University Medical Center of Princeton
Plainsboro, NJ

Technical Report Two

Building and Plant Energy Analysis Report

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Executive Summary

The purpose of this report is to show and explain the results of a block load analysis performed on the University Medical Center of Princeton bed tower. The analysis included creating a block heating and cooling model in Tran Trace700 and completing energy consumption and emissions calculations.

To create the block model, the construction documents of the medical center were used to gather the reauired data. To simplify the model, some repetitive spaces (ie. patient rooms) were grouped together into a single larger space. It was determined that this method provided a reasonable total load when compared to the detailed room by room model results created by Syska Hennessy.

From this block model the operating costs and emissions were calculated. Using utility rates from PSE&G, the annual cost to operate the building is approximately \$1.11 million or \$5.51/ft^2. To calculate the emissions, factors for CO_2, NO_x, SO_x, PM10, and CO_{2e} were taken from National Renewable Energy Laboratory. The annual CO_{2e} is estimated at 257 lb/ft^2.

The block model created is a reasonable evaluation of building loads. The Trace700 model provided a good estimate of the energy consumption when compared to the detailed model. The annual operating cost and emissions are therefore reasonable estimates. The details of all of the assumptions and results are found within this report.

Mechanical System Overview

The University Medical Center of Princeton has a large multi zone mechanical system to provide the required cooling and ventilation air for each type of space. There are 11 air handling units within the scope of this report (17 total for the building); eight of these units are atop the roof of the bed tower, while the other three are placed in the basement. The six roof top units supply 100% outside air and each is connected to its own heat recovery unit.

However, each floor is not serviced by its own air handler. The basement, first floor and lobby are supplied by the three basement units. The remainder of the building is separated into sectors. Each sector is supplied from its own air handler via a vertical supply shaft. See the Figure 1 so see how the sectors correspond to the building.

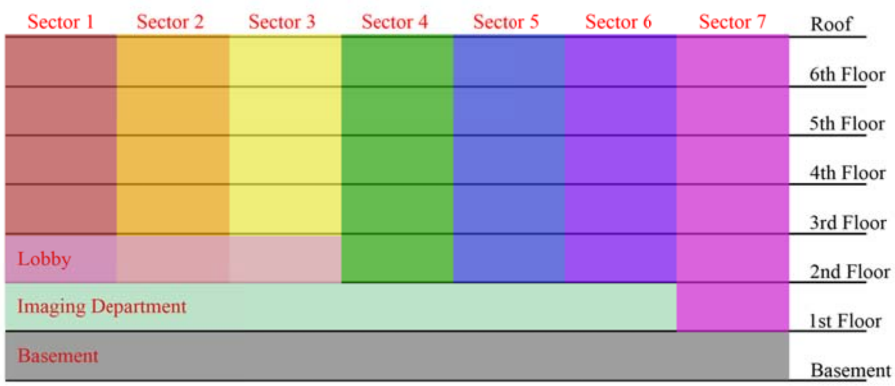

Figure 1. Sector Layout Diagram

The following table describes the designed sector and supply air for each air handler.

Design Sectors and Supply Air by AHU		
Air Handler	Sector	Supply Air (CFM)
AHU -1	Lobby	60,000
AHU -2	Imaging Department	35,000
AHU -4	Basement	33,000
AHU -7	Sector 1	46,000
AHU -8	Sector 2	50,000
AHU -9	Sector 3	35,000
AHU -10	Sector 4	42,000
AHU -11	Sector 5	50,000
AHU -12	Sector 6	30,000
AHU -13	Sector 7	30,000

Table 1. Designed Sectors and Supply Air

The hot and chilled water used by the air handlers is supplied by a central utility plant located next to the medical center. Steam provided from the utility plant is reduced from 120psi to 15psi on the sixth floor and used to generate hot water. The chilled water is used as supplied at 50.5 degrees Fahrenheit.

