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Broad Institute Expansion : 75 Ames Street

Cambridge, Massachusetts

Technical Report Two :

[Building and Plant Energy Analysis Report]

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Executive Summary

For Technical Report two the total building energy usage and cost was estimated using Trane Trace 700 on 75 Ames Street, a new high-rise in Cambridge Massachusetts containing labs, research and development, office and retail space. 75 Ames first 11 floors contain the offices, labs and retail, on the 12th floor is a vivarium. The total area is approximately 550,000 sf .

The TRACE model 700 model calculated a total heating load of 770,900 btuh and a cooling load of 2530.1 tons. The heating loads are greater than the cooling loads which makes since seeing as Massachusetts is a mostly cold place. But through further analysis of the load there seems to be an error in the heating value when compared to the engineers design. This is apparent when the 150,597 therms of natural gas needed for heating is compared with the 348,500 therms called for by the design engineers at BR+A. Cooling loads capacity per SF also seemed a bit high when compared to rules of thumb for office cooling loads having values of .95 and .98 tons/SF.

The Trace model came to within 8% of the total energy cost of electricity and natural gas consumption. Electricity estimation was very close with 8,954,124 kWh coming within .21% of the price determined by the mechanical engineers. Again the mistake in natural gas consumption is the reason for that 8% difference. The yearly bill calculated by trace came out to be $2,040,282.41 making the cost per square foot only $6.98 dollars.

The dilemma with the natural gas consumption is going to have to be investigated, and solved moving forward. Much can still be learned from this report. And may be looked back on as a reference to future assignments to see where a majority of the costs are incurred for the electrical consumption.

Building Overview

75 Ames Street is a new 250,000 sq. ft., 15-story high-rise addition to Kendal Square in Cambridge, Massachusetts (figure1 below). This building is designed to bring together the multiple Broad institute offices around the Cambridge area into one location attached to their main office at 7 Cambridge Center.

This structure is set to finish the Ames Street frontage and add to the current pedestrian walk space. This is done with a new pedestrian entrance to a 5 floor garage attached to Ames Street as well as 4000 sq. ft. of retail and restaurant space on the ground floor. The primary design is for offices and research & development labs which use a majority of the area. Some other notable areas of the 75 Ames are a vivarium on the 12th floor and 3 mechanical rooms making up the penthouse.

The exterior is mainly composed of a mixture of stone, terra cotta, Viracon vision glass and spandrel glass. The penthouse is primarily constructed of aluminum louvers and metal panels. The front façade adds to the vibrant community on Ames Street while the other three facades connect 75 Ames to the current Broad Institute main office next door at 7 Cambridge Center.

Figure 1: A look at the location of 75 Ames Street in Cambridge (courtesy of ELKUS|MANFREDI ARCHITECTS)

Mechanical System Overview

Four 115,000 CFM 100% outside air, air-handling units are located inside the mechanical rooms on M1, M2 and M3, supplying the basement through level 11. A fifth 100% outside air, air handler is located on M3 serving the vivarium on level 12. Two 230,000 CFM dedicated exhaust air handling units located on the roof exhaust through 8 air induction nozzles roughly 28 feet off the roof.

Level M2 hosts the heating plant consisting of two 500 BHP preheat fire tube boilers, four 120 BHP Reheats with one standby, two 215 BHP MPS boilers for humidification and process steam loads, and finally a pressure reducing LPS for humidifiers. Also on M2 is the chiller plant consisting of three 1000 ton chillers for air cooling air handing units 1 through 4 and two 450 ton chillers to serve vivarium (AHU-5) and fan coil units which serve freezer rooms, tel/data, electrical, and the penthouse for spot cooling. Each chiller has a corresponding cooling tower located on the roof.

The ducting on each floor was taken with future floor plan changes in mind. In order to achieve this, air-handling units 1 through 4 each connect to a main ring on each floor. This can be seen in the following figures 2 & 3 which show the supply and exhaust duct respectively. These rings then supply air to each zone on their floor. Since they are serving both labs and offices together return air cannot be utilized since labs call for 100 % outside air. The only return air used in this building is 16000 CFM of air from the connector of 75 Ames Street to 7 Cambridge Center to level M1.

Figure 2: Dedicated Exhaust Ductwork

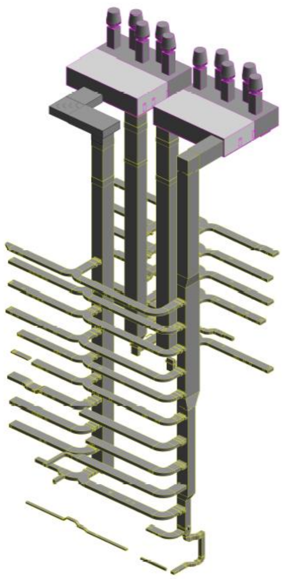
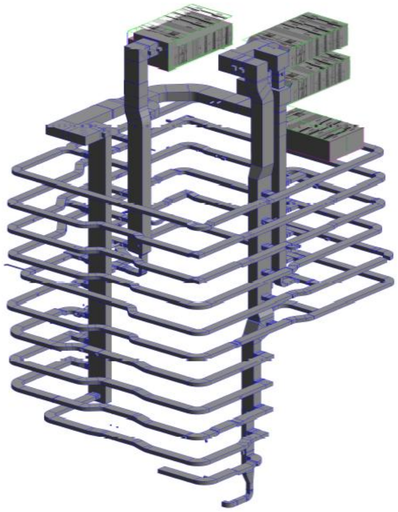


Figure 3: Supply Air Ductwork



Building Load Calculations

Using Trane TRACE 700 a building energy analysis was conducted for 75 Ames Street. Heating, cooling and energy usage were all found. Information for the model was obtained through construction documents, specs, and reports provided by the mechanical engineer, BR+A. The various assumptions, schedules, and design conditions for this model can be found below.

Design conditions

Cambridge is located in ASHRAE weather region 5A. This weather data is used by TRACE when Boston Massachusetts is selected for the weather information. These weather inputs can be found in appendix A. The interior design temperature and humidity as specified by the engineers at BR+A may be found in Tables 1 & 2 below.

