Technical Report Two

Building and Plant Energy & Emissions Analysis

APPELL LIFE SCIENCES

York College of Pennsylvania

York, PA

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Mechanical Option

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Executive Summary

The purpose of this report is to design and analyze an energy model of the Appell Life Sciences Building. The Life Sciences Building is a university building that contains labs, classrooms and offices that have varying electrical equipment loads.

To determine airflows, design load to the systems, and other energy values a model was created in the Carrier HAP analysis program. Room dimensions, space occupancies, window areas, and wall exposures were all input into the building simulation. This model was done as a block load calculation to simply compare to the design documents.

The Carrier HAP's results were very similar to the figures in the design documents. In terms of accuracy: Cooling was within 2%, Air supply was within 6%, Ventilation rate was within 25%, and heating was within 31%. The heating load computed was lower than the design document mostly because the greenhouses were most likely not modeled accurately in the Carrier program. The ventilation rate is higher because AHU-3 was computed to have more ventilation than that of the design documents.

The Carrier HAP model was also used to calculate the building's total energy use which is approximately 8.59 million kWh per year. Heating was found to be the largest energy user at 33% of the total. This can be attributed to the building's location, orientation, and the three 2640 MBH boilers.

Overall, there are some minor deviations from the design document and comparison figures from the Energy Information Administration. However, the model was successful at approximating the life sciences building's energy use to that of a comparatively similar building.

Design Load Estimation

Energy Modeling Program Selection

For my analysis of the Life Sciences Building I chose to model the building in Carrier HAP. This program was chosen because of my familiarity with it from this past summer. I believe it is also more user friendly than Trane Trace. These reasons will help my energy model to be as accurate as possible.

Assumptions

For effective modeling purposes, the building spaces and elements were simplified into blocks.

- The wall was modeled as a CMU wall with face brick, which is the same as the existing life sciences wall (the R-values and U-values were obtained from the design documents)
- The roof was modeled as steel deck with board insulation and a membrane. (the values for this roof were obtained from the design documents)
- Area temperature setpoints for the Life Sciences building are 74º F and 71 º F for summer and winter respectively.
- The buildings location is York, Pa, however the design conditions used are from the Harrisburg International Airport.
- Lighting and Miscellaneous loads have been approximated. Table 1 below shows these assumed values.

Table 1: Electrical Load Assumptions

Electrical Load Assumptions		
Space Type	Lighting (W/SF)	Miscellaneous (W/SF)
Office	1.1	1.2
Laboratory	1.4	1.2
General Classroom	1.4	1.5
Computer Classroom	1.4	5
Mechanical/Electrical	1.5	2
Conference Room /Student Lounge	1.3	1
Restroom	0.9	0
Corridor	0.5	0

The miscellaneous loads for the computer labs are higher than the rest because of their smaller square footage but having about 30 computers and a couple printers each. The offices have a high miscellaneous value as well because of their small square footage.

Load Sources and Scheduling

Since this building is a university building it has a different schedule than a normal school building. The schedule used to remain consistent with the loads was 100% for lighting, people, and miscellaneous because the university schedule varies day by day. The thermostat schedules were also run at 100% to remain consistent with the rest of the schedules. Loads from the laboratories will be coming from the lab equipment that is provided in each room. There will also be a large load from the lab fume hoods when they are being used. Because of the number of offices and computer labs in this building there will be a large load from computers and printers. In the workroom/mail facilities there will be a large load from copiers and printers.

Design Conditions

The outdoor design conditions used for the Life Sciences Building are the Harrisburg International Airport, which are given below.

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Design conditions for MIDDLETOWN HARRISBURG INT, PA, USA

Station Information

Station name	WMO#	Lat	Long	Elev	StdP	Hours +/- UTC	Time zone code	Period
1a	1b	1c	1d	1e	1f	1g	1h	1i
MIDDLETOWN HARRISBURG INT	**725115**	**40.20N**	**76.77W**	**302**	**14.536**	**-5.00**	**NAE**	**8201**

Annual Heating and Humidification Design Conditions

Coldest month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
2	3a	3b	4a	4b	4c	4d	4e	4f	5a	5b	5c	5d	6a	6b
1	**10.4**	**14.8**	**-4.1**	**4.5**	**15.1**	**0.5**	**5.7**	**18.2**	**29.0**	**25.3**	**27.4**	**26.8**	**9.9**	**300**

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest month	Hottest month DB range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	8	9a	9b	9c	9d	9e	9f	10a	10b	10c	10d	10e	10f	11a	11b
7	**17.5**	**92.8**	**74.7**	**90.0**	**73.8**	**87.3**	**72.6**	**78.1**	**87.9**	**76.5**	**85.5**	**75.0**	**83.4**	**10.5**	**270**

Dehumidification DP/MCDB and HR									Enthalpy/MCDB					
0.4%			1%			2%			0.4%		1%		2%	
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB
12a	12b	12c	12d	12e	12f	12g	12h	12i	13a	13b	13c	13d	13e	13f
75.2	**133.8**	**83.2**	**73.5**	**126.1**	**81.3**	**72.3**	**121.1**	**80.1**	**34.0**	**88.3**	**32.3**	**85.7**	**30.9**	**83.6**

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
14a	14b	14c	15	16a	16b	16c	16d	17a	17b	17c	17d	17e	17f	17g	17h
25.6	**23.3**	**19.2**	**86.4**	**98.0**	**3.4**	**3.9**	**8.1**	**100.8**	**-2.4**	**103.1**	**-7.2**	**105.3**	**-11.7**	**108.1**	**-17.6**

Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18a	18b	18c	18d	18e	18f	18g	18h	18i	18j	18k	18l
0.4%	**62.1**	**57.1**	**64.8**	**51.3**	**79.7**	**63.8**	**84.7**	**64.5**	**90.3**	**72.3**	**94.7**	**74.3**
1%	**58.6**	**54.2**	**60.5**	**50.1**	**74.3**	**58.9**	**80.7**	**63.4**	**88.3**	**70.7**	**92.6**	**73.9**
2%	**53.4**	**49.6**	**56.0**	**47.6**	**70.0**	**57.2**	**76.8**	**61.5**	**86.0**	**69.1**	**90.5**	**73.5**