Design Load Estimation

The design load loads have been estimated using Trane Trace 700. Because of the size of the building, spaces of similar type were grouped together into a single larger space. This created an energy model with fewer "rooms" while still modeling the total area. To simplify the model further, the building was not broken down into sectors (as done by Syska Hennessy) but rather into individual floors. Table 2 lists a sample of the design assumptions used for these calculations.

Design Temperatures

The design temperatures were taken from ASHRAE. The interior design temperature is the ASHRAE default given in Trace700 and was used for the entire building. The exterior temperatures are the 0.4% and 99.6% design temperatures for Newark, NJ. Newark is the closest city to Plainsboro with ASHRAE data.

Internal Loads

The University Medical Center of Princeton has a variety of rooms. These rooms have very different lighting, and ventilation requirements as well as people densities. A room or two of each type was analyzed for lighting and people density. If the populations of the space could not be determined from the architectural drawings, values from ASHRAE Standard 62.1 Table 6-1 were used. The internal miscellaneous loads were estimated base on assumed equipment. These loads were then used for that room type throughout the building. A sample of rooms created can be seen in Appendix C.

Sample of Design Assumptions		
Interior Design Temp	Summer	72.3 °F
	Winter	72.0 °F
Exterior Design Temp	Summer (0.4%)	93.4 °F
	Winter (99.6%)	10.3 °F
Internal Load Lighting	Patient Room	0.9 Watt/ft^2
	Office/Conference	1.1 Watt/ft^2
	Treatment Room	1.5 Watt/ft^2
	Lobby/Corridor	0.9 Watt/ft^2
	Others	1.2 Watt/ft^2
Internal Load People	Patient Room	3 per room
	Office	2 per room
	Conference	4 per room
	Treatment Room	2 per room
	Lobby/Corridor	0 per room
Internal Load Misc.	Patient Room	1.2 W/ft^2
	Office/Conference	1.6 W/ft^2
	Treatment Room	2.0 W/ft^2
	Lobby/Corridor	0.0 W/ft^2
Construction	Wall U-value	0.084 Btu/h-ft^2-°F
	Roof U-value	0.214 Btu/h-ft^2-°F
	Window U-value	0.3 Btu/h-ft^2-°F
	Shading Coeff	0.33

Table 2. Sample of Design Assumptions

Construction Values

The construction values were either hand calculated or defined by Trace700. The wall construction values used are an average of the calculated Assembly U-Factors for the Brick on Metal Stud (0.039) and Glass Curtain Wall (0.13) found in Table 3 of Technical Report One. The roof and window U-values are Trace700 defaults for materials similar to those specified in the design documents.

Load Schedule

As is any hospital, the University Medical Center can be considered to be continuously operating. The schedules used for both heating and cooling are 100% at all times. This is because any and all of the spaces and equipment may in use simultaneously at any time during the day or night, weekday or weekend. The cooling season was considered to be January to December, while the heating season was set to an as needed basis.

System Assumptions

The system selected demonstrates the overall floor system. The system used for all floors is a constant volume non-mixing with terminal reheat, See Figure 2 below for a diagram. The only deviation from this type of system is the hot water heating only system used in the vestibules on the first floor. Because most floors had the same outdoor air requirements each floor was assumed to have only one system. An exception to this is the first floor which was broken into two systems (one for 31% OA and one for 100% OA). The design specifies for heat recovery units on air handlers 7-13; these were not modeled to demonstrate a worst case scenario.

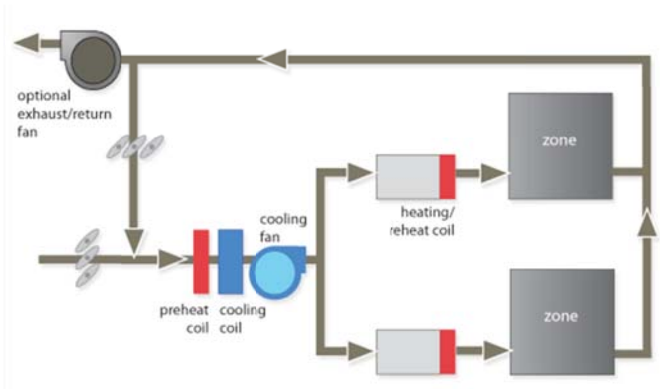

Figure 2. Schematic of modeled system in Trace700

The diagram shows return air before the exhaust fan, the 100% outside air units have no return air and no exhaust fan. However, the space is exhausted by the heat recover units to create a piston system. To account for this in the model, the system is specified to provide 100% outside air at all times.

