Technical Report 2

Building and Plant Energy Analysis

EMD Serono Research Center - existing | Billerica, MA

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1 Executive Summary

The purpose of this report is to perform a block load energy analysis to predict the energy consumption, energy cost and carbon footprint for EMD Serono Research Center – existing lab building. An energy model simulation was performed in Trane Trace 700. Block load analysis was chosen due to its simplicity and level of accuracy.

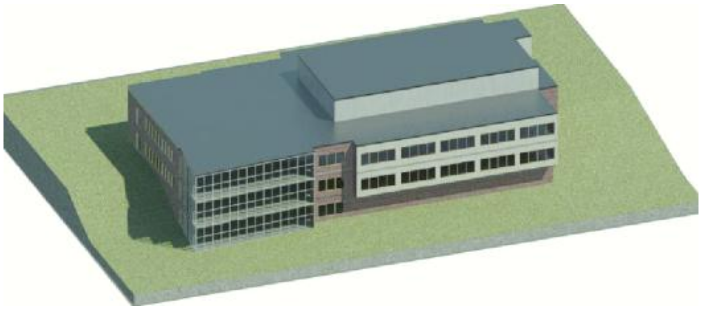
In order for the model to have comparable result when compared to the actual design, modeling data was taken from the actual design documents, such as design criteria, equipment load, and lighting loads. This building was divided into 5 types of spaces: lunch area, office area, mechanical room area, vivarium area, and research & development area. There are total of 9 blocks for this building. Blocks were assigned to 3 air handling units (AHU) according to the actual design.

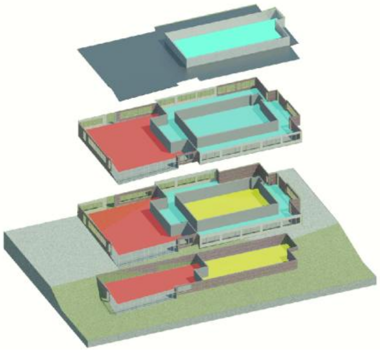
The resulting loads generated by the model were then compared to the actual design load. Some of the discrepancies in this energy analysis were higher heating load, higher cooling load, and higher ventilation rate. Variation from the design values was mainly due to the assumptions for block load modeling.

The total annual energy consumption for the EMD Serono Research Center-existing lab building is 4,721,208 kWh, with 3,610,276 kWh coming from electricity, 1,110,932 kWh (37907 therms) coming from natural gas. The annual water consumption for mechanical equipment of this building is 1,875,000 gallon. This building has a large equipment and lighting load, due to the fact that pharmaceutical research and development building has high electric demand of lab instruments and light.

The total energy consumption calculated for EMD Serono Research Center – existing lab building is $112,097/year, with $75,697/year coming from electricity, $34,525/year coming from gas, and $1875/year coming from water. Based on the energy consumption of the building, it will require $1.99/sf to operate annually.

Overall, the modeled energy simulation was within a reasonable range to the design. The biggest difference between the actual design and the model is the modeling method used. Room by room calculation method was used for the designed calculation versus block load method for the modeled calculation.





2 Building Summary

EMD Serono Research Center – existing lab building was constructed as the research and development building. This building has 2 stories, a basement, and a penthouse, with gross area of 56,700 square foot. The building program contains management office, research and development laboratories, and vivarium rooms. Mechanical rooms are located on the basement floor and in the penthouse. Vivarium facilities, research lab rooms, support rooms are located on both the 1st and 2nd floor.

3 Mechanical System Description

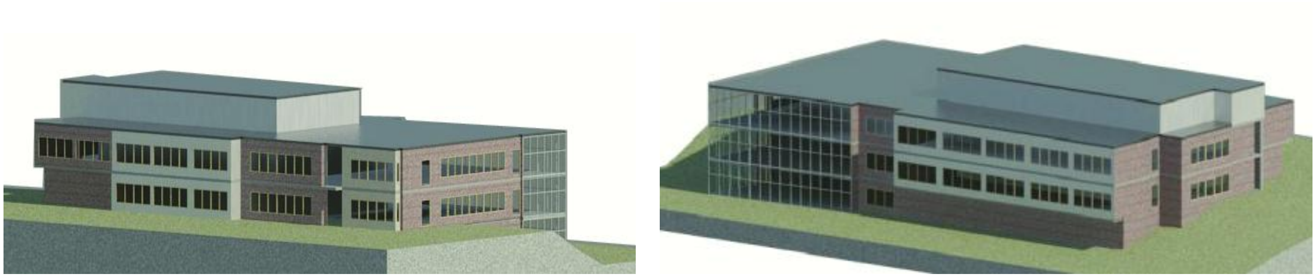
The building receives conditioned supply air from 3 air handling units (AHU). AHU-1 is located in the penthouse and supplies a total of 45,000 cfm conditioned outside air to research and development laboratory spaces in the building. The occupied spaces of the basement and administration offices on 1st and 2nd floor are conditioned by AHU-2 in the penthouse with 19,000 cfm total. The mechanical room in the basement and the vivarium rooms on the 1st floor are conditioned by AHU-3 which is located in the basement and supplies a total of 5,000 cfm.

One 350 ton centrifugal chiller is located in the basement. Two steam boilers and a boiler feed water pump are located in the penthouse. A 4200MBtuh cooling tower and a 60 ton air cooled chiller are located on the roof adjacent to the penthouse.

4 Design Load Estimation

Trane TRACE 700 Version 6.2 was used to determine the design load and energy consumption of the EMD Serono Research Center- existing lab building.

A simplified Revit model of this building was built based on the architectural drawing. Other design information such as building envelope, equipment load, outside air ventilation rate, and design criteria were input to the Trace model based on actual data taken from the design document



East and South Sides

South and Ease Sides

Figure-1 Revit Model of EMD Serono – Existing Lab Building

4.1 Block Load Assumption

A block load analysis was performed for this building. The advantages of using a block load analysis as opposed to a space by space analysis are calculation time reduction, manageable model file size, and reasonable accurate results.

The EMD Serono Research Center- existing lab building is comprised of a variety of areas such as office area, conference rooms, lobby, corridor, research and development lab, vivarium lab, and tissue culture rooms. In order to properly model the block load of this building, block were assigned to best represent the building function. There are 5 types of block with a total of 9 blocks. Lunch area, office area, mechanical room area, vivarium room area, and research & development area were selected as block types. In order to compare load results to the design air handling units' load, blocks were assigned to 3 air handling units (AHU) according to the actual design.

Some of the assumptions that were made during the creation of this block model are listed below.

1) Each block was calculated as one type of space. However, there are a variety of rooms in each block. For example, office block comprised of office rooms, conference room, lobby, corridors, and restroom.

2) Boston MA weather information was used as opposed to Billerica MA weather information.

Table-1 shows the list of blocks with the corresponding Air Handling Units. Figure-2 shows the block division in the building model.

AHU-1	AHU-2	AHU-3
3-1-AHU1-Mechanical	2-3-AHU2-Office	1-2-AHU3-Vivarium
2-1-AHU1-R&D	1-3-AHU2-Office	0-2-AHU3-Mechanical
2-2-AHU1-R&D	0-1-AHU2-Lunch Room	
1-1-AHU1-R&D		

Table-1 AHUs for Blocks

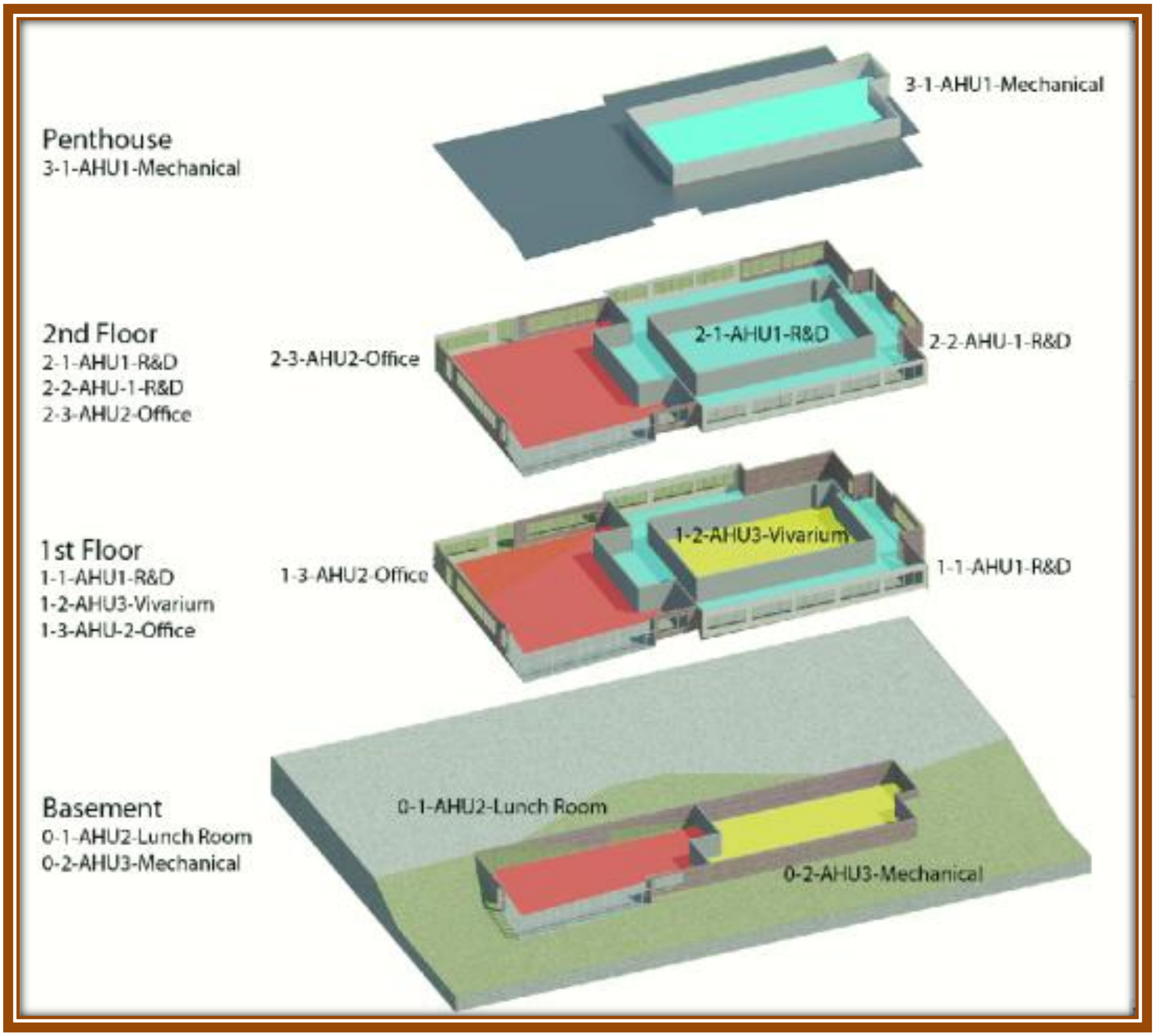


Figure-2 Building Block Division

4.2 Load Source and Modeling Information

4.2.1 Weather Data

Outdoor air conditions for heating and cooling for Boston, MA were used for this analysis. Weather conditions were taken from the ASHRAE Handbook of Fundamentals 2009, and they represented the 0.4% summer cooling design and 99.6% winter heating design.