Table 1

Space	Temperature	
	Winter (F)	Summer (F)
Office/Conference/Lobby	72	75
Labs	72	75
General Spaces	72	75
Vivarium	68-75(ADJ)	68-75(ADJ)
Shell/Mech./Elec. Spaces	60	Ventilation Only
Loading Dock	60	Ventilation Only

Table 2

Space	Humidity	
	Winter (%RH)	Summer (%RH)
Office/Conference/Lobby	25 (+/-5)	50 (+/-5)
Labs	25 (+/-5)	50 (+/-5)
General Spaces	25 (+/-5)	50 (+/-5)
Vivarium	25-40 (+/-5)	50 (+/-5)

Model design

For design purposes air handlers one, two, three and four were modeled as one 460,000 CFM unit that serves the basement through to the 11th floor. Zones were decided by the similarity and proximity of rooms and the VAV boxes serving them.

Load assumptions

Room areas were exported from a Revit model of 75 Ames and small/unnecessary spaces were not included. Exterior wall and window areas were calculated using Revit and the construction drawings. U-values for exterior materials were found in the specifications. Each exterior area and material was added to the appropriate room.

Occupancy

Occupancy values were not directly given for spaces. So values were taken from ASHRAE Standard 62.1-2010. These values can be found in Appendix B.

Ventilation

75 Ames is set at 100% outside air for all spaces due to a ganged duct design which supplies both the labs and offices. Even with this fans still must maintain a minimum occupied and unoccupied ventilation rate to maintain occupant's safety. These ventilation rates can be seen in table 3 below along with the rooms requiring 100% outside air.

Table 3

Space	%OA	Min ventilation
Labs	100	6-12 ACH
Tissue Culture Rooms	100	8-15 ACH
Office Area		20 CFM/Occupant
Auditorium/Seminar/Conf./Class		15 CFM/Occupant
Cagewash/Glasswash/Bottlewash	100	15-20 ACH
Equipment/Instrument Rooms	100	10-20 ACH
Animal Rooms	100	10-15
Animal Imaging		20 CFM/Person
Toilet/Janitor/Darkroom/Locker	100	10 ACH (Exhaust)
Mech. Spaces	100	2 ACH

Lighting and Equipment Electrical loads

Lighting and miscellaneous loads were both detailed in the design documents for 75 Ames. These loads are given in watts per square foot in table four below. For area not given a reasonable estimate was made by looking at ASHRAE 90.1 and the design documents. For rooms with large equipment the equipment specifications were examined to find the watts needed to operate.

Table 4

Space	Loads	
	Lighting (Watts/SF)	Misc./Equipment (Watts/SF)
Labs	2	10 Watts/SF
Tissue Culture Rooms	2	20
Office Area	1.2	2
Auditorium/Seminar/Conf./Class	4	2
Cagewash/Glasswash/Bottlewash	2	Per equip. cuts
Equipment/Instrument Rooms	2	40
Animal Rooms	Not given	Not given
Animal Imaging	2	Per manufacturer
Toilet/Janitor/Darkroom/Locker	1.5	1
Mech. Spaces	Not given	Per equip. cuts

Construction

Templates were designed in trace to act as the different facades of 75 Ames. Below Table 5 shows the various U values and shading coefficients. Vertical Glazing makes up nearly 40% of the building's exterior with no exterior shading, this could result in very high loads in perimeter rooms bringing up the yearly cooling and heating loads on the building

Table 5

Construction	U-value Btu/h-ft2-F	Shading Coefficient
Exterior Wall	0.083	
Roof	0.05	
Floor	0.15	
Windows	0.29	0.44

Schedules

Three main schedules were utilized in TRACE for the modeling of 75 Ames. Those schedules are lighting, miscellaneous and people. Since this is primarily an office/lab most activity occurs during normal work hours and the building load will significantly decrease at night. The schedules used can be found in Appendix C.

Calculated Load vs. Design Load Analysis

After running the model the system checksums sheet was used to analyze the heating and cooling airflows, along with the total heating and cooling coil capacities. System Checksums can be found in appendix D. A standard value of cooling capacity was found for an office building but none could be found for a lab so the lab is substituted with a hospital. As can be seen by table 6 below, the cooling capacity falls well above the standard for an office and just above that of a hospital. This could be a result of a large amount of glazing utilized by the building.

Table 6

		Area	Supply Air Per Unit Area (CFM/SF)		TOTAL CFM		Capacity Per Area		Total (tons)	
			Cooling	Heating	Cooling	Heating	Heating (Btuh/sf)	Cooling (tons/SF)	Heating	Cooling
Calculated	**AHU 1-2-3-4**	244,902	1.608	0.4217	393,868	103283	15.86	.0095	388,300	2,325.4
	AHU-5	20,817	1.57	0.538	32,716	11,199	18.379	.0098	382600	204.7
Standard for office			0.25 - 0.9					.00278-.005		
Standard for hospitals			0.33 - 0.67					.003-.006		

System Energy Consumption and Cost

In this report Trane TRACE was also used to calculate the use of electricity and gas for a typical year. Through this energy consumption the yearly operating cost is also found. This data is then compared to an E-quest report by BR+A containing the same information.

Fuel Costs

The following energy costs are real estimates per Massachusetts's average pricing.

Table 7

Utility Rates		
Electricity	$0.201	Per kWh
Natural Gas	$1.597	Per Therm

Results

The Trace model predicted electricity, total cost per year and cost per square foot relatively accurately. One main problem in the design was an under estimate of the natural gas usage by over 50%. This is clearly shown below in table 8 and figures 9 & 10.

Table 8

	Electricity (kWh)	Natural Gas (Therms)	Electricity Cost Per Year	Natural Gas Cost Per year	Total Cost per Year	Cost Per Square Foot
TRACE	8,954,124	150597.05	$1,799,778.92	$240,503.49	$2,040,282.41	$6.98
BR+A	8,973,000	348,500	$1,803,573.00	$556,554.50	$2,360,127.50	$7.57
Difference (%)	0.21036443	56.78707	0.210364427	56.78707317	13.55202578	7.772873269

Below in figures 7 and 8 is a breakdown of the monthly electricity consumption in a bar chart. Figure 7 is from the mechanical engineers at BR+A and totals consumption per month with a breakdown of where the load comes from. As seen by the graphs the energy consumption per month is relatively similar. Further below is the gas energy consumption figure 9 being BR+A's model and 10 being the Trace model. In comparing these two graphs it is evident where the severe lack in gas consumption from the trace to BR+A's model. Heating demand for the Trace model in May, June, July, August, September, and October are all nearly nonexistent. This problem was attempted to be solved but no method has worked as of yet. Possible reasons for this drastic difference could be a bad template, or missing equipment.

