm	6:00pm	75
6:00pm	Midnight	70

Research Misc.		
From	**To**	**% Peak**
Midnight	6:00am	25
6:00am	7:00am	35
7:00am	8:00am	70
8:00am	11:00am	100
11:00am	Noon	90
Noon	1:00pm	75
1:00pm	2:00pm	90
2:00pm	5:00pm	100
5:00pm	6:00pm	90
6:00pm	7:00pm	70
7:00pm	8:00pm	55
8:00pm	9:00pm	50
9:00pm	10:00pm	35
10:00pm	Midnight	25

Example Room Templates (Both a lab and non-lab space):





Regional Grid emission Factors 2007 table B10:

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

Pollutant (lb)	AK	AL	AR	AZ	CA	CO	CT	DC	DE	FL	GA	HI	IA
CO_{2e}	1.71E+00	1.58E+00	1.57E+00	1.67E+00	7.75E-01	2.23E+00	7.29E-01	4.26E+00	2.43E+00	1.49E+00	1.62E+00	1.91E+00	2.41E+00
CO_2	1.55E+00	1.50E+00	1.48E+00	1.56E+00	6.88E-01	2.10E+00	6.76E-01	4.11E+00	2.28E+00	1.40E+00	1.54E+00	1.83E+00	2.28E+00
CH_4	6.28E-03	3.23E-03	3.47E-03	4.02E-03	3.60E-03	4.96E-03	2.14E-03	6.27E-03	5.94E-03	3.74E-03	2.95E-03	2.96E-03	4.90E-03
N_2O	3.05E-05	3.55E-05	4.16E-05	3.69E-05	1.39E-05	5.36E-05	1.48E-05	2.89E-05	4.56E-05	2.63E-05	3.75E-05	2.00E-05	6.51E-05
NO_X	1.95E-03	2.78E-03	2.65E-03	2.64E-03	5.88E-04	3.68E-03	1.10E-03	9.94E-03	3.92E-03	2.46E-03	2.98E-03	4.32E-03	4.14E-03
SO_X	1.12E-02	8.24E-03	5.13E-03	8.86E-03	6.42E-03	9.64E-03	4.23E-03	2.15E-02	1.53E-02	9.44E-03	7.73E-03	9.04E-03	6.75E-03
CO	2.05E-03	5.33E-04	6.44E-04	6.16E-04	5.36E-04	7.78E-04	7.89E-04	1.96E-02	1.85E-03	1.80E-03	5.20E-04	7.43E-03	8.19E-04
TNMOC	8.40E-05	8.18E-05	9.48E-05	5.34E-05	8.89E-05	6.72E-05	8.71E-05	1.28E-04	7.93E-05	8.88E-05	7.60E-05	1.15E-04	7.09E-05
Lead	6.30E-08	1.22E-07	1.48E-07	1.19E-07	6.95E-09	1.87E-07	4.00E-08	2.71E-07	1.42E-07	8.22E-08	1.37E-07	1.32E-07	2.46E-07
Mercury	3.80E-08	2.50E-08	3.15E-08	2.41E-08	2.86E-09	3.75E-08	1.81E-08	4.44E-07	4.91E-08	4.29E-08	2.82E-08	1.72E-07	4.93E-08
PM10	1.09E-04	7.82E-05	9.07E-05	8.36E-05	4.71E-05	1.16E-04	4.78E-05	4.25E-04	1.27E-04	8.91E-05	7.98E-05	1.79E-04	1.34E-04
Solid Waste	7.89E-02	1.88E-01	2.27E-01	1.84E-01	1.25E-02	2.88E-01	5.39E-02	7.07E-02	2.03E-01	1.05E-01	2.11E-01	7.44E-02	3.78E-01