Results Analysis

The findings of the simplified model as well as the detailed model done by Syska Hennessey are comparable. The variation in assumptions for the design data, space grouping, as well as the system selection creates acceptable differences in the calculated values. These differences in calculations are broken down and explained in detail within this section.

Adjustment of Syska Results

To compare apples to apples, the results of the Syska Hennessy model needed to be modified to fit those of the simplified block model. This issue arose from the simplified model assuming only one system per floor, where Syska Hennessy broke each floor into the sectors as described in the mechanical summary. The sector results of each floor from the Syska model were recalculated to a weighted average based on the floor area that each sector covered. Table 3 and 4 show a sample of how this averaging was completed.

Syska Model Results By Sector for Level 4				
Sector	Area	Cooling ft^2/ton	Heating Btu/ft^2	Supply cfm/ft^2
1	5135	132.53	59.38	1.10
2	7332	134.70	58.30	1.09
3	3796	76.09	103.08	1.96
4	5926	138.12	57.27	1.07
5	7366	94.48	81.42	1.55
6	3991	147.36	54.56	1.01
7	4159	142.22	56.98	1.04
Total Area	37705			

Table 3. Syska Model Results from Trace700

Weighted Average Values for Level 4				
Sector	% Total Area	% TotalArea * Cooling ft^2/ton	% Total Area * Heating Btu/ft^2	% Total Area * Supply cfm/ft^2
1	0.14	18.05	8.09	0.15
2	0.19	26.19	11.34	0.21
3	0.10	7.66	10.38	0.20
4	0.16	21.71	9.00	0.17
5	0.20	18.46	15.91	0.30
6	0.11	15.60	5.78	0.11
7	0.11	15.69	6.29	0.11
Totals	1.00	123.35	66.77	1.25

Table 4. Area Weighted Values and Totals

This same procedure was conducted for all 7 levels of the medical center. Although Syska modeled areas outside the scope of this report (outside of the bed tower) all of the values were used. The reason this is based on an assumption that the spaces outside the scope are similar to those within. The final result is a weighted average therefore possible skews from the other data is considered negligible.

Comparison to Simplified Block Model

After adjusting the design data created by the detailed Syska Hennessy model, a comparison was made to the simplified block model. The results varied from floor to floor. Over all the modeled values on Floors two, three, and four were very close. The remaining floors were off plus or minus 20%. Table 5 shows a summary of the results. The modeled values colored red are plus 20% of Syska's values; the modeled values colored green are minus 20% of Syska's values.

Modeled vs. Syska Design Building Loads by Floor								
	Cooling (ft^2/tons)		Heating (Btuh/ft^2)		Total Supply (cfm/ft^2)		Ventilation Air (cfm/ft^2)	
Floor - % Outside Air	Modeled	Syska Designed	Modeled	Syska Designed	Modeled	Syska Designed	Modeled	Syska Designed
Level 0 -31% OA	330	253	19	25	0.85	1.11	0.26	0.36
Level 1 -33% OA	345	210	44	34	2.15	1	0.66	1
Level 1 -100% OA	89	146	78	54	1.79	1.24	1.79	1.24
Level 2 -100% OA	104	118	73	67	1.43	1.37	1.43	1.37
Level 3 -100% OA	131	137	69	63	1.24	1.17	1.24	1.17
Level 4 -100% OA	131	123	69	67	1.24	1.25	1.24	1.25
Level 5 -100%OA	131	141	69	57	1.24	1.06	1.24	1.06
Level 6 -100% OA	78	106	150	71	1.81	1.37	1.81	1.37

Table 5. Simplified Model vs. the Detailed Syska Model by floor

The differences on the basement level (level 0) are among the greatest. The assumptions for the basement level were therefore the most deviant of the Syska design model. Analyzing the assumptions between the two models shows that the internal load created by lighting is approximately 10% higher on the block model. This combined with the fact that the scope covers a smaller area creates a higher cooling load per unit area. This also explains that lower heating load; because of the higher internal heat generated by the lights less heat is required.