Weather Data		
	Dry Bulb (F)	**Wet Bulb (F)**
Summer Design Cooling	**90.8**	**73.1**
Winter Design Heating	**7.7**	**N/A**

Table-2 Weather Data

4.2.2 Design Condition

Five types of blocks were selected because each block type has its unique design criteria from the design documents.

Design Criteria					
	Cooling DB (F)	**Cooling Driftpoint (F)**	**Heating DB (F)**	**Heating Driftpoint (F)**	**Relative Humidity (%)**
Office	**75**	**77**	**72**	**70**	**50**
Lunch	**75**	**77**	**72**	**70**	**50**
Mechanical	**10^{o} above ambient**	**N/A**	**65 minimum**	**N/A**	**50**
R&D	**72**	**74**	**72**	**70**	**47**
Vivarium	**72**	**74**	**72**	**70**	**47**

Table-3 Design Criteria

4.2.3 Building Envelope

Building envelope data were taken from the actual design documents and input into the Trace energy model to get comparable results.

Construction		
Location	**Type**	**U-factor (Btu/h-ft^{2}-F)**
Slab	**6” HW Concrete**	**0.53**
Roof	**Steel Sheet, 3.33” Ins**	**0.08**
Wall	**Face Brick, 4” LW Conc. Blk, 6’ Ins**	**0.04**

Table-4 Construction

Glass Type			
Location	Type	U-factor (Btu/h-ft^2-F)	Shading Coefficient
Window	Double Clear ¼”	0.6	0.82
Skylight	Double Clear ¼”	0.6	0.82

Table-5 Glass Type

Height	
Wall (ft.)	11.3
Floor to Floor (ft.)	14
Plenum (ft.)	2.7

Table-6 Height

4.2.4 Equipment Load and Lighting Load

The following equipment loads and lighting loads are taken from the design documents.

Load (Design Document)		
	Equipment Load (W/sf)	Lighting Load (W/sf)
Laboratories	10	2
Administration/Office	3.5	2
Lab Equipment Room	15	2
Animal Holding Room	N/A (15 AH/hr.)	N/A
Cage Washing	N/A (15 AH/hr.)	N/A
Corridor	2	1.5
Procedure Room	8	1.5

Table-7 Design Equipment and Lighting Loads

Adjustments were made for the block’s equipment and lighting loads to reflect the variety of rooms in each block.

Load (Block)		
	Equipment Load (W/sf)	Lighting Load (W/sf)
Office	3.5	2
Lunch	3.5	2
Mechanical	3.5	2
R&D	10	2
Vivarium	N/A (15 AH/hr.)	N/A

Table-8 Adjusted Equipment and Lighting Loads for Block Load Model

4.2.5 Outside Air Ventilation Rate

The table listed below shows the ventilation rate used in this energy analysis that was taken from the design document.

Outside Air Ventilation Rate	
	Outside Air Ventilation Rate (%)
Office	**20 cfm/occupant minimum**
Lunch	**20 cfm/occupant minimum**
Mechanical	**100**
R&D	**100**
Vivarium	**100**

Table-9 Outside Air Ventilation Rate

4.2.6 Design Occupancy

Design occupancy was not explicitly available for EMD Serono Research Center – existing lab building. Therefore, ASHRAE recommended occupancies were used in this analysis.

4.3 System Load Analysis Results

Design and modeled heating load, cooling load, and ventilation rates were compared in Table-10, Table-11, Table-12, and Table-13. Results were within a reasonable range when compared to design values. . One of the reasons that modeled values were different from design values is the use of simplified block load calculation method.

The modeled block heating load resulted in values that were greater than the actual design values. AHU-3 had the largest variation among the 3 air handling units. AHU-3 solely serves the vivarium block on the first floor during winter heating mode and serves both the mechanical block in the basement and the vivarium block during the summer cooling mode. The vivarium block comprised of animal holding room, cold room, instrument room, preparation rooms and corridor. Animal holding rooms have the highest heating demand among the other rooms. Calculation were done based on the animal holding room design criteria, which led to an over-estimated value of heating load on the vivarium block for AHU-3.

Heading Load						
	System Load			System Load/Area		
	Design	Model	Difference	Design	Model	Difference
	Mbh	Mbh	%	Mbh/sf	Mbh/sf	%
AHU-1	2126	2295	8%	0.08	0.09	8%
AHU-2	920	1004	9%	0.05	0.05	9%
AHU-3	320	526	64%	0.03	0.06	64%
Overall	3366	3825	14%	0.06	0.07	14%

Table-10 Heating Load Comparison

When comparing the design and modeled cooling loads, there was an average of 29% deviation. The main differences for this deviation are the outside air conditions and the cooling coil selections. The actual design cooling load was not given from the design document. Calculations were done to find the sensible and latent loads of the air handling units from the given entering and leaving air temperature of the cooling coil. As shown in Table-14, there were different entering and leaving air temperatures for design and modeled cooling coils in air handling units. 99.6% summer outdoor air conditions was taken from the ASHRAE Handbook of Fundamentals 2009 for the modeled load. The design calculation used different outdoor air conditions, therefore different entering air temperature for the cooling coil. The modeled air handling units have higher humidity ratio difference than the design air handling units which caused higher latent loads.

Cooling Load						
	System Load			Area/System Load		
	Design	Model	Difference	Design	Model	Difference
	Mbh	Mbh	%	SF/Ton	SF/Ton	%
AHU-1	3245	4125	27%	0.1	0.08	-21%
AHU-2	1039	1345	29%	0.23	0.18	-23%
AHU-3	307	465	51%	0.37	0.24	-34%
Overall	4592	5935	29%	0.15	0.11	-23%

Table-11 Cooling Load Comparison

Both AHU-1 and AHU-3 provides 100% outside air to their conditioned spaces. AHU-3 utilizes return air to the system. Two ventilation rate comparisons were done: outside air ventilation rate and total supply air rate comparisons. There was a slight variation on modeled outside air ventilation rates and the actual design rates. However, there was a large difference between the modeled total supply air rate and the designed rate for AHU-2. One of the reasons that these value differ significantly was due to the different temperature differences across the cooling coil on the airside stream. As shown in Table-14, modeled air temperature differences were around 10-20F lower than the temperature differences from the actual design data. Therefore, larger amount of air flow rate (cfm) were needed to meet to load requirement for lower temperature difference.

Total Ventilation (Cooling)							
	Type	Design OA	Design TA	Model OA	Model TA	Difference OA	Difference TA
		cfm	cfm	cfm	cfm	%	%
AHU-1	100%OA	45000	45000	39198	39198	-13%	-13%
AHU-2	With RA	6300	19000	7194	45976	14%	141%
AHU-3	100%OA	5000	5000	7829	7829	57%	57%
Overall		56300	69000	54221	92790	-4%	34%

Table-12 Ventilation Rate Comparison

Ventilation per Area (Cooling)							
	Type	Design OA	Design TA	Model OA	Model TA	Difference OA	Difference TA
		cfm/sf	cfm/sf	cfm/sf	cfm/sf	%	%
AHU-1	100%OA	1.68	1.68	1.46	1.46	-13%	-13%
AHU-2	With RA	0.31	0.95	0.36	2.28	14%	141%
AHU-3	100%OA	0.53	0.53	0.83	0.83	57%	57%
Overall		1	1.23	0.96	1.65	-4%	34%

Table-13 Ventilation Rate per Area Comparison

Cooling Coil Air Side Temperature												
	Design						Model					
	EDB	EWB	LDB	LWB	ΔW	ΔT	EDB	EWB	LDB	LWB	ΔW	ΔT
AHU-1	95	75	53	53	0.0062	39	88	78	45	45	0.0120	19
AHU-2	86	68	53	53	0.0026	29	77	66	58	58	0.0020	21
AHU-3	95	75	53	53	0.0062	39	88	78	69	63	0.0074	19

Table-14 Cooling Coil Air Side Temperature Comparison

4.4 Conclusion

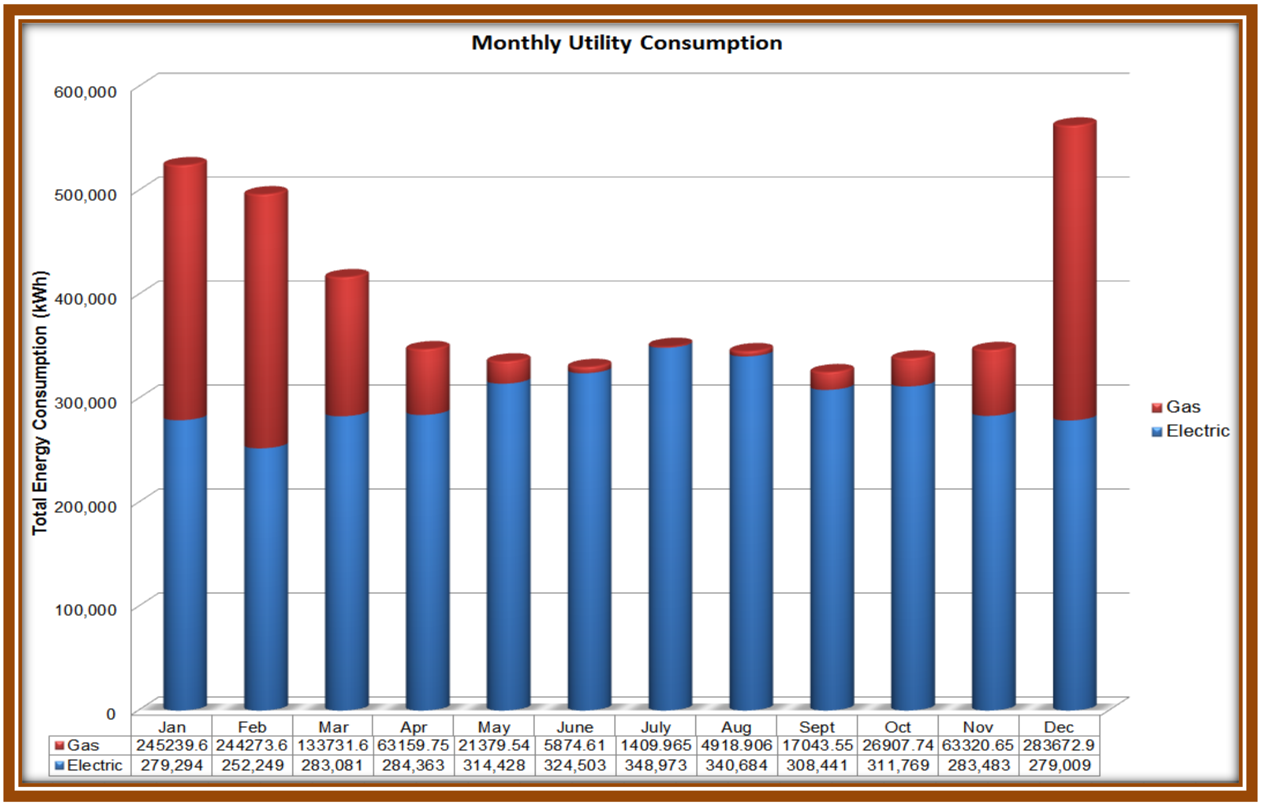
Block load energy analysis was performed for the EMD Serono Research Center – existing lab building using Trane Trace 700 energy simulation software. The building was divided into 5 types of spaces with a total of 9 blocks. Load sources and modeling information such as design criteria, equipment load, and lighting loads were taken from the actual design documents. Comparisons were done for actual design load and the modeled load. These results showed that the modeled heating load, cooling load, and ventilation rates were within a reasonable range while compared to the actual design.