%	Jul		Aug		Sep		Oct		Nov		Dec	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18m	18n	18o	18p	18q	18r	18s	18t	18u	18v	18w	18x
0.4%	**98.7**	**76.2**	**94.7**	**76.2**	**91.0**	**73.5**	**82.1**	**68.5**	**72.2**	**61.4**	**67.1**	**59.8**
1%	**96.5**	**75.3**	**92.5**	**75.8**	**88.1**	**72.3**	**79.5**	**67.3**	**69.3**	**59.4**	**62.4**	**56.9**
2%	**93.9**	**74.9**	**90.5**	**75.3**	**85.7**	**71.3**	**76.8**	**65.7**	**66.4**	**58.4**	**58.8**	**53.3**

Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19a	19b	19c	19d	19e	19f	19g	19h	19i	19j	19k	19l
0.4%	**58.8**	**61.9**	**55.3**	**61.8**	**64.2**	**75.7**	**68.1**	**79.0**	**75.2**	**84.6**	**78.4**	**88.4**
1%	**54.3**	**57.2**	**52.3**	**57.2**	**61.9**	**74.1**	**66.0**	**75.9**	**73.3**	**83.2**	**77.5**	**87.4**
2%	**49.7**	**52.4**	**48.7**	**54.9**	**58.5**	**67.5**	**64.0**	**74.4**	**72.1**	**82.2**	**76.5**	**85.8**

%	Jul		Aug		Sep		Oct		Nov		Dec	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19m	19n	19o	19p	19q	19r	19s	19t	19u	19v	19w	19x
0.4%	**80.2**	**90.6**	**80.1**	**91.0**	**76.5**	**84.6**	**71.1**	**78.1**	**64.5**	**68.3**	**60.8**	**66.1**
1%	**79.1**	**89.9**	**78.9**	**88.4**	**75.3**	**83.2**	**69.2**	**75.9**	**62.8**	**66.6**	**57.7**	**62.2**
2%	**78.2**	**88.6**	**77.8**	**86.6**	**74.3**	**81.8**	**68.0**	**74.2**	**60.5**	**65.1**	**54.5**	**57.9**

Monthly Mean Daily Temperature Range

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20a	20b	20c	20d	20e	20f	20g	20h	20i	20j	20k	20l
13.2	**15.0**	**16.6**	**18.6**	**18.8**	**18.6**	**17.5**	**17.4**	**17.5**	**18.5**	**15.6**	**12.9**

WMO#	World Meteorological Organization number	Lat	Latitude, °	Long	Longitude, °
Elev	Elevation, ft	StdP	Standard pressure at station elevation, psi		
DB	Dry bulb temperature, °F	DP	Dew point temperature, °F	WB	Wet bulb temperature, °F
WS	Wind speed, mph	Enth	Enthalpy, Btu/lb	HR	Humidity ratio, grains of moisture per lb of dry air
MCDB	Mean coincident dry bulb temperature, °F	MCDP	Mean coincident dew point temperature, °F	MCWB	Mean coincident wet bulb temperature, °F
MCWS	Mean coincident wind speed, mph	PCWD	Prevailing coincident wind direction, °, 0 = North, 90 = East		

Design Documents vs. Computed Load

As seen from Table 2 below, the computed loads and the design document loads are relatively similar. The computed cooling load is within 2% of the documented cooling load. The computed heating load is much lower than the documented load, being within 31%. This could be due to the fact that the systems that I ran for the greenhouses could be much different than the systems that were run for the design documents. The greenhouses were most likely modeled inaccurately because it was difficult to model wall hung radiation units and horizontal unit heaters in Carrier HAP. The heating load from the greenhouses should have made the overall heating load larger, because they are enclosed in glass and the area the building is located normally has a large heating load for the winter months. The computed supply air rate is within 6% of the documented supply air rate. The computed ventilation rate is within 25% of the documented ventilation rate. This is most likely from AHU-3 which serves the second and third floor offices. The ventilation rate from the design documents is lower than the computed rate. The model for this system that was computed was taken from the design documents saying that AHU-3 needed the same amount of outdoor air as total supply cfm. This value was input into the system for ventilation cfm so this could be why they are different.

Table 2: Load and Ventilation Comparison

Load and Ventilation Comparison				
	Cooling (ft^2/ton)	Heating (BTU/hr-ft^2)	Supply Air (cfm/ft^2)	Ventilation (cfm/ft^2)
Design Document	325.9	32.75	0.61	0.41
Computed	320.6	22.4	0.65	0.55

Annual Energy Consumption and Operating Costs

Annual Energy Consumption

The annual energy consumption was calculated using the same model that was used for the load calculations. With the exception of the gas-fired boilers, the rest of the building is powered by delivered electric power.

Table 3 below shows the energy usage for the entire year separated into different loads for the building.

Table 3: Annual Energy Consumption

Annual Energy Consumption				
Load	Electricity (kWh)	Natural Gas (kWh)	Total (kWh)	% of Total
Heating				
Gas-Fired		2637639	2637639	31
Electric Heaters	190608		190608	2
Cooling				
Chiller	1991808		1991808	23
Cooling Tower	727097		727097	8
Condenser Pump	56390		56390	1
Auxiliary				
Supply Fans	221632		221632	3
Pumps	1573235		1573235	18
Lighting	703482		703482	8
Receptacles	487998		487998	6
		Total	8589889	100

The values above were computed using the energy model with equipment inputs taken from the design documents for the building.

From this analysis it can be seen that the largest load is from heating at 31%. This could be due to a number of things including, the buildings location, orientation, and boilers being the main supply for hot water to all the various systems in this project.