Analysis of the level 1 -33% outside air values shows that the differences are attributed to the lack of area modeled. The area of the block model is about half of the Syska model. The reason for such a small area is that the majority of this level system is outside the scope of this report. The major loads of this level are generated within the bed tower from the large two story glass concourse. This causes the two models to have similar loads. The block model is over a smaller area and therefore the loads per unit area are much larger.

The difference in the level 1-100% outside air results demonstrates the effects of assuming smaller loads in the same square footage. After analyzing this zone, it was found that the simplified model covers the same area, but the misc. and people internal loads are smaller. The lower misc. loads can be attributed to the assumptions of the equipment placed within the space. It is clear that these equipment loads were underestimated and further research would be needed to accurately model them.

Levels two through five are within the 20% error of the Syska model, and most are within 10%. The reason for this can be attributed to the fact there are not areas outside the bed tower on these levels. An exception to this is level two which has additional area outside of the scope. This space consists of the same type of rooms that are within the bed tower.

Level six shows similar symptoms of that of the level 1-100% outside air. This can again be attributed to the under estimation of the internal equipment loads.

Concluding Remarks

In conclusion, it can be said that the assumption that the space outside of the scope of the bed tower is similar to that of the bed tower only holds true for part of the building. The basement and level one have a large area outside of the bed tower creating an error in the block model. However that does not mean that the simplified model is incorrect. Because the Syska analysis is based on weighted averages, the values for the spaces outside of the scope could skew the weighted average. The differences in level 1-100% outside air and level six are most likely attributed to inaccurate equipment assumptions in the block model. The differences almost balance over the scope of the entire bed tower. This means the block model can be used to analyze operating costs and emissions of the bed tower.

Energy Analysis

Using the simplified block model, calculations of the building energy consumption and costs were performed. The details of this analysis are in this section.

The University Medical Center of Princeton is fortunate to have its own central utility plant. The details of the equipment used in this plant were not available in time for this report, therefore general assumptions of equipment efficiencies were used. These efficiencies are listed in Table 6 below. The amount of electricity and natural gas to produce the required steam and chilled water for the HVAC system were calculated with these equipment assumptions.

Equipment Information					
Chiller Information			Boiler Information		
Brand:	Carrier		Brand:	Brunham	
Model:	19XRV		Model:	C series	
Nominal Tons:	1450		Output (MBh):	6695	
IPLV kW/ton:	0.35		Efficiency:	0.82	

Table 6. Equipment Efficiencies

The lighting densities used within the simplified model were used to estimate the annual lighting bills. Trace700 provided totaled value for the electricity consumption of the lights and misc. equipment loads. These values were then used to calculate the total electrical consumption.

The chiller and boiler were selected based on the estimated loads of the tower. The chiller is a Carrier water cooled centrifugal chiller. Two of this sized chiller would be needed to meet the estimated load. The boiler is a Brunham gas fired boiler. Three of these would be needed to meet the estimated demand.

The electricity consumption of the fans and motors were calculated based on the horse power of each unit. The horsepower was taken from the fan and motor schedules and converted to kilowatts.

The estimated demands from Trace700 were analyzed and adjusted with the efficiencies of the equipment in table 6. Table 7 shows a summary of these values. Each value was then prorated for an entire year and evaluated at current utility rates for the area of Plainsboro, NJ.