5 Annual Energy Consumption and Operating Costs

The annual energy simulation analysis was performed for EMD Serono Research Center –existing lab building using the same Trace700 model. Cooling equipments use electricity to operate. water consumption is mainly come from the cooling tower operation. The gas fired central heating plant operates year-round. Low pressure steam boilers provide winter heating, humidification, and summer reheat for temperature control.

5.1 Annual Energy Consumption and Cost

Figure-3 shows the monthly gas and electric consumptions for the EMD Serono Research Center – exisiting lab building. There is large gas consumption during the winter time for space heating and minimal gas consumption during the summer time for cold supply air reheat. Maximum electric consumption occurs in July due to maximum cooling equipment operation. Electric consumption is fairly consistant throught out the year due to the large lab equipment load year-round. Water is used year round to operate cooling tower in the summer and humidify air in the winter. Figure-4 shows the montly water consumption for this builiding. Figure-5 shows the montly water, gas, and electric cost for the builiding. Figure-6 shows annual cost per square foot to operate the building. The average annual utility cost per area is 1.99$/sf.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
🟥 Gas	245239.6	244273.6	133731.6	63159.75	21379.54	5874.61	1409.965	4918.906	17043.55	26907.74	63320.65	283672.9
🟦 Electric	279,294	252,249	283,081	284,363	314,428	324,503	348,973	340,684	308,441	311,769	283,483	279,009

Figure-3 Annual Energy Consumption

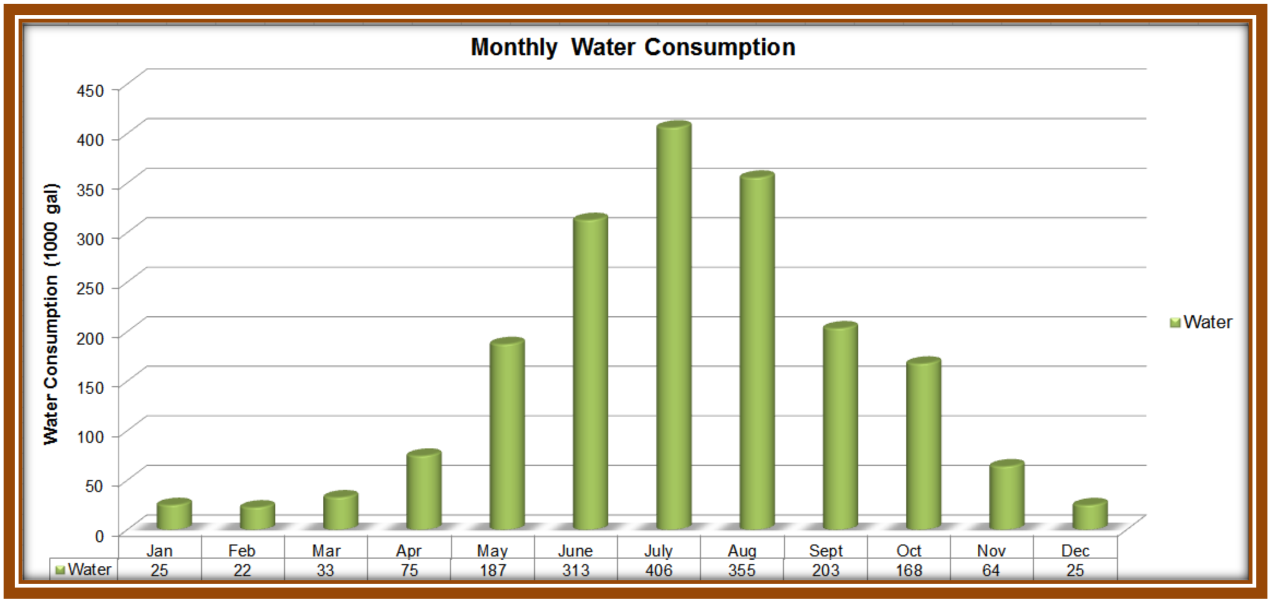


Figure-4 Annual Water Consumption

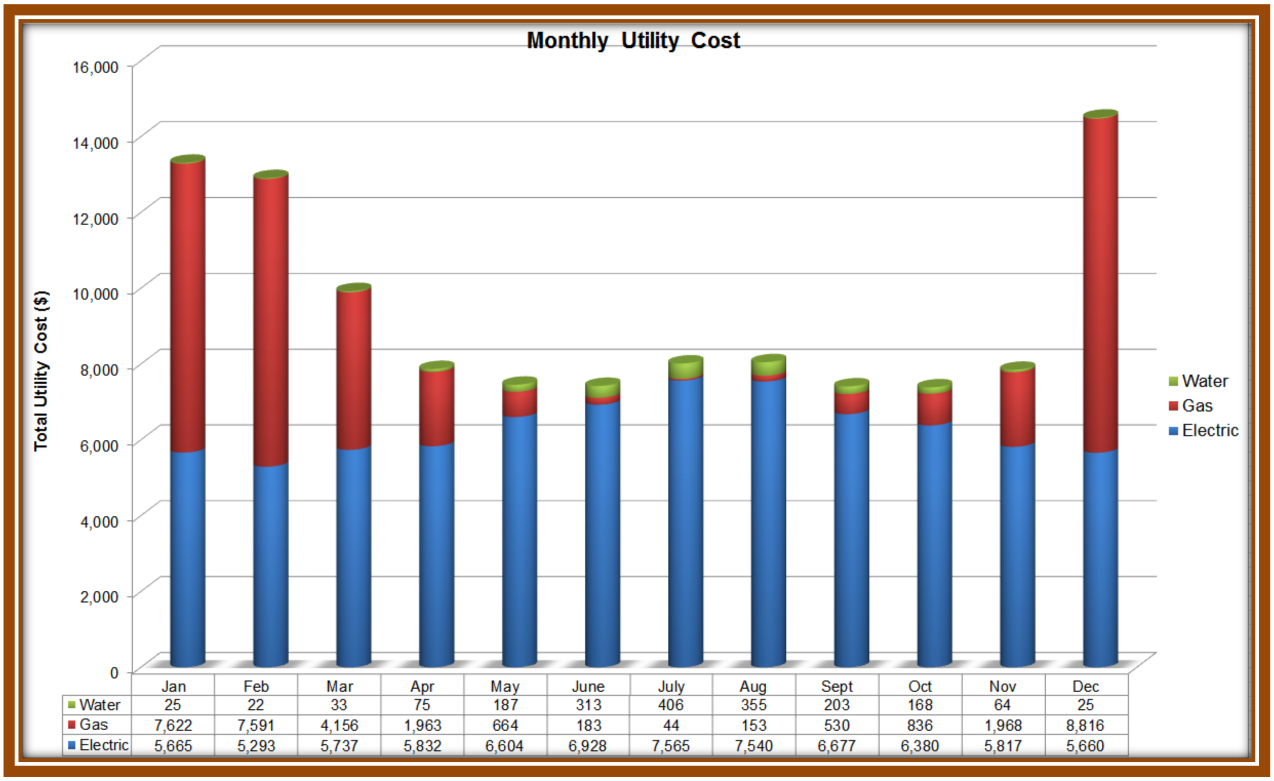


Figure-5 Annual Utility Cost

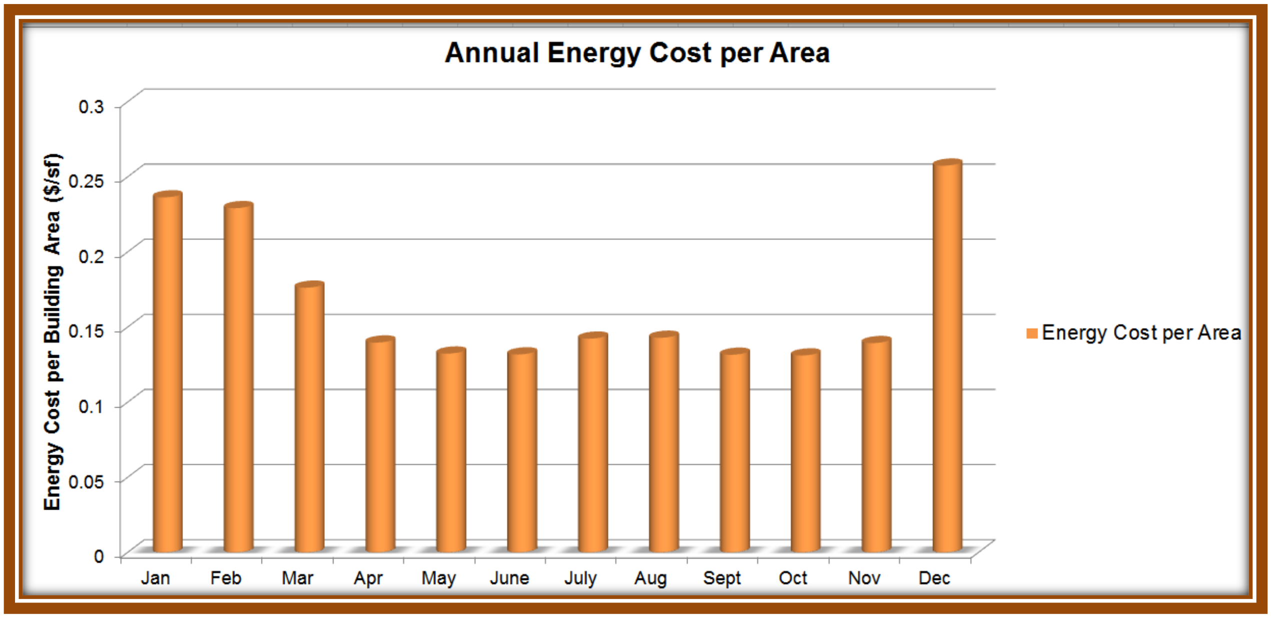


Figure-6 Annual Utility Cost per Area

5.1.1 Energy Analysis by Design Engineer

Energy analysis for this builidng was not performed by the design engineer. The analysis was not performed because it was not a LEED certified building and it was not required by code.