The buildings location is in York, PA, which can have very cold winters. The orientation of the building is mostly north, which is not the best for winter solar gain. The boilers supply a large amount of hot water to ahu's, fan coil units, horizontal unit heaters, wall hung radiation units, vav boxes, and cabinet unit heaters.

The second largest load is from cooling at 23%. This is most likely because of the large amounts of various equipment in the computer labs, office, laboratories, and workroom/mail facilities.

As seen in Chart 1 and Chart 2 below, the energy usage for natural gas and electricity changes throughout the year with the seasons. For electric energy consumption the highest peaks are during the warmer months. This is most likely because the chilled water pumps are working much harder to supply chilled water. The natural gas consumption is peaked during the winter months because of the boilers.

Chart 1: Monthly Electrical Energy Consumption

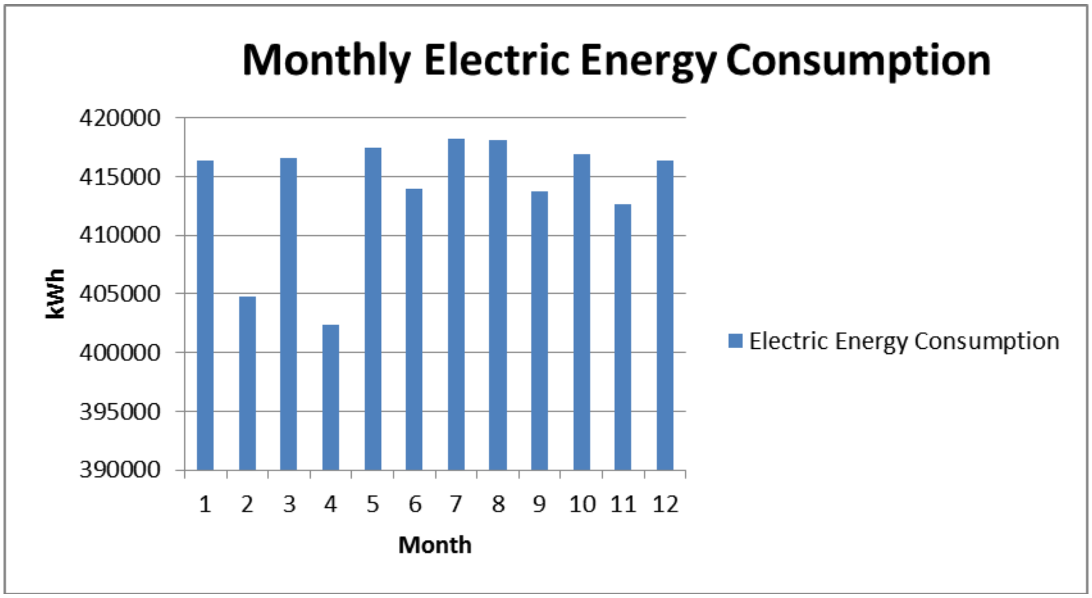
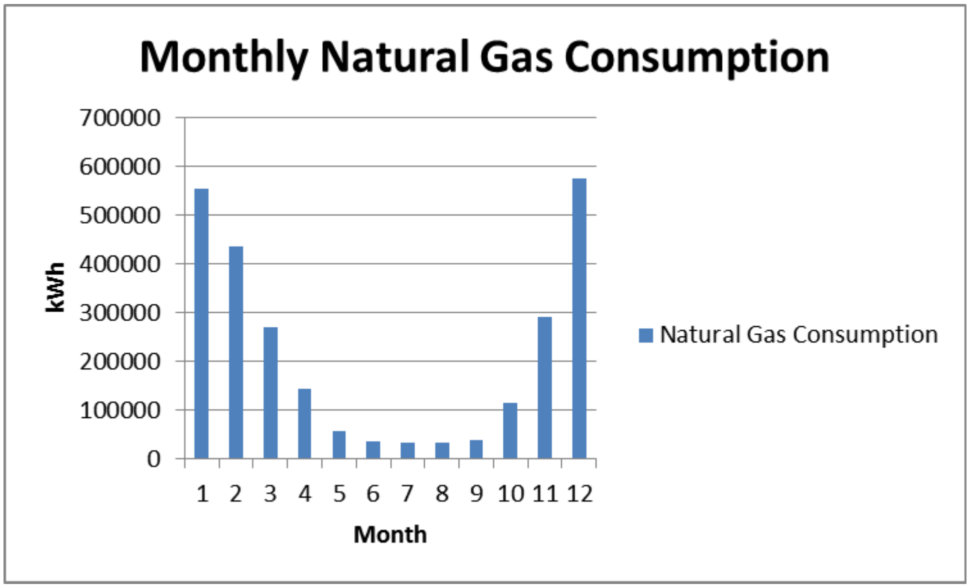


Chart 2: Monthly Natural Gas Consumption



The costs per unit of electricity and fuel are listed in Table 4 below. Due to the lack of information, Met-ED and Columbia Gas rates were used for this analysis. These two companies are two of the largest for electric and natural gas service in the York area.

Table 4: Utility Cost Information

Utility Cost Information	
Electricity (cents/kWh)	Natural Gas ($/1000ft^3)
9.35	7.31

This cost data was used to determine the cost per month for electricity and natural gas in Chart 3 and 4, respectively. As seen in the charts the cost for both electricity and natural gas fluctuate the same as the monthly energy consumption for each. This is most likely because the energy consumption for each was just multiplied by a price factor.