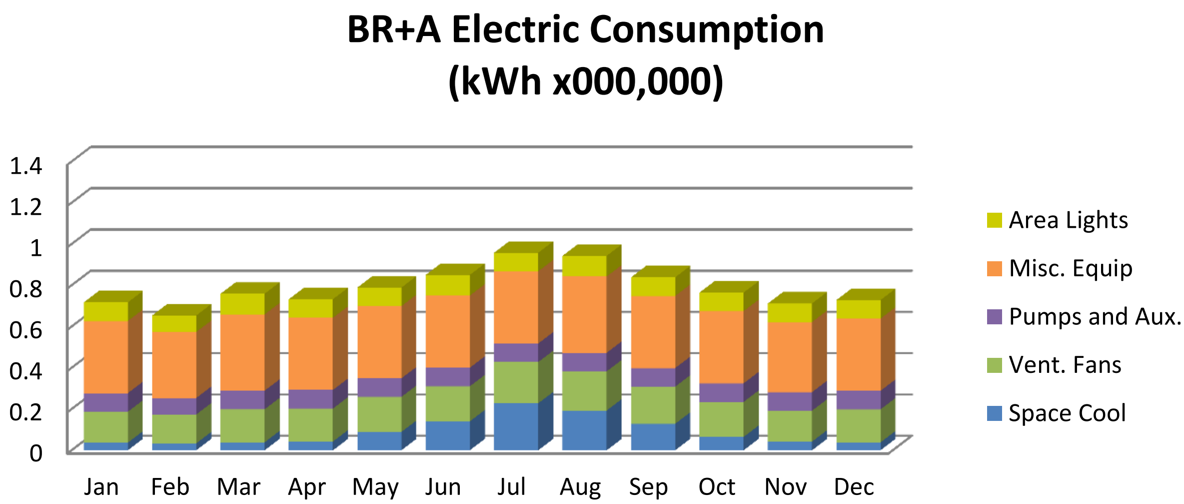


Figure 4

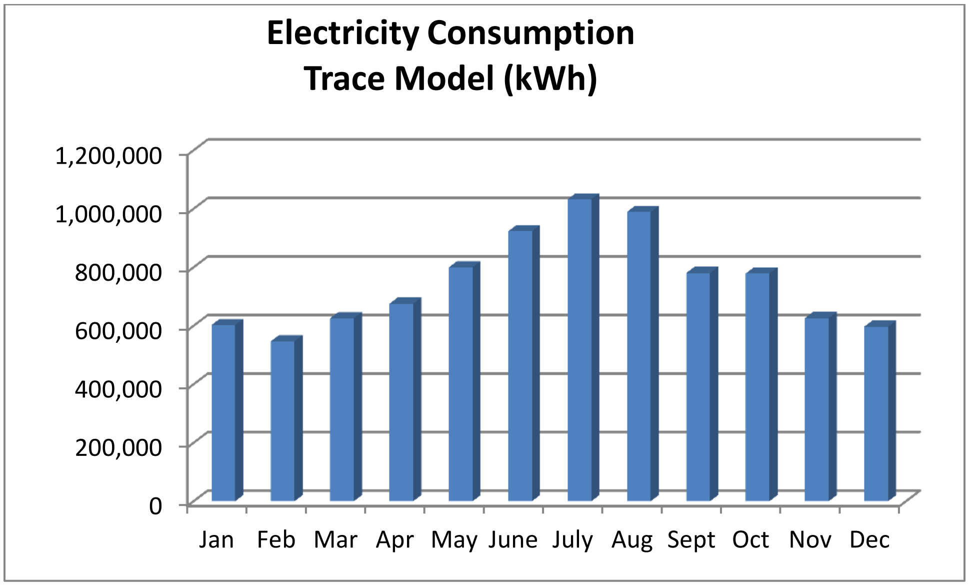


Figure 5

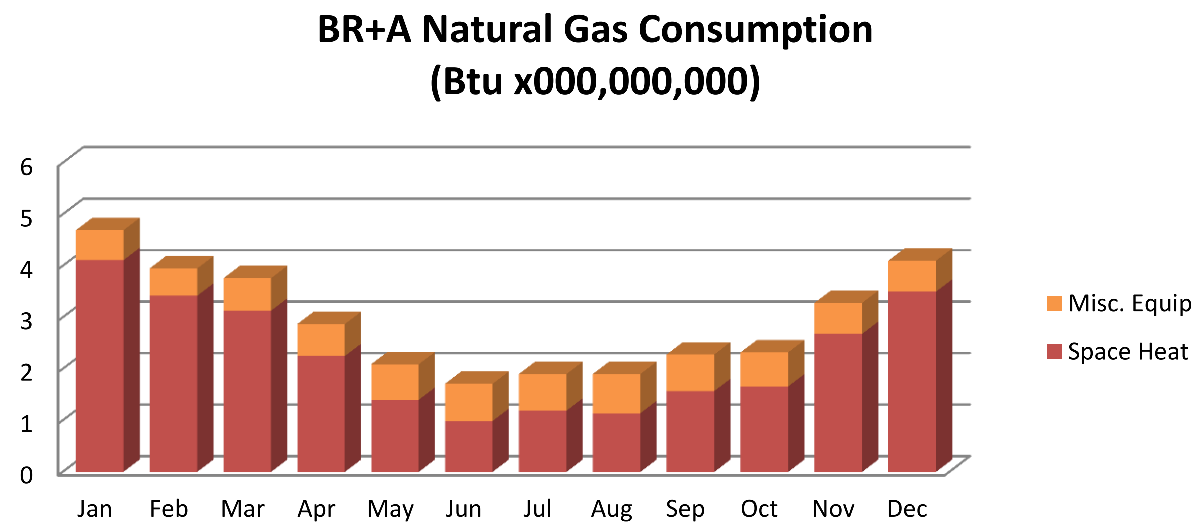


Figure 6

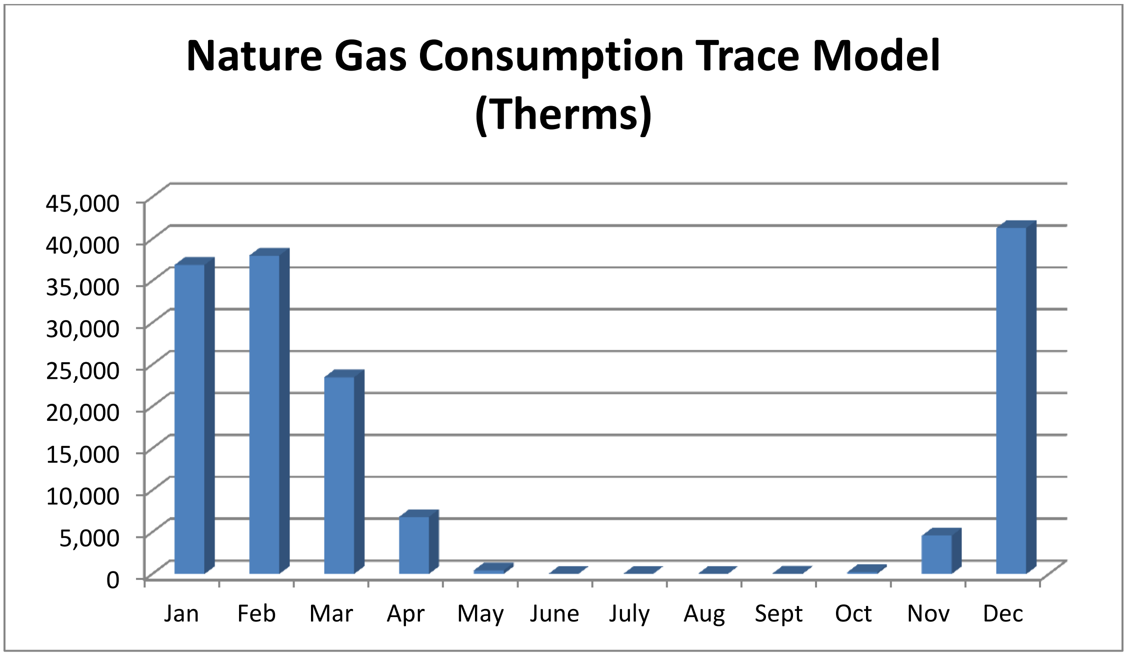


Figure 7

Below in Figure 11 is a graph of the cooling and heating profiles. It is clear here that heating is dominating the winter months and cooling takes over in the hotter months as expected.

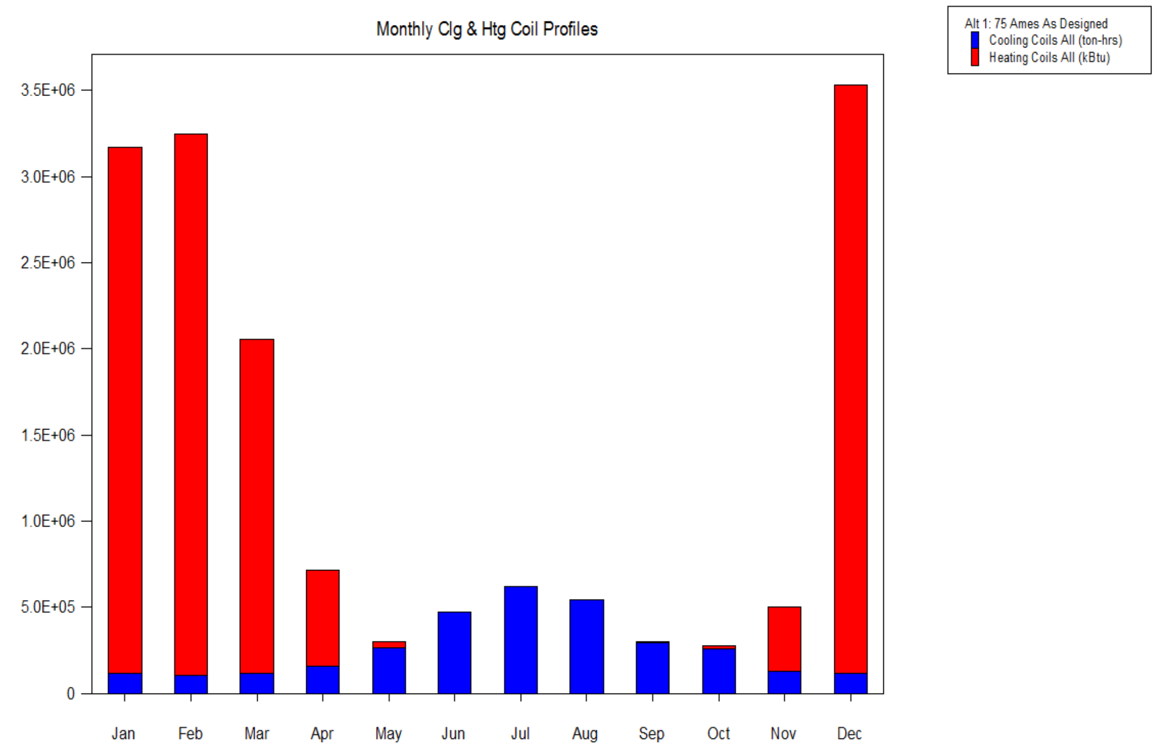


Figure 8

Emissions

In order to find the building's carbon footprint using emissions profiles is suggested. Emission rates per electricity consumed are found using the National Renewable Energy Laboratory's report on Source Energy and Emission Factors for Energy Use in Buildings. These factors take into account electricity delivered (table 9), fuel delivered (table 10) and on site fuel combusted (table 11) can be found in the following tables. The last two figures (table 12 and figure 9 show the total pollutant output per year.