5.1.2 Fuel Costs

The primary electrical service to the building is provided by the Massachusetts Electric Company. Since the building has a electrical demand of 1158kW, greater than 200kW, it is qualify for the Time-of-Use(G-3) electric rate.

$0.9108/therm was used as the natural gas rate. This gas rate was taken from the National Grid for Boston area with G-42-Low Load Factor General Service Rate-Medium building type.

Electricity Rate	
Customer Charge	$200.00/month
Distribution Demand Charge	$3.92/kW
Distribution Charge	
Peak Hours	1.374¢/kWh
Off-Peak Hours	0.621¢/kWh
Transmission Charge	1.328¢/kWh
Transition Energy Charge	0.030¢/kWh
Energy Efficiency Charge	0.433¢/kWh
Renewables Charge	0.050¢/kWh

Table-15 Electric Rate for Time-of-Use (G-3) Building

5.1.3 Schedule

Schedules were based on a typical office space provided by the Trace software.

Equipment Operation Schedule		
Start Time	End Time	Status
Midnight	5 a.m.	Storage
5 a.m.	6 a.m.	Off
6 a.m.	6 p.m.	Normal
6 p.m.	Midnight	Storage

Light Operation Schedule		
Start Time	End Time	Percentage
Midnight	6 a.m.	0
6 a.m.	7 a.m.	10
7 a.m.	8 a.m.	50
8 a.m.	5 p.m.	100
5 p.m.	6 p.m.	50
6 p.m.	7 p.m.	10
7 p.m.	Midnight	0

Occupancy Schedule		
Start Time	End Time	Percentage
Midnight	6 a.m.	0
6 a.m.	7 a.m.	10
7 a.m.	8 a.m.	30
8 a.m.	5 p.m.	100
5 p.m.	6 p.m.	30
6 p.m.	7 p.m.	10
7 p.m.	Midnight	0

Table-16 Equipment Operation, Lighting, and Occupancy Schedule

5.1.4 Equipment Performance Characteristics

The following tables shows the equipment performance characteristics that were used in the energy model. All the informations were taken from the actual desing schedules.

Equipment Characteristics		
	Air Flow (cfm)	Water Flow (GPM)
AHU-1	45,000	675
AHU-2	19,000	155
AHU-3	5,000	70

	Capacity (Ton)	GPM	BHP
Cooling Tower	5,000	70	50

	Capacity (Ton)	Energy Rate (kW/Ton)
Centrifugal Chiller	350	0.56
Air Cooled Chiller	60	1.24

	Capacity (Mbh)	Efficiency (%)
Boiler 1	6400	81%
Boiler 2	1600	81%

	Capacity (GAL)	GPM	RMP
Boiler Feeder	200	28/10	1750

	Capacity (GAL)	GPM	Number of Pumps
Condensate Pump 1	45	4	2
Condensate Pump 2	22 1/2	8	2

	GPM	MHP
Water Pump 1	840	20
Water Pump 2 (2)	135	3
Water Pump 3 (2)	1050	15
Water Pump 4 (2)	225	5

Table-17 Equipment Characteristics

5.2 System Energy Breakdown

The EMD Serono Research Center – existing lab building has a significant receptable and lighting load. Since this building is a pharmarchutical research facility, large equipment load and lighting loads are demanded. The equipment load for this builidng has a range of 3.5 to 10 W/sf while the average lighting laod is 2 W/sf. Figure-6shows the enegry breakdown of the building. Figure-7 shows HVAC energy consumption breakdown.

Energy Breakdown		
	Total Building Energy (kBtu/yr)	Percentage (%)
Primary Heating	3,980,583	25%
Primacy Cooling	1,135,188	7%
Auxiliary	876,000	5%
Lighting	2,395,708	15%
Receptacle	7,725,055	48%
Total	16,112,534	100%

Table-18 Energy Consumption Breakdown

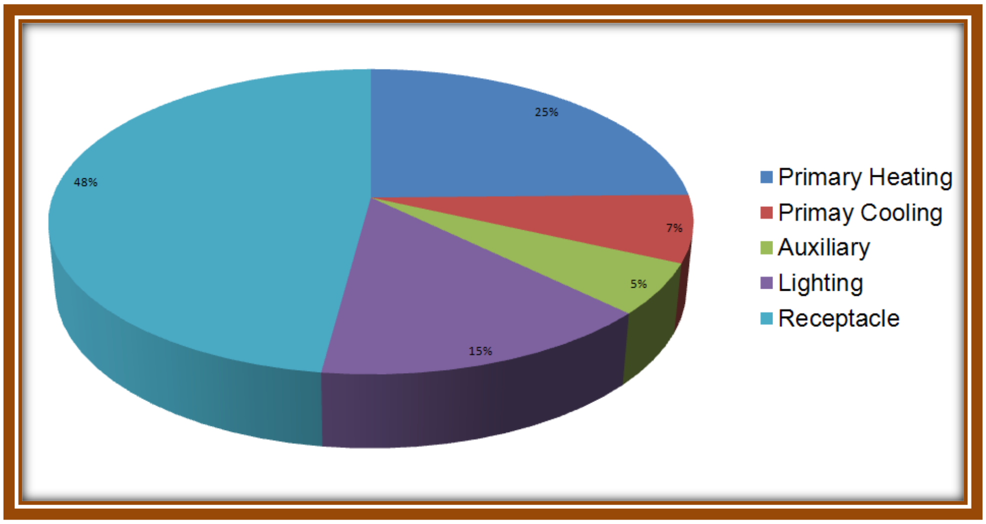
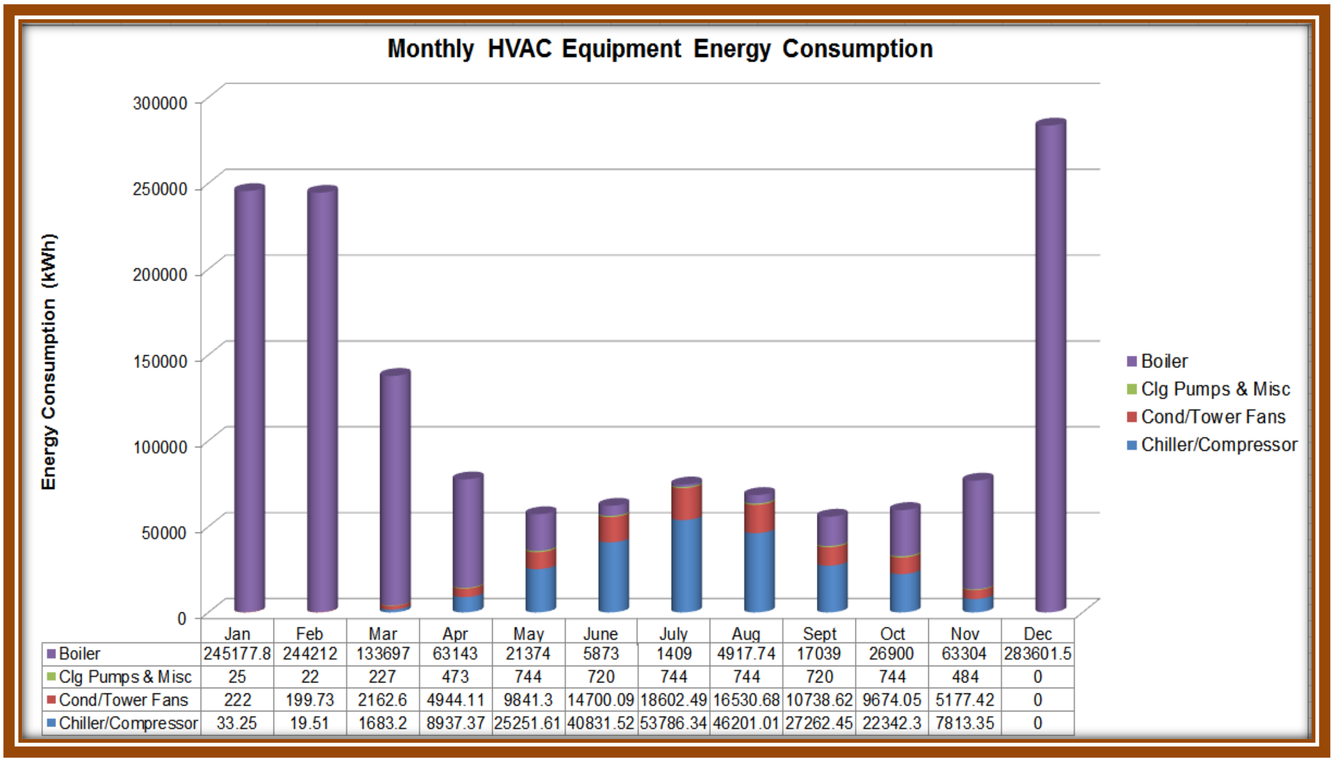