Chart 3: Monthly Cost of Electrical Energy

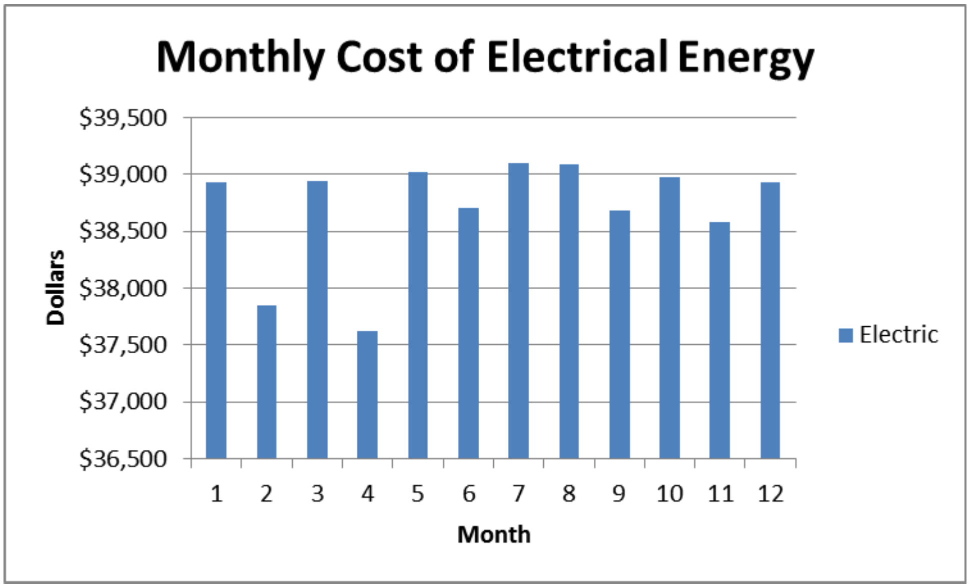


Chart 4: Monthly Cost of Natural Gas

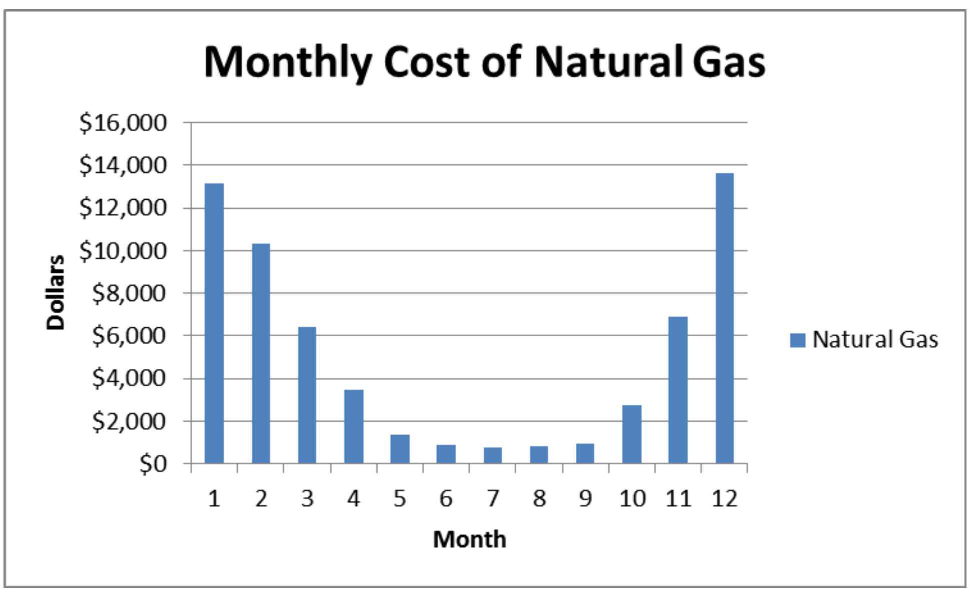


Table 5 below shows the equipment inputs used for the major systems in the building from the design documents.

Table 5: Equipment Inputs

Equipment Inputs	
Chiller	
	kW/ton - 0.57
	400 tons
	960 gpm
Boilers	
	2640 MBH each
	Exit Temp - 180 F
AHU's	
AHU-1	4200 cfm
	1300 OA cfm
	7.5 hp Supply Fan
	2 hp Exhaust Fan
AHU-2	6900 cfm
	6900 OA cfm
	15 hp SF
	7.5 hp EF
AHU-3	8000 cfm
	8000 OA cfm
	15 hp SF
	5 hp EF
AHU-4	8100 cfm
	8100 OA cfm
	15 hp SF
	5 hp EF
AHU-5	7550 cfm
	7550 OA cfm
	15 hp SF
	5 hp EF

Cost to Run Systems

The specific costs to run each of the systems has been specified in Table 6 below, the purpose being to show the total energy cost of running the building. It can be seen that the largest cost is for cooling the building. Some reasons for this include the location of the building and the various equipment loads from offices, labs, computer labs, and workrooms being high.

The second largest energy cost is for the pumps. This is most likely because of the larger cooling load, so the chilled water pumps have more work to do. It could also be because there are a number of hot water pumps to supply the systems with hot water during the winter heating months.

With this information it can be concluded that the cost to heat the building is about 61 cents per square foot. The cost to cool the building is about $1.8 per square foot. From the EIA, (Energy Information Administration), universities spend an average of $1.95 per square foot on electricity and 15 cents per square foot on natural gas. The cost for natural gas could be much larger than the national average because there are three boilers that each output 2640 MBH.

Table 6: System Specific Annual Energy Cost

System Specific Annual Energy Cost				
Load	Electricity ($)	Natural Gas ($)	Total ($)	% of Total
Heating				
Gas-Fired		62480	62480	10
Electric Heaters	17822		17822	3
Cooling				
Chiller	186234		186234	30
Cooling Tower	67984		67984	11
Condenser Pump	5272		5272	1
Auxiliary				
Supply Fans	20723		20723	3
Pumps	147097		147097	24
Lighting	65776		65776	11
Receptacles	45628		45628	7
		Total	619015	100

Professional Energy Analysis

The design engineer chose not to run an energy analysis simply because the envelope and HVAC systems were not in question. Since this is the case the energy analysis run for this report will be compared to the average numbers from the Energy Information Administration for Pennsylvania.