Table 9

Total Emission Factors for Delivered Electricity (lb of Pollutant per kWh of Electricity)			
Pollutant (lb)	Eastern factor	Electrical consumption per year (kWh/year)	Total Pollutants [lbs/year]
CO2e	1.74E+00	8,954,124	15580175.76
CO2	1.22E+00	8,954,124	10924031.28
CH4	3.51E-03	8,954,124	31428.98
N2O	2.97E-05	8,954,124	265.94
NOX	1.95E-03	8,954,124	17460.54
SOX	6.82E-03	8,954,124	61067.13
CO	5.46E-04	8,954,124	4888.95
TNMOC	6.45E-05	8,954,124	577.54
Lead	8.95E-08	8,954,124	0.80
Mercury	1.86E-08	8,954,124	0.17
PM10	6.99E-05	8,954,124	625.89
Solid Waste	1.39E-01	8,954,124	1244623.24

Table 10

Pre combustion Emission Factors for Fuel Delivered to Buildings (lb pollutant per unit of fuel)			
Pollutant (lb)	Eastern	Fuel per 1000 cubic feet natural gas	Total Pollutants [lbs/year]
CO2e	2.78E+01	10044.82324	279246.0859
CO2	1.16E+01	10044.82324	116519.95
CH4	7.04E-01	10044.82324	7071.56
N2O	2.35E-04	10044.82324	2.36
NOX	1.64E-02	10044.82324	164.74
SOX	1.22E+00	10044.82324	12254.68
CO	1.36E-02	10044.82324	136.61
TNMOC	4.56E-05	10044.82324	0.46
Lead	2.41E-07	10044.82324	0.00
Mercury	5.51E-08	10044.82324	0.00
PM10	8.17E-04	10044.82324	8.21
PM-unspecified	1.42E-03	10044.82324	14.26
Solid Waste	1.60E+00	10044.82324	14.26

Table 11

Table 8 Emission Factors for On-Site Combustion in a Commercial Boiler (lb of pollutant per unit of fuel)			
Pollutant (lb)	natural Gas	Fuel per 1000 cubic feet natural gas	Total Pollutants [lbs/year]
CO2e	1.23E+02	10044.82324	1235513.258
CO2	1.22E+02	10044.82324	1225468.43
CH4	2.50E-03	10044.82324	25.11
N2O	2.50E-03	10044.82324	25.11
NOX	1.11E-01	10044.82324	1114.98
SOX	6.32E-04	10044.82324	6.35
CO	9.33E-02	10044.82324	937.18
TNMOC	6.13E-03	10044.82324	61.57
Lead	5.00E-07	10044.82324	0.01
Mercury	2.60E-07	10044.82324	0.00
PM10	8.40E-03	10044.82324	84.38

Table 12

Total Pollutants (lb/yeart)	
CO2e	17094935.1
CO2	12266019.66
CH4	38525.65
N2O	293.41
NOX	18740.26
SOX	73328.16
CO	5962.74
TNMOC	639.57
Lead	0.81
Mercury	0.17
PM10	718.48
PM-unspecified	14.26
Solid Waste	1244637.5

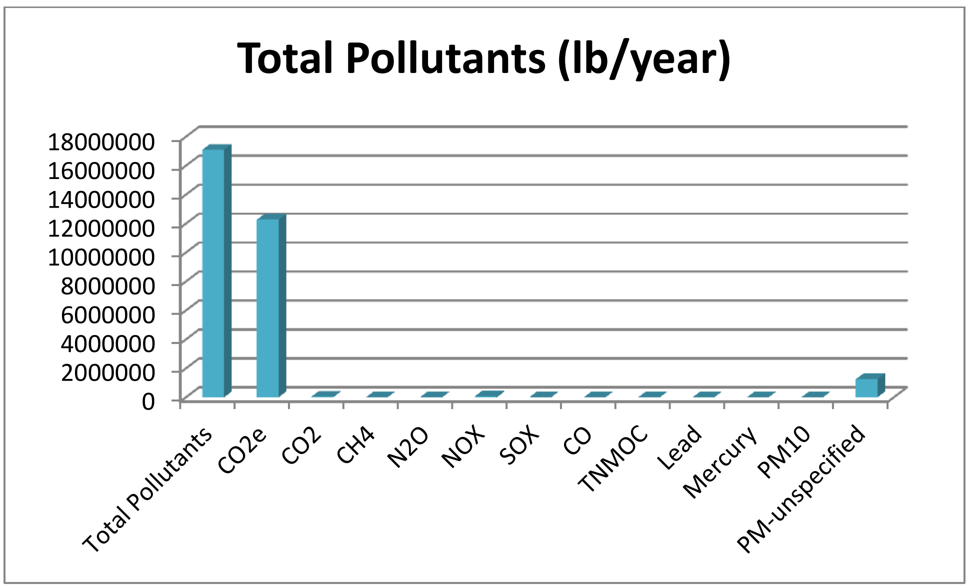


Figure 9

Conclusion

75 Ames Street contains various different rooms with different loads due to occupancy, space type, and heat gain through exterior walls and windows. Building loads and energy simulations were obtained by setting specific values for each room in TRACE 700, and setting up the heating and cooling plants. Overall trace came out with a reasonable estimate for cooling loads but the heating load design conditions needs to be further examined to find out why the value differs so much from the mechanical engineers values. Even with that glitch the cost estimate for a year was still only 8% off of the designed value.

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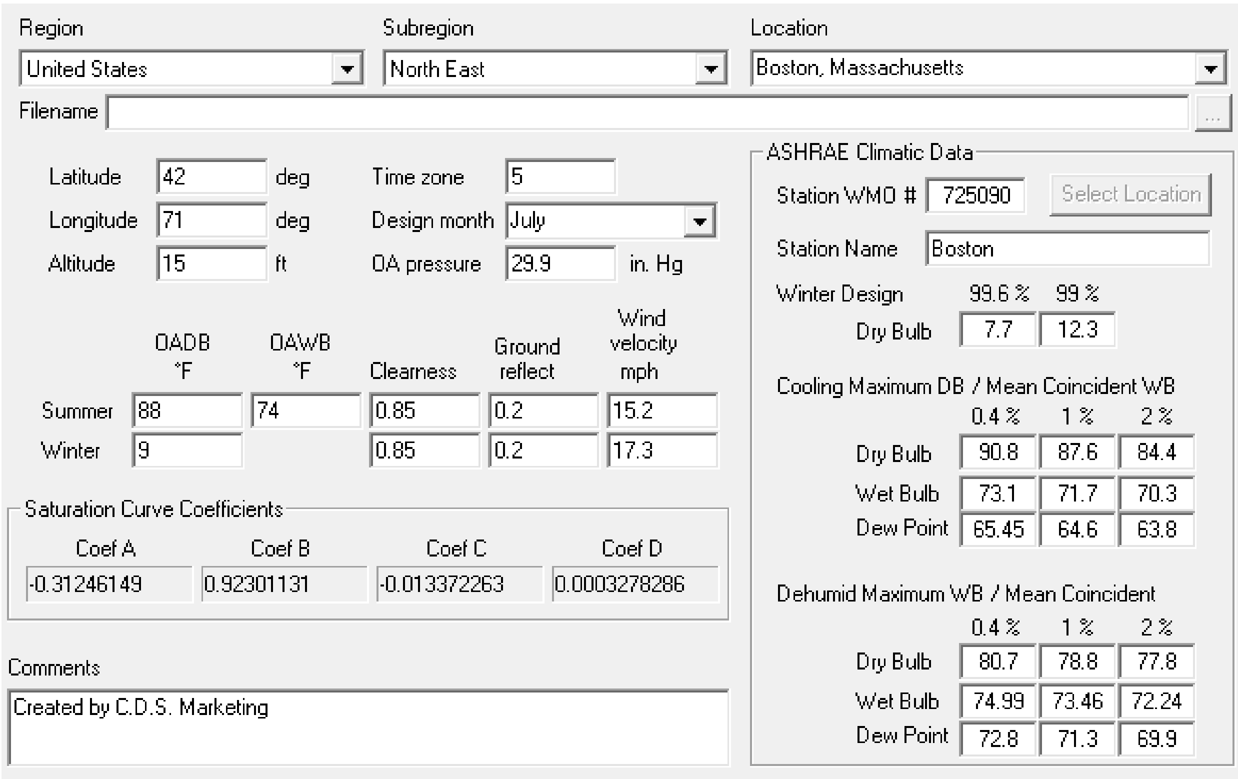
Appendix A