Figure-7 Building Energy Breakdown

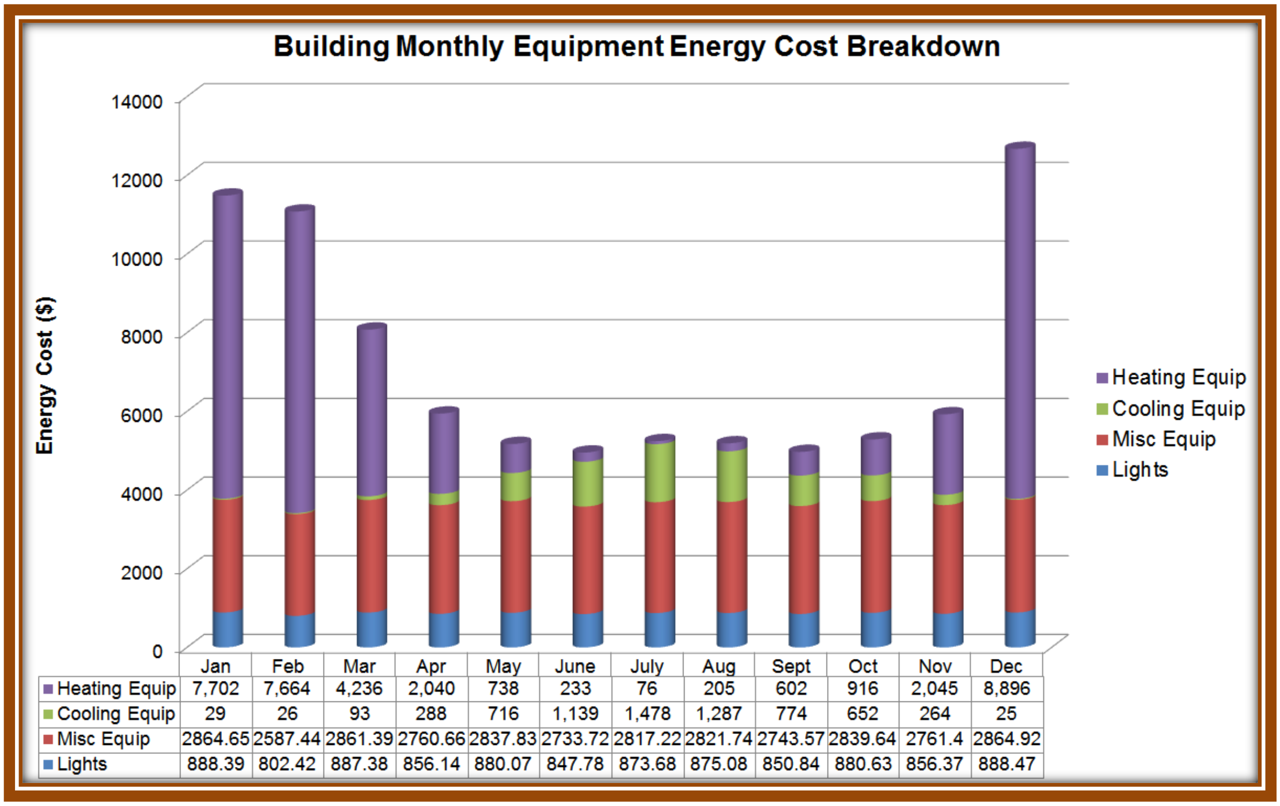


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Boiler	245177.8	244212	133697	63143	21374	5873	1409	4917.74	17039	26900	63304	283601.5
Clg Pumps & Misc	25	22	227	473	744	720	744	744	720	744	484	0
Cond/Tower Fans	222	199.73	2162.6	4944.11	9841.3	14700.09	18602.49	16530.68	10738.62	9674.05	5177.42	0
Chiller/Compressor	33.25	19.51	1683.2	8937.37	25251.61	40831.52	53786.34	46201.01	27262.45	22342.3	7813.35	0

Figure-8 HVAC Energy Consumption

5.3 System Cost Breakdown

Figure-7 shows the cost associated with energy usage. The highest percentage of cost came from the heating equipment and followed by miscellaneous equipment. The reason for the high cost of heating equipment is the high cost of gas compared to electricity.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Heating Equip	7,702	7,664	4,236	2,040	738	233	76	205	602	916	2,045	8,896
Cooling Equip	29	26	93	288	716	1,139	1,478	1,287	774	652	264	25
Misc Equip	2864.65	2587.44	2861.39	2760.66	2837.83	2733.72	2817.22	2821.74	2743.57	2839.64	2761.4	2864.92
Lights	888.39	802.42	887.38	856.14	880.07	847.78	873.68	875.08	850.84	880.63	856.37	888.47

Figure-9 HVAC Energy Consumption

Energy Cost Breakdown		
	Annual Energy Cost ($/yr)	Percentage (%)
Lighting	10387	12%
Misc. Equipment	33494	39%
Cooling Equipment	6770	8%
Heating Equipment	35353	41%

Table-19 Energy Cost Breakdown

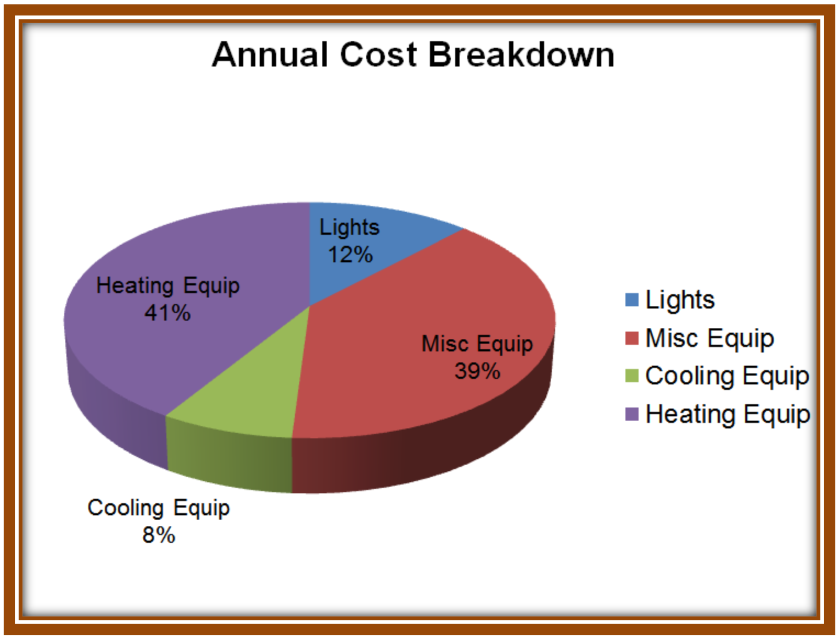


Figure-10 Annual Energy Cost Breakdown

5.4 Conclusion

Analyses for annual energy consumption and annual utility cost were done. Electricity rates and gas rates that were used in this analysis were taken from the National Grid for Massachusetts. System energy consumption and energy cost breakdown analyses were also performed in this report. Results showed that the EMD Serono Research Center – existing lab building has large plug load and lighting load. This was due to that fact that pharmaceutical research and development building has high electric demand for lab instruments and light. Heating equipment has the highest percentage on energy cost due to the high cost of natural gas.

6 System Pollution Emission

6.1 System Pollution Emission

Values for the emission factors were taken form the “Regional Grid Emission Factors 2007”for the Eastern region. The total pollution emissions that are generated from EMD Serono Research Center-existing lab building were due to the use of electricity and natural gas. The total pollution emissions are generated by delivered electricity, delivered natural gas, and on-site combustion in gas-fired boilers. 3,610,276 kWH of electricity and 37907 therm were used for this analysis.

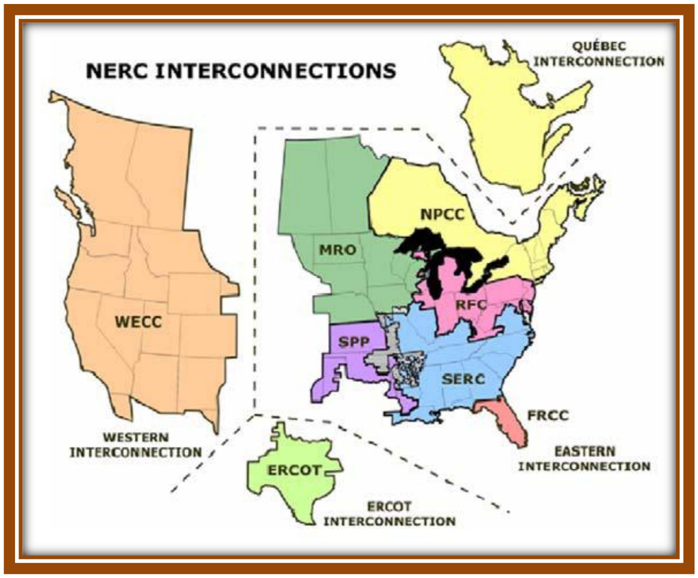


Figure-9 North American Electric Grid Connections, Including the 10 NERC Regional Reliability Councils (NERC 2007)

Emission for Delivered Electricity		
Pollutant	**lb./kWh**	**lb.**
CO_{2e}	1.74	6.28E+06
CO_2	1.64	5.92E+06
CH_4	3.59	1.30E+07
N_2O	3.87	1.40E+07
NO_x	3	1.08E+07
SO_x	8.57	3.09E+07
CO	8.54	3.08E+07
TNMOC	7.26	2.62E+07
Lead	1.39	5.02E+06
Mercury	3.36	1.21E+07
PM10	9.26	3.34E+07
Solid Waste	2.05	7.40E+06

Table-20 Emission for Delivered Electricity

	Precombustion Emission for Natural Gas Delivered to Bldg		Emission for On-Site Combustion in a Commercial Boiler	
Pollutant	**Lbm/1000cf**	**Lbm**	**Lbm/1000cf**	**Lbm**
CO_{2e}	2.08E+01	7.62E+04	1.9700E+00	7.2212E+03
CO_2	1.16E+01	4.25E+04	1.9600E+00	7.1846E+03
CH_4	7.04E-01	2.58E+03	4.0000E-05	1.4662E-01
N_2O	2.35E-04	8.61E-01	4.0000E-05	1.4662E-01
NO_x	1.64E-02	6.01E+01	1.7800E-03	6.5248E+00
SO_x	1.22E+00	4.47E+03	1.0100E-05	3.7023E-02
CO	1.36E-02	4.99E+01	1.5000E-03	5.4984E+00
TNMOC	4.56E-05	1.67E-01	9.8200E-05	3.5996E-01
Lead	2.41E-07	8.83E-04	8.0100E-09	2.9362E-05
Mercury	5.51E-08	2.02E-04	4.1600E-09	1.5249E-05
PM10	8.17E-04	2.99E+00	1.3500E-04	4.9486E-01
PM-unspecified	1.42E-03	5.21E+00		
Solid Waste	1.60E+00	5.86E+03		

Table-21 Precombustion Emission for Natural Gas Delivered to Building and Emission for On-Site Combustion in a Commercial Boiler

Total Emission for Building	
Pollutant	**Lbm**
CO_{2e}	6.37E+06
CO_2	5.97E+06
CH_4	1.30E+07
N_2O	1.40E+07
NO_x	1.08E+07
SO_x	3.09E+07
CO	3.08E+07
TNMOC	2.62E+07
Lead	5.02E+06
Mercury	1.21E+07
PM10	3.34E+07
PM-unspecified	5.21E+00
Solid Waste	7.41E+06

Table-22 Total Emission for Building

6.2 Conclusion

System pollution emission analysis was performed for the EMD Serono Research Center – existing lab building. This building has an annual emission of 5.97E6 lbm CO_2/year, 1.08E7 lbm NO_x/year, and 3.09E7 lbm SO_x/year.

References

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Torcellini, M. D. (June 2007). Source Energy and Emission Factors for Energy Use in Buildigns. Golden, Colorado: National Renewable Energy Laboratory.