Comparison to Energy Information Administration

The annual cost of electricity for the Carrier HAP model is $556,535. The annual cost of natural gas for the model is $62,480. The cost for electricity from the EIA is $614,272. The cost for natural gas from the EIA is $103,730. The average cost values used to compare to the model's cost can be found below in Table 7 and 8. The cost from the EIA is much larger for natural gas most likely because Columbia Gas rates are lower than most other natural gas companies in PA.

Table 7: EIA Average Natural Gas Cost per Year

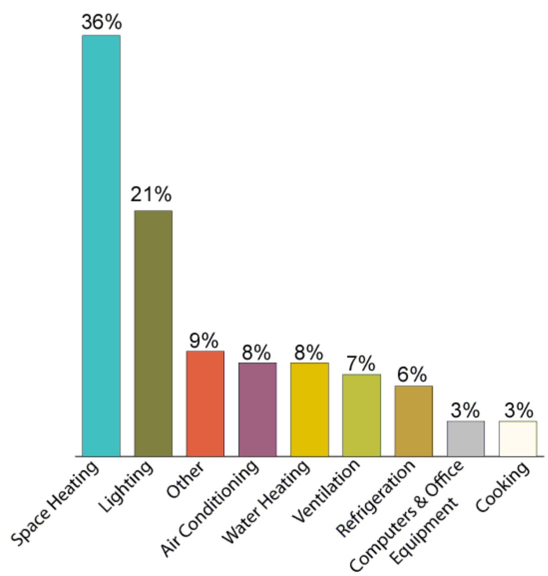
Show Data By: ◉ Data Series ○ Area	2004	2005	2006	2007	2008	2009
Wellhead Price	NA	NA	NA	NA	NA	
Pipeline and Distribution Use Price	--	--				
Citygate Price	7.56	9.98	10.30	9.35	10.39	7.81
Residential Price	12.27	14.21	16.45	14.66	16.22	14.77
Percentage of Total Residential Deliveries	100.00	100.00	100.00	100.00	100.00	
Commercial Price	10.60	13.04	14.30	12.77	14.30	12.01
Percentage of Total Commercial Deliveries	100.0	100.0	100.0	100.0	100.0	100.0
Industrial Price	8.97	11.25	12.30	10.64	12.09	9.51
Percentage of Total Industrial Deliveries	6.4	7.0	5.5	5.4	5.7	4.2
Vehicle Fuel Price	9.30	9.95	13.53	10.83	8.30	
Electric Power Price	7.49	10.30	7.76	8.01	10.46	4.60

Table 8: EIA Average Electricity Cost per Month

Census Division and State	Residential		Commercial[1]		Industrial[1]		Transportation[1]		All Sectors	
	July-10	July-09	July-10	July-09	July-10	July-09	July-10	July-09	July-10	July-09
New England	**16.12**	**17.32**	**14.68**	**16.42**	**13.45**	**11.42**	**8.64**	**7.57**	**15**	**15.56**
Connecticut	19.03	20.44	16.51	16.73	14.54	15.4	11.29	10.03	17.44	18.02
Maine	15.44	15.2	12.18	12.15	9.21	9.54	--	--	12.62	12.54
Massachusetts	14.71	16.69	14.92	18.63	14.41	10.87	6.78	6.08	14.65	15.53
New Hampshire	16.11	16.4	14.13	15.3	12.75	13.74	--	--	14.74	15.46
Rhode Island	15.11	14.55	11.54	13.02	15.5	9.88	13.46	--	13.55	13.13
Vermont	15.27	14.88	13.21	12.89	9.35	9.14	--	--	13.06	12.69
Middle Atlantic	**16.72**	**16.29**	**15.1**	**14.34**	**9.11**	**8.37**	**13.7**	**13**	**14.78**	**13.98**
New Jersey	17.37	17.86	15.17	16.18	13.17	11.34	12.94	18.3	15.99	16.39
New York	19.58	19.13	17.88	16.16	10.27	11.27	15.27	13.95	17.89	16.7
Pennsylvania	13.34	12.44	10.32	9.7	8.03	6.97	8.29	7.69	10.83	9.81

The EIA has done research into energy use by system for commercial buildings. According to Chart 5 below, 36% of commercial building energy use comes from space heating. A total of 33% from the model run is used for space heating. The chart also has lighting at 21%. The lighting energy usage from the HAP model is 8%. Cooling energy usage from EIA is about 8% of a commercial building. The lighting for the life sciences is much lower than the average commercial building, most likely because the building used more energy efficient fixtures. The energy usage for cooling from the model is about 24%. This is much higher than an average commercial building, most likely because of the various electrical equipment loads throughout the building being high.

Chart 5: Commercial Building Energy Consumption



Source: U.S. Energy Information Administration, *2003 Commercial Building Energy Consumption Survey*, Table E1A (September 2008).

Annual Emissions Footprint

Table 9 and 10 below show the emissions from delivered electricity and on-site combustion for the values from the Carrier HAP model. The electricity has a high emission of CO_2 and solid waste. The natural gas also has a high emission of CO_2. The emissions from the natural gas are most likely elevated during the winter months because of the heating load required. The emissions from the electricity are most likely elevated during the warmer months because of the cooling load and other electrical equipment.

Table 9: Emissions from Delivered Electricity

Emission Factors for Delivered Electricity			
Pollutant (lb)	Factors (lb of pollutant/kWh)	Electricity (kWh/year)	Emissions (lb of pollutant/year)
CO_{2e}	1.55	5952250	9225987.5
CO_2	1.48	5952250	8809330.0
CH_4	0.0027	5952250	16071.1
N_2O	0.0000322	5952250	191.7
NO_X	0.00291	5952250	17321.0
SO_X	0.00888	5952250	52856.0
CO	0.000601	5952250	3577.3
TNMOC	0.0000546	5952250	325.0
Lead	0.000000117	5952250	0.7
Mercury	0.000000027	5952250	0.2
PM10	0.0000714	5952250	425.0
Solid Waste	0.178	5952250	1059500.5

Table 10: Emissions from On-site Combustion

Emission Factors for On-Site Combustion			
Pollutant (lb)	Factors (lb of pollutant/1000 ft^3)	Natural Gas (1000 ft3/year)	Emissions (lb of pollutant/year)
CO_{2e}	123	8763	1077849.000
CO_2	122	8763	1069086.000
CH_4	0.0025	8763	21.908
N_2O	0.0025	8763	21.908
NO_X	0.111	8763	972.693
SO_X	0.000632	8763	5.538
CO	0.0933	8763	817.588
TNMOC	0.00613	8763	53.717
Lead	0.0000005	8763	0.004
Mercury	0.00000026	8763	0.002
PM10	0.0084	8763	73.609

The emission factor values used for this analysis can be found in the appendix.