Boston, Ma – TRACE Weather Conditions



Region: United States
Subregion: North East
Location: Boston, Massachusetts
Filename:

Latitude	42	deg	Time zone	5	
Longitude	71	deg	Design month	July	
Altitude	15	ft	OA pressure	29.9	in. Hg

	OADB °F	OAWB °F	Clearness	Ground reflect	Wind velocity mph
Summer	88	74	0.85	0.2	15.2
Winter	9		0.85	0.2	17.3

Saturation Curve Coefficients

Coef A	Coef B	Coef C	Coef D
-0.31246149	0.92301131	-0.013372263	0.0003278286

Comments: Created by C.D.S. Marketing

ASHRAE Climatic Data

Station WMO #: 725090 (Select Location)

Station Name: Boston

Winter Design	99.6 %	99 %
Dry Bulb	7.7	12.3

Cooling Maximum DB / Mean Coincident WB

	0.4 %	1 %	2 %
Dry Bulb	90.8	87.6	84.4
Wet Bulb	73.1	71.7	70.3
Dew Point	65.45	64.6	63.8

Dehumid Maximum WB / Mean Coincident

	0.4 %	1 %	2 %
Dry Bulb	80.7	78.8	77.8
Wet Bulb	74.99	73.46	72.24
Dew Point	72.8	71.3	69.9

Appendix B

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/person	L/s·person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s·person	
Correctional Facilities									
Cell	5	2.5	0.12	0.6		25	10	4.9	2
Dayroom	5	2.5	0.06	0.3		30	7	3.5	1
Guard stations	5	2.5	0.06	0.3		15	9	4.5	1
Booking/waiting	7.5	3.8	0.06	0.3		50	9	4.4	2
Educational Facilities									
Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6	2
Daycare sickroom	10	5	0.18	0.9		25	17	8.6	3
Classrooms (ages 5–8)	10	5	0.12	0.6		25	15	7.4	1
Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7	1
Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3	1
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3		150	8	4.0	1
Art classroom	10	5	0.18	0.9		20	19	9.5	2
Science laboratories	10	5	0.18	0.9		25	17	8.6	2
University/college laboratories	10	5	0.18	0.9		25	17	8.6	2
Wood/metal shop	10	5	0.18	0.9		20	19	9.5	2
Computer lab	10	5	0.12	0.6		25	15	7.4	1
Media center	10	5	0.12	0.6	A	25	15	7.4	1
Music/theater/dance	10	5	0.06	0.3		35	12	5.9	1
Multi-use assembly	7.5	3.8	0.06	0.3		100	8	4.1	1
Food and Beverage Service									
Restaurant dining rooms	7.5	3.8	0.18	0.9		70	10	5.1	2
Cafeteria/fast-food dining	7.5	3.8	0.18	0.9		100	9	4.7	2
Bars, cocktail lounges	7.5	3.8	0.18	0.9		100	9	4.7	2
Kitchen (cooking)	7.5	3.8	0.12	0.6		20	14	7.0	2
General									
Break rooms	5	2.5	0.06	0.3		25	10	5.1	1
Coffee stations	5	2.5	0.06	0.3		20	11	5.5	1
Conference/meeting	5	2.5	0.06	0.3		50	6	3.1	1
Corridors	–	–	0.06	0.3		–			1
Occupiable storage rooms for liquids or gels	5	2.5	0.12	0.6	B	2	65	32.5	2
Hotels, Motels, Resorts, Dormitories									
Bedroom/living room	5	2.5	0.06	0.3		10	11	5.5	1
Barracks sleeping areas	5	2.5	0.06	0.3		20	8	4.0	1
Laundry rooms, central	5	2.5	0.12	0.6		10	17	8.5	2
Laundry rooms within dwelling units	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies/prefunction	7.5	3.8	0.06	0.3		30	10	4.8	1
Multipurpose assembly	5	2.5	0.06	0.3		120	6	2.8	1

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/person	L/s·person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s·person	
Office Buildings									
Breakrooms	5	2.5	0.12	0.6		50	7	3.5	1
Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5	1
Occupiable storage rooms for dry materials	5	2.5	0.06	0.3		2	35	17.5	1
Office space	5	2.5	0.06	0.3		5	17	8.5	1
Reception areas	5	2.5	0.06	0.3		30	7	3.5	1
Telephone/data entry	5	2.5	0.06	0.3		60	6	3.0	1
Miscellaneous Spaces									
Bank vaults/safe deposit	5	2.5	0.06	0.3		5	17	8.5	2
Banks or bank lobbies	7.5	3.8	0.06	0.3		15	12	6.0	1
Computer (not printing)	5	2.5	0.06	0.3		4	20	10.0	1
General manufacturing (excludes heavy industrial and processes using chemicals)	10	5.0	0.18	0.9		7	36	18	3
Pharmacy (prep. area)	5	2.5	0.18	0.9		10	23	11.5	2
Photo studios	5	2.5	0.12	0.6		10	17	8.5	1
Shipping/receiving	10	5	0.12	0.6	B	2	70	35	2
Sorting, packing, light assembly	7.5	3.8	0.12	0.6		7	25	12.5	2
Telephone closets	–	–	0.00	0.0		–			1
Transportation waiting	7.5	3.8	0.06	0.3		100	8	4.1	1
Warehouses	10	5	0.06	0.3	B	–			2
Public Assembly Spaces									
Auditorium seating area	5	2.5	0.06	0.3		150	5	2.7	1
Places of religious worship	5	2.5	0.06	0.3		120	6	2.8	1
Courtrooms	5	2.5	0.06	0.3		70	6	2.9	1
Legislative chambers	5	2.5	0.06	0.3		50	6	3.1	1
Libraries	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies	5	2.5	0.06	0.3		150	5	2.7	1
Museums (children's)	7.5	3.8	0.12	0.6		40	11	5.3	1
Museums/galleries	7.5	3.8	0.06	0.3		40	9	4.6	1
Residential									
Dwelling unit	5	2.5	0.06	0.3	F,G	F			1
Common corridors	–	–	0.06	0.3					1
Retail									
Sales (except as below)	7.5	3.8	0.12	0.6		15	16	7.8	2
Mall common areas	7.5	3.8	0.06	0.3		40	9	4.6	1
Barbershop	7.5	3.8	0.06	0.3		25	10	5.0	2