Appendix A: List of Tables and Figures

List of Tables

List of Figure

Appendix B

Supplemental Tables

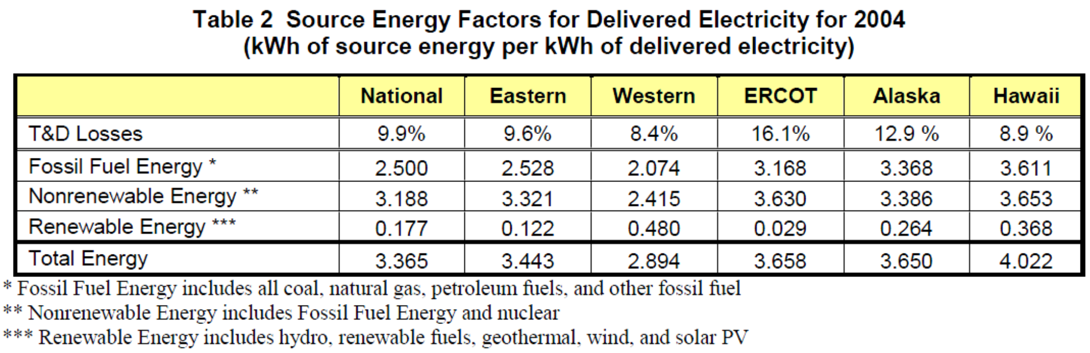


Table 2 Source Energy Factors for Delivered Electricity for 2004
(kWh of source energy per kWh of delivered electricity)

	National	Eastern	Western	ERCOT	Alaska	Hawaii
T&D Losses	9.9%	9.6%	8.4%	16.1%	12.9 %	8.9 %
Fossil Fuel Energy *	2.500	2.528	2.074	3.168	3.368	3.611
Nonrenewable Energy **	3.188	3.321	2.415	3.630	3.386	3.653
Renewable Energy ***	0.177	0.122	0.480	0.029	0.264	0.368
Total Energy	3.365	3.443	2.894	3.658	3.650	4.022

* Fossil Fuel Energy includes all coal, natural gas, petroleum fuels, and other fossil fuel
** Nonrenewable Energy includes Fossil Fuel Energy and nuclear
*** Renewable Energy includes hydro, renewable fuels, geothermal, wind, and solar PV

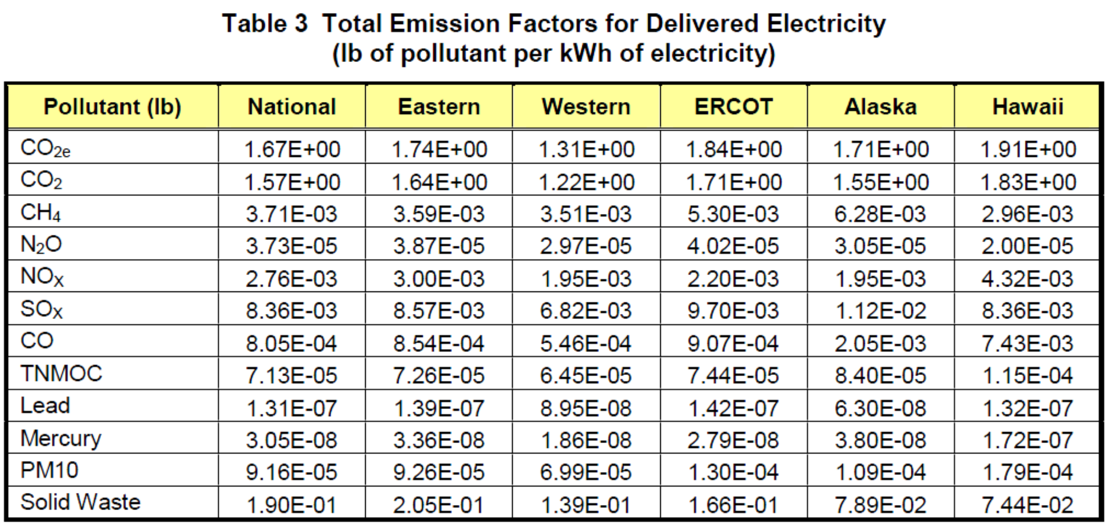
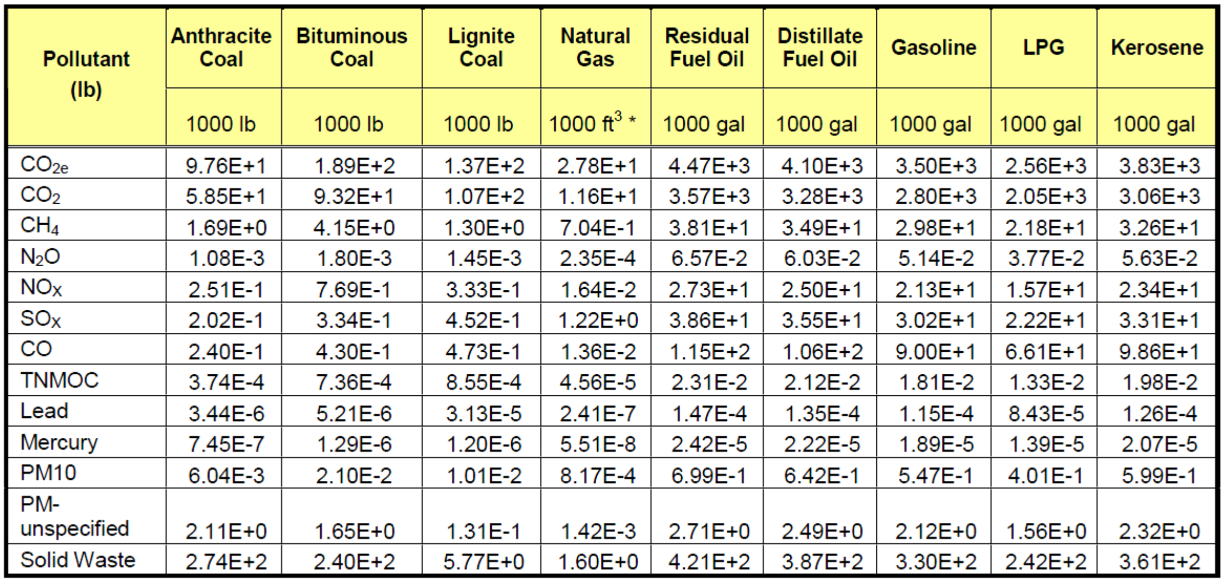


Table 3 Total Emission Factors for Delivered Electricity
(lb of pollutant per kWh of electricity)

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

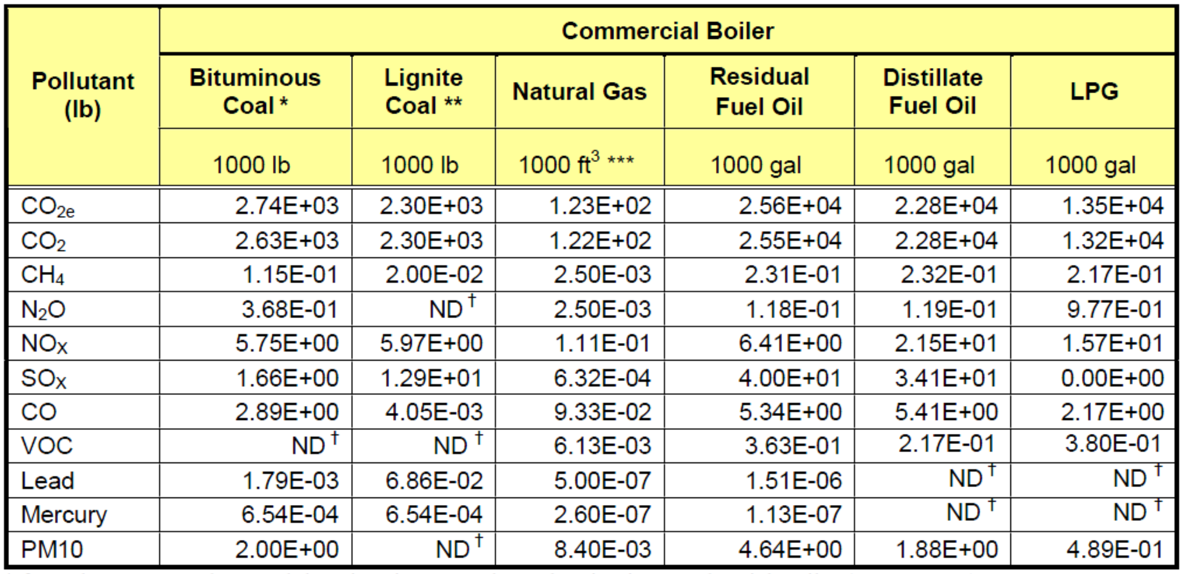
Table 6 Precombustion Emission Factors for Fuel Delivered to Buildings
(lb of pollutant per unit of fuel)



Pollutant (lb)	Anthracite Coal	Bituminous Coal	Lignite Coal	Natural Gas	Residual Fuel Oil	Distillate Fuel Oil	Gasoline	LPG	Kerosene
	1000 lb	1000 lb	1000 lb	1000 ft^3 *	1000 gal	1000 gal	1000 gal	1000 gal	1000 gal
CO_{2e}	9.76E+1	1.89E+2	1.37E+2	2.78E+1	4.47E+3	4.10E+3	3.50E+3	2.56E+3	3.83E+3
CO_2	5.85E+1	9.32E+1	1.07E+2	1.16E+1	3.57E+3	3.28E+3	2.80E+3	2.05E+3	3.06E+3
CH_4	1.69E+0	4.15E+0	1.30E+0	7.04E-1	3.81E+1	3.49E+1	2.98E+1	2.18E+1	3.26E+1
N_2O	1.08E-3	1.80E-3	1.45E-3	2.35E-4	6.57E-2	6.03E-2	5.14E-2	3.77E-2	5.63E-2
NO_X	2.51E-1	7.69E-1	3.33E-1	1.64E-2	2.73E+1	2.50E+1	2.13E+1	1.57E+1	2.34E+1
SO_X	2.02E-1	3.34E-1	4.52E-1	1.22E+0	3.86E+1	3.55E+1	3.02E+1	2.22E+1	3.31E+1
CO	2.40E-1	4.30E-1	4.73E-1	1.36E-2	1.15E+2	1.06E+2	9.00E+1	6.61E+1	9.86E+1
TNMOC	3.74E-4	7.36E-4	8.55E-4	4.56E-5	2.31E-2	2.12E-2	1.81E-2	1.33E-2	1.98E-2
Lead	3.44E-6	5.21E-6	3.13E-5	2.41E-7	1.47E-4	1.35E-4	1.15E-4	8.43E-5	1.26E-4
Mercury	7.45E-7	1.29E-6	1.20E-6	5.51E-8	2.42E-5	2.22E-5	1.89E-5	1.39E-5	2.07E-5
PM10	6.04E-3	2.10E-2	1.01E-2	8.17E-4	6.99E-1	6.42E-1	5.47E-1	4.01E-1	5.99E-1
PM-unspecified	2.11E+0	1.65E+0	1.31E-1	1.42E-3	2.71E+0	2.49E+0	2.12E+0	1.56E+0	2.32E+0
Solid Waste	2.74E+2	2.40E+2	5.77E+0	1.60E+0	4.21E+2	3.87E+2	3.30E+2	2.42E+2	3.61E+2

* Gas volume at 60°F and 14.70 psia.