Energy Consumption Summary			
Equipment	Fuel	Consumption	units
Boiler	Nat. Gas	23	1000 ft3/hr
Chiller	Electricity	743	kWh
Fan/motor	Electricity	1569	kWh
Lighting and Misc.	Electricty	552	kWh

Table 7. Energy Consumption of the bed tower

The utility rates for the Plainsboro area were taken from the Public Service Electric and Gas Company (PSE&G). PSE&G is a major supplier of electricity and natural gas southern New Jersey. The totaled utility rates used are detailed below and were used to calculate the total yearly cost of each fuel type. The results of this calculation are summarized in table 8.

Gas:

Monthly Service Charge	$100.94 per Month
Distribution Charge	$0.2409 per therm for first therm
Distribution Charge	$0.1966 per therm for remaining

Electric:

Monthly Service Charge	$397.13 per Month
Distribution Charge	$0.0263 per kWh
Peak off season	$9.152 per kW
Peak on season	$16.556 per kW

Energy Cost Summary		
Equipment	Fuel	Total Cost per year
Boiler	Nat. Gas	$397,425.48
Chiller	Electricity	$279,006.16
Fan/motor	Electricity	$583,761.20
Lighting and Misc.	Electricity	$208,523.97
Total Cost		$1,468,716.82

Table 8. Calculated Yearly Operating Cost

The cost to operate a large building is very high. When this cost is broken down, it comes to $5.51 per ft^2. It is expected that a hospital will have higher operating cost, however not this high. A possible reasons for this is an over estimation of the cooling load found in the load calculations. The high cooling load shown in the basement and level 1 may have skewed the number.

This cost is also in accurate in the fact that the central utility plant will also be acting as a cogeneration plant. This will help offset the peak electrical loads of the building and send electricity back into the grid during periods of low demand. Even though this will reduce the electricity cost, it will increase the natural gas cost as that is most likely to be the fuel used to power a steam or gas turbine generator.

Emissions Analysis

The University Medical Center of Princeton is located in the NPCC region. This region is part of the Eastern Interconnection. This interconnection services the eastern half of the United States as shown in Appendix A. The total emission factors for delivered electricity and on-site boiler were taken from the National Renewable Energy Laboratory and are shown in Appendix B. The values for CO2, NOx, SOX, PM10, and CO_{2e} were used to calculate the estimated emissions of the building. A summary of these calculated emissions is found in table 9 and table 10.

Electricity Emisions per Year (Eastern)			
Yearly Usage kWh	*Emission*	*Emission Factor lb/kWh*	*Thousand pounds of per year*
25,088,640	*CO_2*	*1.64E+00*	*41,145.37*
	NO_x	*3.00E-03*	*75.27*
	SO_x	*8.57E-03*	*215.01*
	PM10	*9.26E-05*	*2.32*
	Co2e	*1.74E+00*	*43,654.23*

Table 9. Electricity Emission per year

Natural Gas Emisions per Year			
Yearly Usage 1000ft^3/h	Emission	Emission Factor lb/kWh	Thousand pounds of per year
201,480	CO_2	1.22E+02	24,580.56
	NO_x	1.11E-01	22.36
	SO_x	6.32E-04	0.13
	PM10	8.40E-03	1.69
	Co2e	1.23E+02	24,782.04