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE *(Continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft²	L/s·m²		#/1000 ft² or #/100 m²	cfm/person	L/s·person	
Beauty and nail salons	20	10	0.12	0.6		25	25	12.4	2
Pet shops (animal areas)	7.5	3.8	0.18	0.9		10	26	12.8	2
Supermarket	7.5	3.8	0.06	0.3		8	15	7.6	1
Coin-operated laundries	7.5	3.8	0.12	0.6		20	14	7.0	2
Sports and Entertainment									
Sports arena (play area)	–	–	0.30	1.5	E	–			1
Gym, stadium (play area)	–	–	0.30	1.5		30			2
Spectator areas	7.5	3.8	0.06	0.3		150	8	4.0	1
Swimming (pool & deck)	–	–	0.48	2.4	C	–			2
Disco/dance floors	20	10	0.06	0.3		100	21	10.3	2
Health club/aerobics room	20	10	0.06	0.3		40	22	10.8	2
Health club/weight rooms	20	10	0.06	0.3		10	26	13.0	2
Bowling alley (seating)	10	5	0.12	0.6		40	13	6.5	1
Gambling casinos	7.5	3.8	0.18	0.9		120	9	4.6	1
Game arcades	7.5	3.8	0.18	0.9		20	17	8.3	1
Stages, studios	10	5	0.06	0.3	D	70	11	5.4	1

GENERAL NOTES FOR TABLE 6-1
1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.
2 **Environmental Tobacco Smoke:** This table applies to ETS-free areas. Refer to Section 5.17 for requirements for buildings containing ETS areas and ETS-free areas.
3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.
4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.
5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.
6 **Unlisted occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities and building construction shall be used.

ITEM-SPECIFIC NOTES FOR TABLE 6-1
A For high school and college libraries, use values shown for Public Assembly Spaces—Libraries.
B Rate may not be sufficient when stored materials include those having potentially harmful emissions.
C Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture. "Deck area" refers to the area surrounding the pool that would be expected to be wetted during normal pool use, i.e., when the pool is occupied. Deck area that is not expected to be wetted shall be designated as a space type (for example, "spectator area").
D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.
E When combustion equipment is intended to be used on the playing surface, additional dilution ventilation and/or source control shall be provided.
F Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.
G Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

different sources can be applied to any other aspect of indoor air quality.

6.2.2.1.1 Design Zone Population. Design zone population (P_z) shall equal the largest (peak) number of people expected to occupy the *ventilation zone* during typical usage.

Exceptions:

a. If the number of people expected to occupy the *ventilation zone* fluctuates, zone population equal to the average number of people shall be permitted, provided such average is determined in accordance with Section 6.2.6.2.

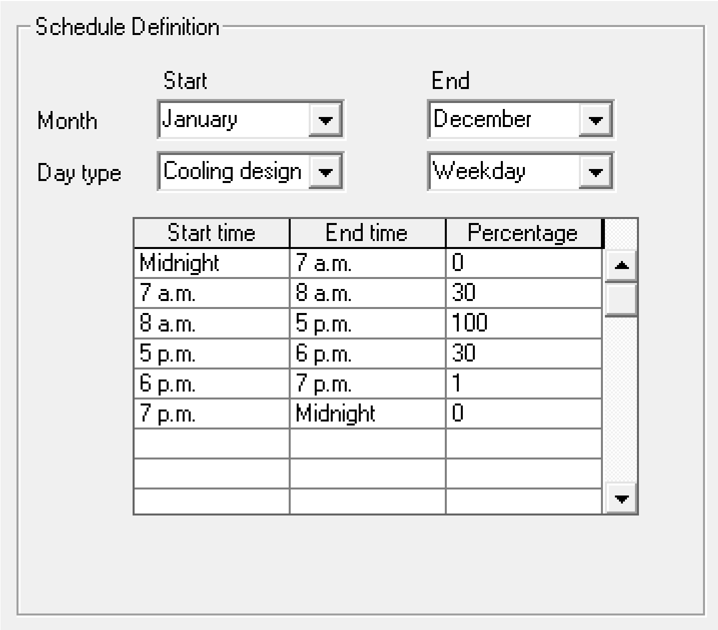
b. If the largest or average number of people expected to occupy the *ventilation zone* cannot be established for a specific design, an estimated value for zone population shall be permitted, provided such value is the product of the *net occupiable area* of the *ventilation zone* and the default occupant density listed in Table 6-1.

6.2.2.2 Zone Air Distribution Effectiveness. The zone air distribution effectiveness (E_z) shall be no greater than the default value determined using Table 6-2.

Note: For some configurations, the default value depends upon space and supply air temperature.