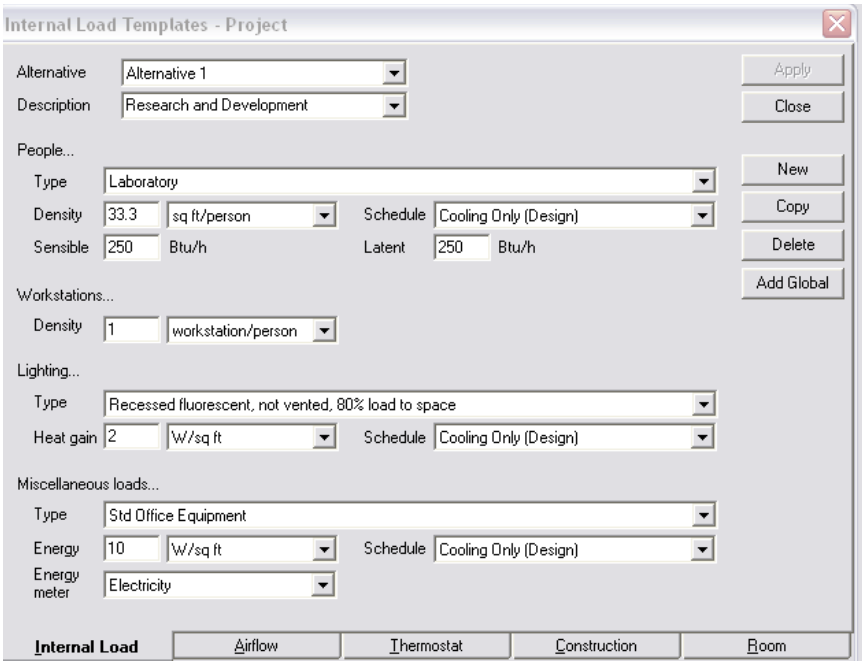
Table 8 Emission Factors for On-Site Combustion in a Commercial Boiler
(lb of pollutant per unit of fuel)



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

Sample of Internal Load



Alternative: Alternative 1
Description: Research and Development

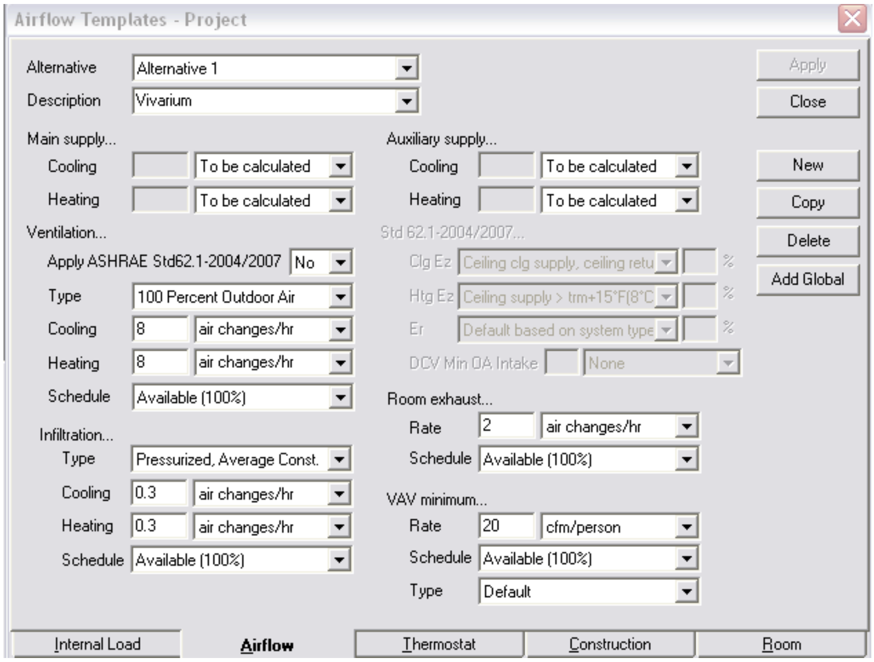
People...
Type: Laboratory
Density: 33.3 sq ft/person
Schedule: Cooling Only (Design)
Sensible: 250 Btu/h
Latent: 250 Btu/h

Workstations...
Density: 1 workstation/person

Lighting...
Type: Recessed fluorescent, not vented, 80% load to space
Heat gain: 2 W/sq ft
Schedule: Cooling Only (Design)

Miscellaneous loads...
Type: Std Office Equipment
Energy: 10 W/sq ft
Schedule: Cooling Only (Design)
Energy meter: Electricity

Sample of Airflow



Alternative: Alternative 1
Description: Vivarium

Main supply...
Cooling: To be calculated
Heating: To be calculated

Ventilation...
Apply ASHRAE Std62.1-2004/2007: No
Type: 100 Percent Outdoor Air
Cooling: 8 air changes/hr
Heating: 8 air changes/hr
Schedule: Available (100%)

Infiltration...
Type: Pressurized, Average Const.
Cooling: 0.3 air changes/hr
Heating: 0.3 air changes/hr
Schedule: Available (100%)

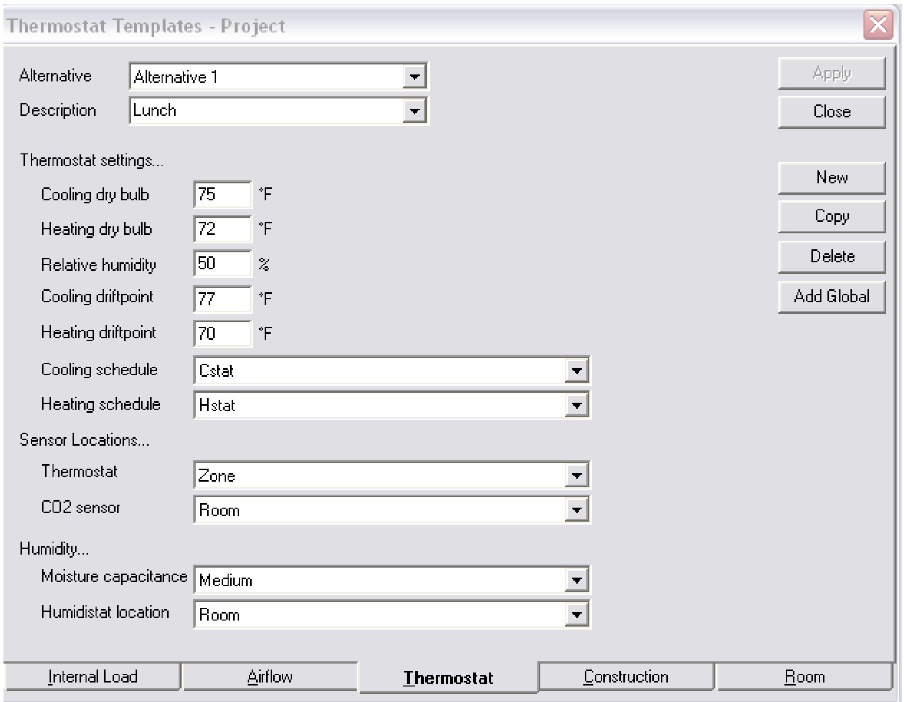
Auxiliary supply...
Cooling: To be calculated
Heating: To be calculated

Std 62.1-2004/2007...
Clg Ez: Ceiling clg supply, ceiling retu %
Htg Ez: Ceiling supply > trm+15°F(8°C %
Er: Default based on system type %
DCV Min OA Intake: None

Room exhaust...
Rate: 2 air changes/hr
Schedule: Available (100%)

VAV minimum...
Rate: 20 cfm/person
Schedule: Available (100%)
Type: Default

Sample of Thermostat



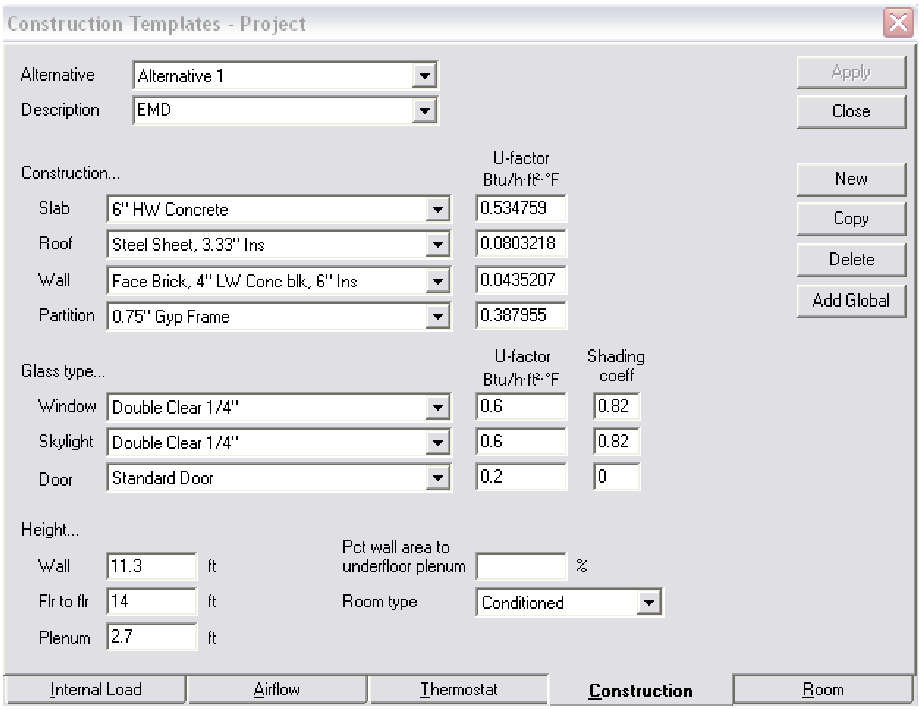
Alternative: Alternative 1
Description: Lunch

Thermostat settings...
Cooling dry bulb: 75 °F
Heating dry bulb: 72 °F
Relative humidity: 50 %
Cooling driftpoint: 77 °F
Heating driftpoint: 70 °F
Cooling schedule: Cstat
Heating schedule: Hstat