Conclusion

The Life Sciences Building is a typical university building, but with a high amount of laboratory equipment and computer labs. After modeling the building with the design document values, the output values of the Carrier HAP model are close to the values from the design documents. Although the final number is only an approximate energy usage, it was close to a comparison of cost with the EIA. This model was used more as a check to see that the simulation was close to that of a similar building. Some of the main energy usage areas such as cooling and lighting were not close to the average commercial building usage. The cooling value was much larger because of the high miscellaneous loads from the laboratories, offices and computer labs. The lighting value was much lower because more efficient fixtures were used in this building. Overall the energy analysis was close to a typical university building.

References

ASHRAE Handbook of Fundamentals

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

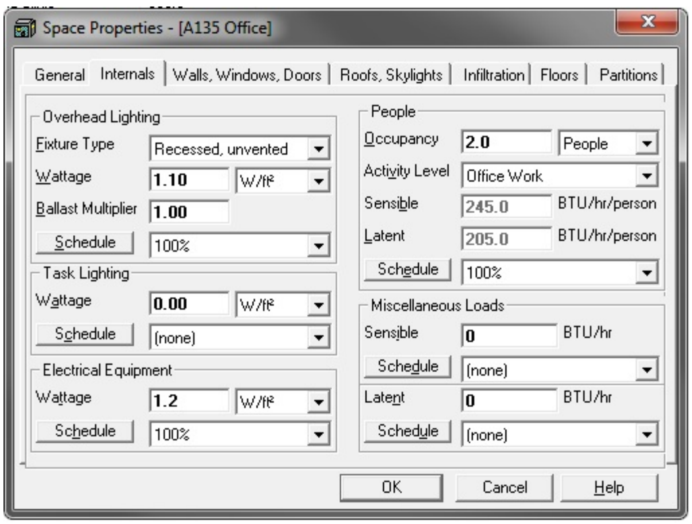
JDB Engineering. Mechanical Specifications. JDB Engineering, York, PA.

JDB Engineering. Mechanical Construction Documents. JDB Engineering, York, PA.

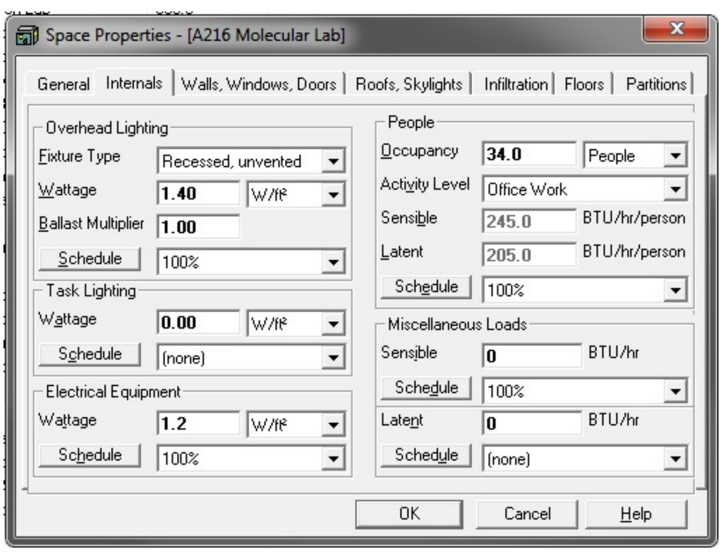
JDB Engineering. Electrical Construction Documents. JDB Engineering, York, PA.