Table 10. Natural Gas Emissions per year

Resources

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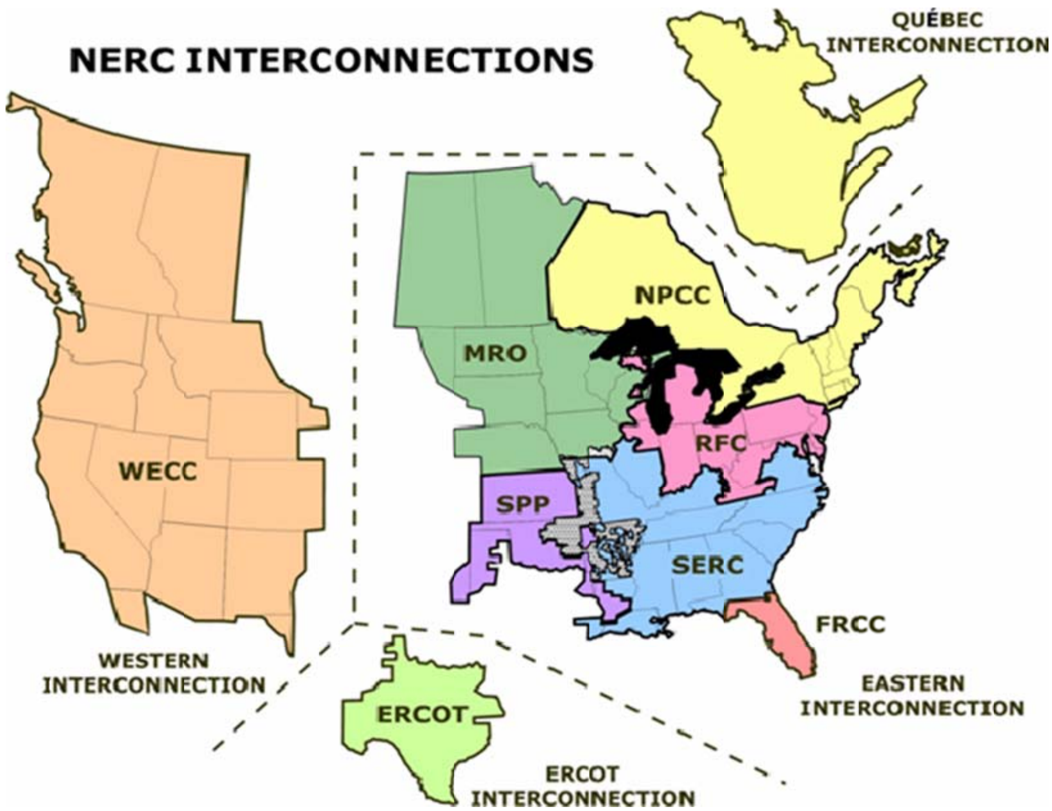
Appendix A


NERC INTERCONNECTIONS
QUÉBEC INTERCONNECTION
NPCC
MRO
RFC
WECC
SPP
SERC
FRCC
WESTERN INTERCONNECTION
EASTERN INTERCONNECTION
ERCOT
ERCOT INTERCONNECTION

Appendix B

Table 3 Total Emission Factors for Delivered Electricity
(lb of pollutant per kWh of electricity)

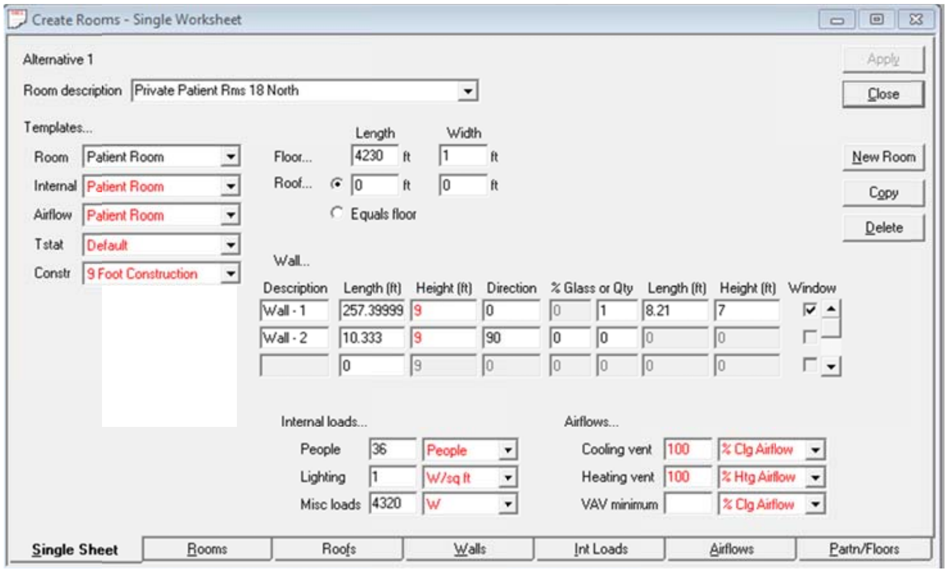
Pollutant (lb)	National	Eastern	Western	ERCOT	Alaska	Hawaii
CO_{2e}	1.67E+00	1.74E+00	1.31E+00	1.84E+00	1.71E+00	1.91E+00
CO_2	1.57E+00	1.64E+00	1.22E+00	1.71E+00	1.55E+00	1.83E+00
CH_4	3.71E-03	3.59E-03	3.51E-03	5.30E-03	6.28E-03	2.96E-03
N_2O	3.73E-05	3.87E-05	2.97E-05	4.02E-05	3.05E-05	2.00E-05
NO_X	2.76E-03	3.00E-03	1.95E-03	2.20E-03	1.95E-03	4.32E-03
SO_X	8.36E-03	8.57E-03	6.82E-03	9.70E-03	1.12E-02	8.36E-03
CO	8.05E-04	8.54E-04	5.46E-04	9.07E-04	2.05E-03	7.43E-03
TNMOC	7.13E-05	7.26E-05	6.45E-05	7.44E-05	8.40E-05	1.15E-04
Lead	1.31E-07	1.39E-07	8.95E-08	1.42E-07	6.30E-08	1.32E-07
Mercury	3.05E-08	3.36E-08	1.86E-08	2.79E-08	3.80E-08	1.72E-07
PM10	9.16E-05	9.26E-05	6.99E-05	1.30E-04	1.09E-04	1.79E-04
Solid Waste	1.90E-01	2.05E-01	1.39E-01	1.66E-01	7.89E-02	7.44E-02