Sensor Locations...
Thermostat: Zone
CO2 sensor: Room

Humidity...
Moisture capacitance: Medium
Humidistat location: Room

Sample of Construction



Alternative: Alternative 1
Description: EMD

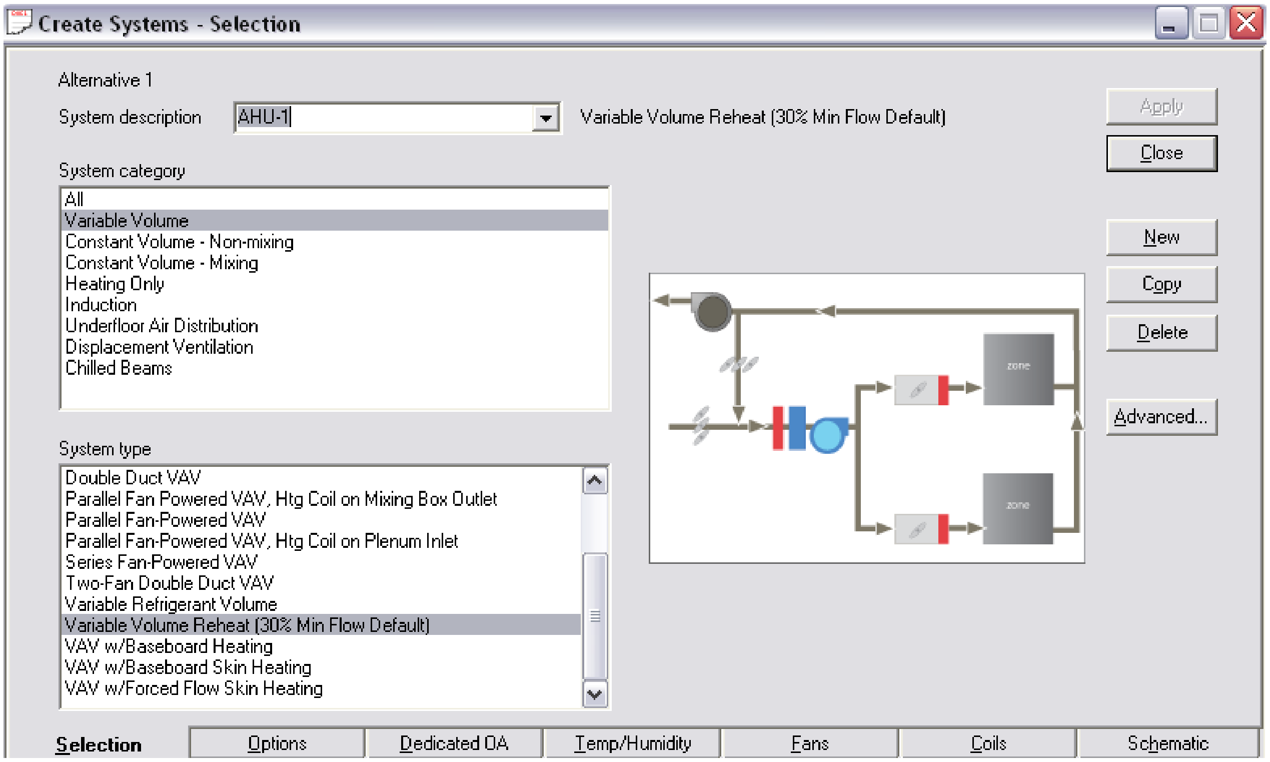
Construction...		U-factor Btu/h·ft²·°F
Slab	6" HW Concrete	0.534759
Roof	Steel Sheet, 3.33" Ins	0.0803218
Wall	Face Brick, 4" LW Conc blk, 6" Ins	0.0435207
Partition	0.75" Gyp Frame	0.387955

Glass type...		U-factor Btu/h·ft²·°F	Shading coeff
Window	Double Clear 1/4"	0.6	0.82
Skylight	Double Clear 1/4"	0.6	0.82
Door	Standard Door	0.2	0

Height...
Wall: 11.3 ft
Flr to flr: 14 ft
Plenum: 2.7 ft

Pct wall area to underfloor plenum: %
Room type: Conditioned

Sample of Schematic



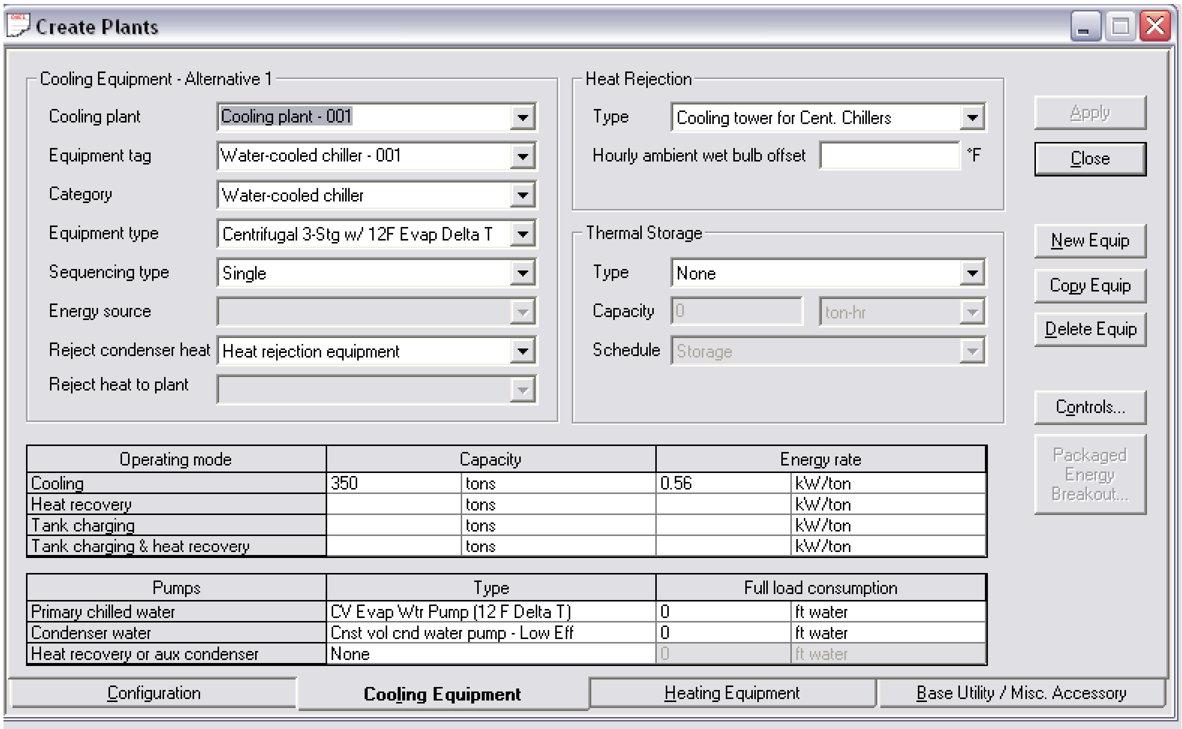
Alternative 1

System description: AHU-1 — Variable Volume Reheat (30% Min Flow Default)

System category
- All
- Variable Volume
- Constant Volume - Non-mixing
- Constant Volume - Mixing
- Heating Only
- Induction
- Underfloor Air Distribution
- Displacement Ventilation
- Chilled Beams

System type
- Double Duct VAV
- Parallel Fan Powered VAV, Htg Coil on Mixing Box Outlet
- Parallel Fan-Powered VAV
- Parallel Fan-Powered VAV, Htg Coil on Plenum Inlet
- Series Fan-Powered VAV
- Two-Fan Double Duct VAV
- Variable Refrigerant Volume
- Variable Volume Reheat (30% Min Flow Default)
- VAV w/Baseboard Heating
- VAV w/Baseboard Skin Heating
- VAV w/Forced Flow Skin Heating

Sample of Cooling Equipment



Cooling Equipment - Alternative 1

Cooling plant: Cooling plant - 001

Equipment tag: Water-cooled chiller - 001

Category: Water-cooled chiller

Equipment type: Centrifugal 3-Stg w/ 12F Evap Delta T

Sequencing type: Single

Energy source:

Reject condenser heat: Heat rejection equipment

Reject heat to plant:

Heat Rejection

Type: Cooling tower for Cent. Chillers

Hourly ambient wet bulb offset: °F

Thermal Storage

Type: None

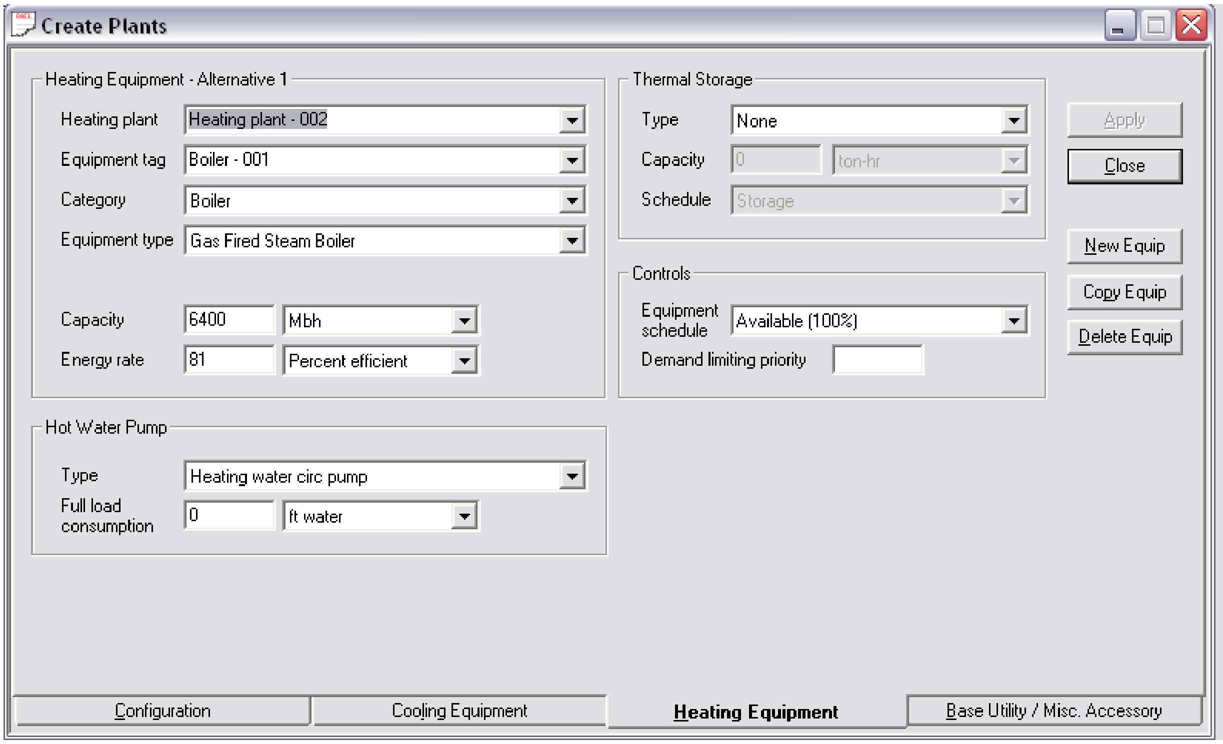
Capacity: 0 ton-hr

Schedule: Storage

Operating mode	Capacity		Energy rate	
Cooling	350	tons	0.56	kW/ton
Heat recovery		tons		kW/ton
Tank charging		tons		kW/ton
Tank charging & heat recovery		tons		kW/ton

Pumps	Type	Full load consumption	
Primary chilled water	CV Evap Wtr Pump (12 F Delta T)	0	ft water
Condenser water	Cnst vol cnd water pump - Low Eff	0	ft water
Heat recovery or aux condenser	None	0	ft water

Sample for Heating Equipment



Heating Equipment - Alternative 1

Heating plant: Heating plant - 002
Equipment tag: Boiler - 001
Category: Boiler
Equipment type: Gas Fired Steam Boiler
Capacity: 6400 Mbh
Energy rate: 81 Percent efficient

Thermal Storage

Type: None
Capacity: 0 ton-hr
Schedule: Storage

Controls

Equipment schedule: Available (100%)
Demand limiting priority:

Hot Water Pump

Type: Heating water circ pump
Full load consumption: 0 ft water