APPENDIX A: Sample Carrier HAP Inputs

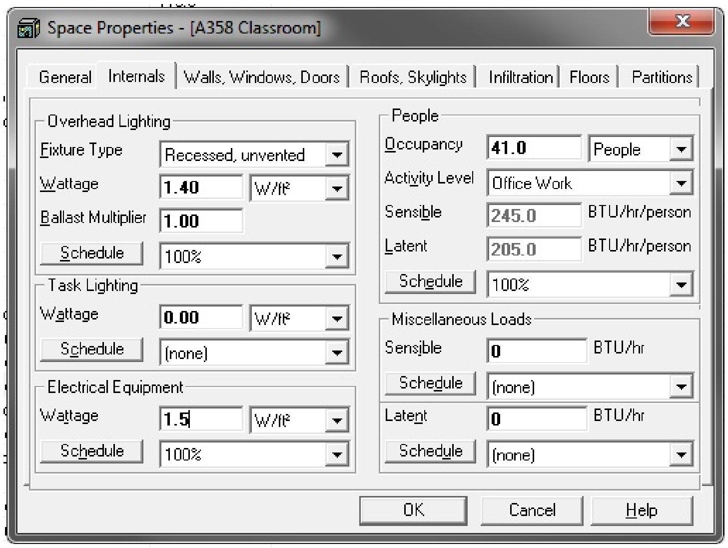
Typical Office



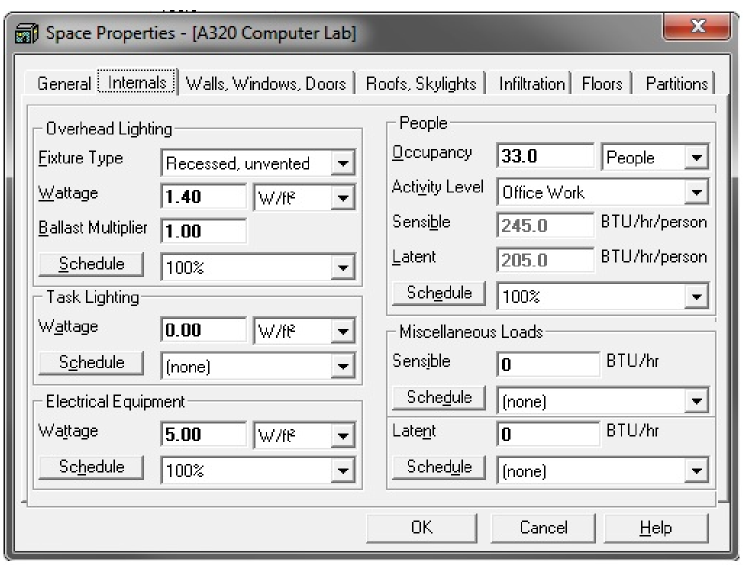
Typical Laboratory



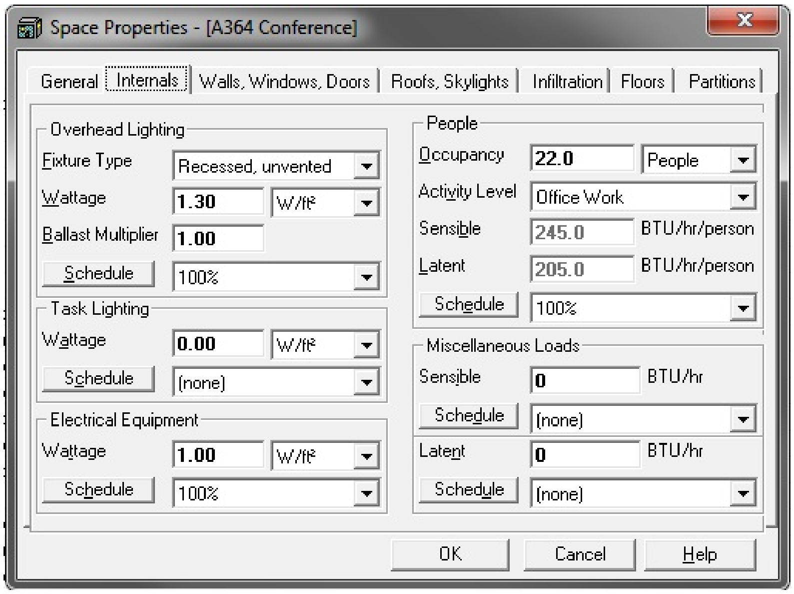
Typical Classroom



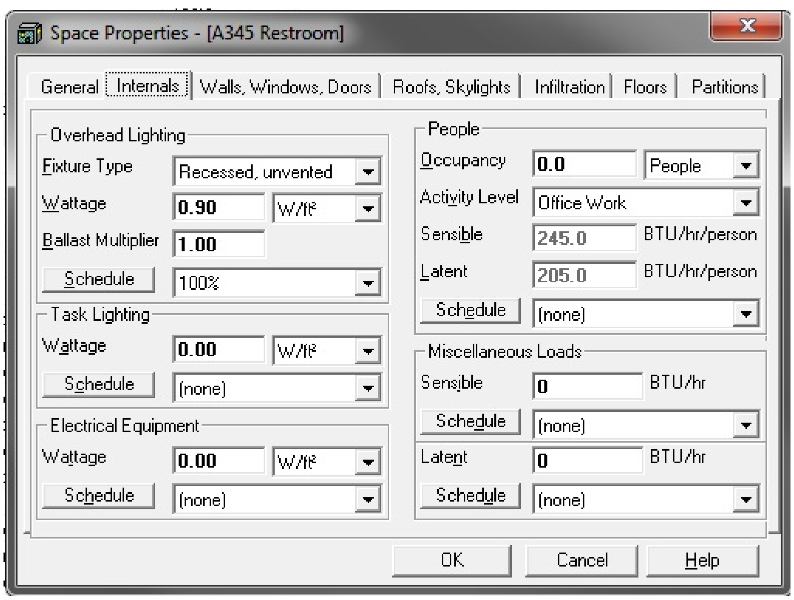
Typical Computer Lab



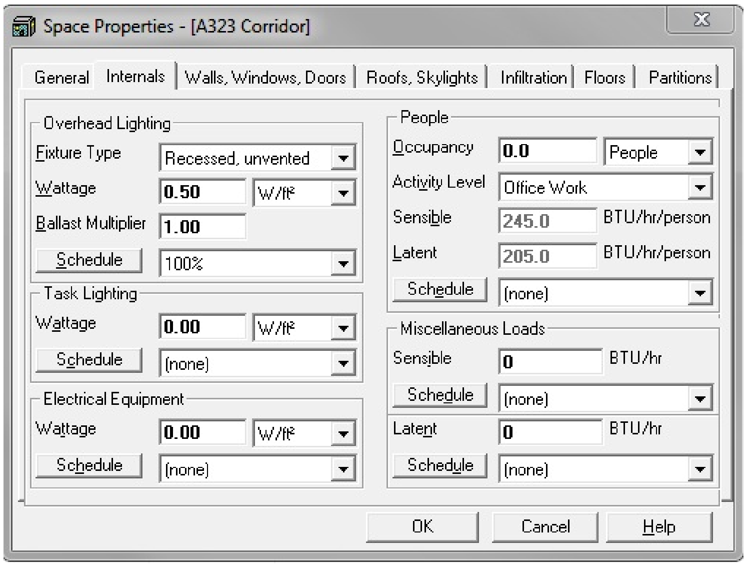
Typical Conference Room/Student Lounge



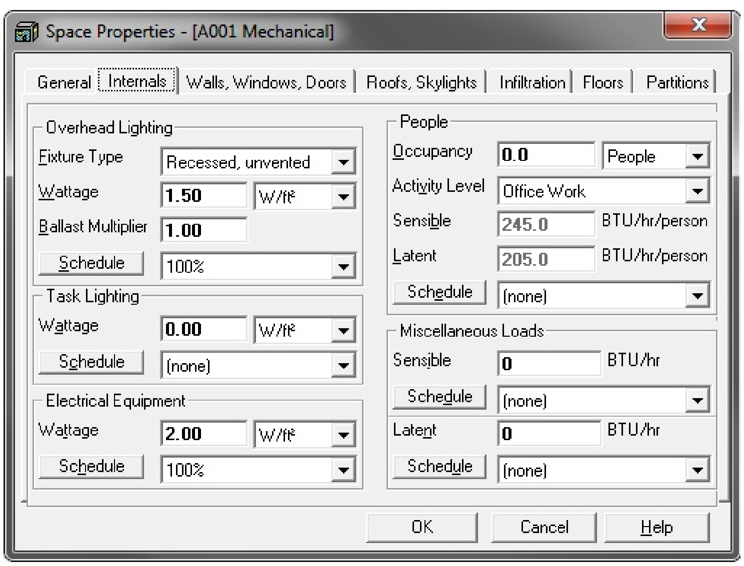
Typical Restroom



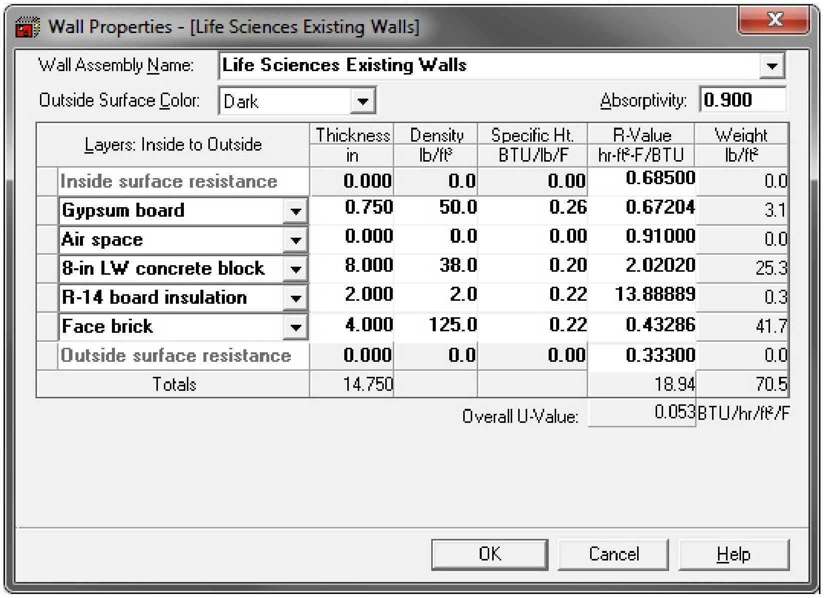
Typical Corridor



Typical Mechanical/Electrical

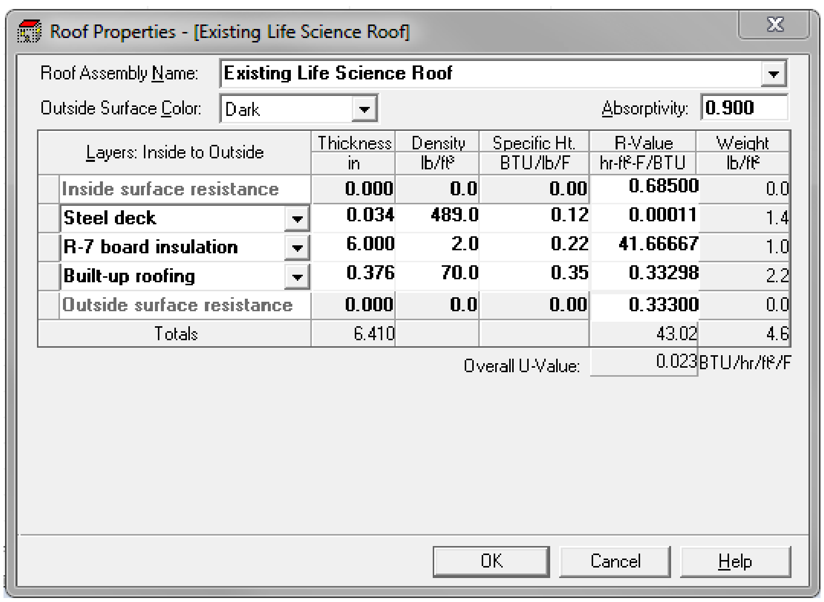


Wall Construction



Layers: Inside to Outside	Thickness in	Density lb/ft³	Specific Ht. BTU/lb/F	R-Value hr-ft²-F/BTU	Weight lb/ft²
Inside surface resistance	0.000	0.0	0.00	0.68500	0.0
Gypsum board	0.750	50.0	0.26	0.67204	3.1
Air space	0.000	0.0	0.00	0.91000	0.0
8-in LW concrete block	8.000	38.0	0.20	2.02020	25.3
R-14 board insulation	2.000	2.0	0.22	13.88889	0.3
Face brick	4.000	125.0	0.22	0.43286	41.7
Outside surface resistance	0.000	0.0	0.00	0.33300	0.0
Totals	14.750			18.94	70.5

Roof Construction



Layers: Inside to Outside	Thickness in	Density lb/ft³	Specific Ht. BTU/lb/F	R-Value hr-ft²-F/BTU	Weight lb/ft²
Inside surface resistance	0.000	0.0	0.00	0.68500	0.0
Steel deck	0.034	489.0	0.12	0.00011	1.4
R-7 board insulation	6.000	2.0	0.22	41.66667	1.0
Built-up roofing	0.376	70.0	0.35	0.33298	2.2
Outside surface resistance	0.000	0.0	0.00	0.33300	0.0
Totals	6.410			43.02	4.6

APPENDIX B: Emission Factor Tables

Delivered Energy Emission Factors

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

On-Site Combustion Emissions

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