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

Appendix C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Close
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Internal Patient Room
Airflow Patient Room
Tstat Default
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Roof... 0 ft 0 ft
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Copy
Delete
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Lighting 1 W/sq ft
Misc loads 4320 W
Airflows...
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Heating vent 100 % Htg Airflow
VAV minimum % Clg Airflow
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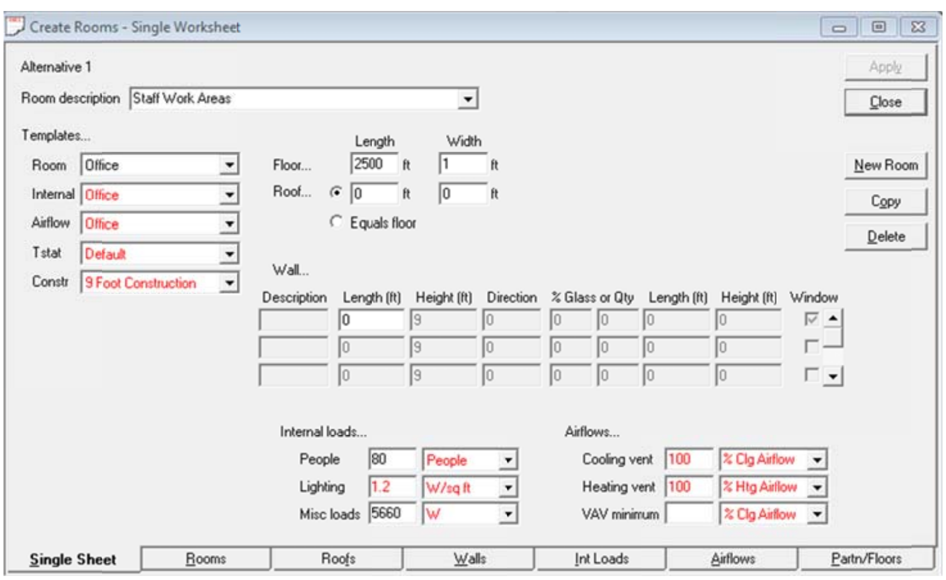
Rooms
Roofs
Walls
Int Loads
Airflows
Partn/Floors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Airflow Office
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0 9 0 0 0 0 0
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Misc loads 5660 W
Airflows...
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Heating vent 100 % Htg Airflow
VAV minimum % Clg Airflow
Single Sheet
Rooms
Roofs
Walls
Int Loads
Airflows
Partn/Floors