Appendix C

Utilizations schedule for people occupying office

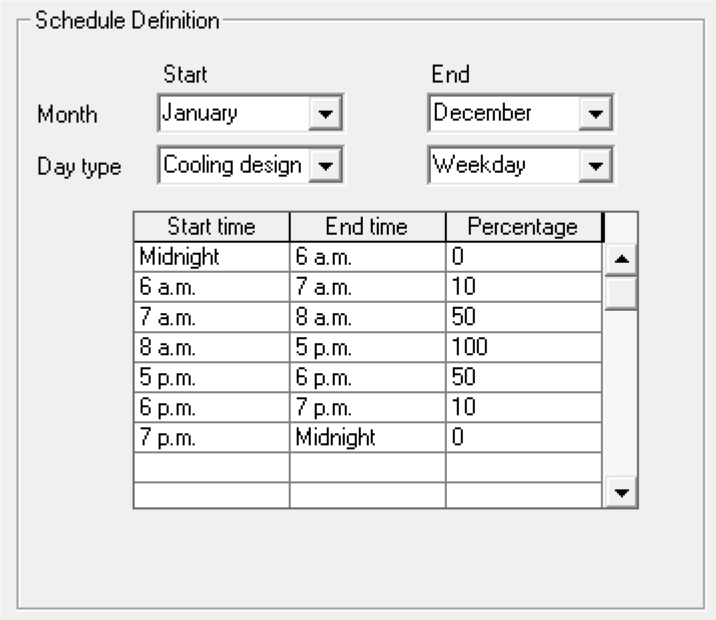


Schedule Definition

	Start	End
Month	January	December
Day type	Cooling design	Weekday

Start time	End time	Percentage
Midnight	7 a.m.	0
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.	1
7 p.m.	Midnight	0

Utilizations for lights in an office

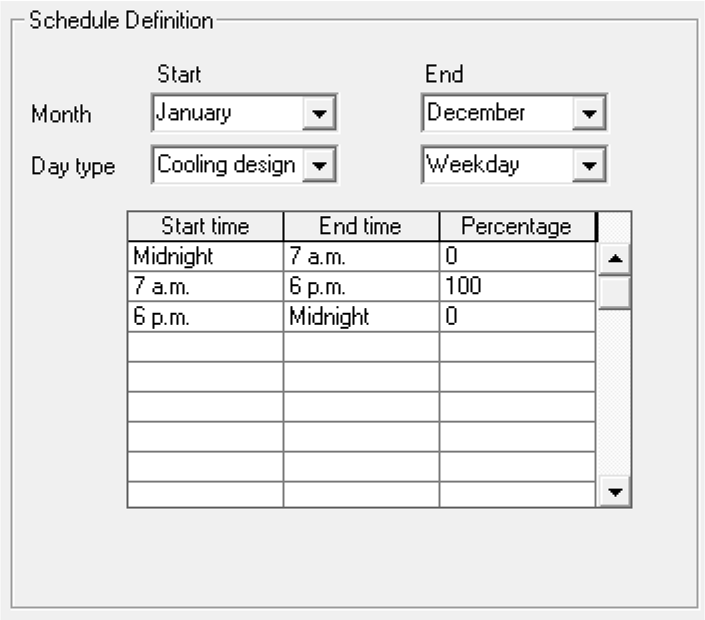


Schedule Definition

	Start	End
Month	January	December
Day type	Cooling design	Weekday

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

Utilization Of Ventilation for an Office



Utilization Schedule for Misc. Loads in Office

Start time	End Time	Percenage
Midnight	7 a.m.	5
7 a.m.	8 a.m.	80
8 a.m.	10 a.m.	90
10 a.m.	Noon	95
Noon	2 p.m.	80
2 p.m.	4 p.m.	90
4 p.m.	5 p.m.	95
5 p.m.	6 p.m.	80
6 p.m.	7 p.m.	70
7 p.m.	8 p.m.	60
8 p.m.	9 p.m.	40
9 p.m.	10 p.m.	30
10 p.m.	Midnight	20

Appendix D

System Checksums

By ACADEMIC

AHU-1-2-3-4 — **Variable Volume Reheat (30% Min Flow Default)**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 16; Outside Air: OADB/WB/HR: 88 / 74 / 105

Clg Space Peak — Mo/Hr: 7 / 10; OADB: 79

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	0	0	0	0	0
Glass Solar	2,141,427	0	2,141,427	8	2,993,256	33
Glass/Door Cond	272,232	0	272,232	1	52,331	1
Wall Cond	13,993	7,824	21,817	0	11,636	0
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	0		0	0	0	0
Sub Total ==>	2,427,652	7,824	2,435,476	9	3,057,223	34
Internal Loads						
Lights	950,477	129,574	1,080,051	4	897,834	10
People	1,622,818	0	1,622,818	6	885,470	10
Misc	4,140,865	0	4,140,865	15	4,140,865	46
Sub Total ==>	6,714,159	129,574	6,843,733	25	5,924,168	66
Ceiling Load	20,983	-20,983	0	0	20,574	0
Ventilation Load	0	0	17,022,189	61	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		53,434	53,434	0		
Sup. Fan Heat			1,549,427	6		
Ret. Fan Heat		1	1	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	9,162,794	169,850	27,904,260	100.00	9,001,966	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 9

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	0	0.00
Glass Solar	0	0	0.00
Glass/Door Cond	-1,425,760	-1,425,760	6.39
Wall Cond	-64,541	-99,729	0.45
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	0	0	0.00
Sub Total ==>	-1,490,301	-1,525,489	6.84
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-15,127	0	0.00
Ventilation Load	0	-7,196,459	32.26
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		92,052	-0.41
OA Preheat Diff.		-13,677,057	61.31
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-1,505,428	-22,306,952	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	85.0
Ra Plenum	75.4	70.7
Return	75.4	70.7
Ret/OA	87.5	9.0
Fn MtrTD	0.2	0.0
Fn BldTD	0.9	0.0
Fn Frict	2.7	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	393,868	103,283
Terminal	393,868	103,283
Main Fan	393,868	103,282
Sec Fan	0	0
Nom Vent	393,868	103,282
AHU Vent	393,868	103,282
Infil	0	0
MinStop/Rh	103,282	103,282
Return	215,248	92,302
Exhaust	215,248	92,302
Rm Exh	178,620	10,980
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	100.0	100.0
cfm/ft²	1.61	0.42
cfm/ton	169.38	
ft²/ton	105.32	
Btu/hr·ft²	113.94	-127.76
No. People	3,675	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	2,325.4	27,904.3	15,070.9	367,988	87.5	74.0	105.0	51.2	51.0	55.4
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	2,325.4	27,904.3								

AREAS

	Gross Total	Glass ft²	(%)
Floor	244,902		
Part	0		
Int Door	0		
ExFlr	0		
Roof	0	0	0
Wall	102,287	64,860	63
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-3,883.3	103,282	51.2	85.0
Aux Htg	0.0	0	0.0	0.0
Preheat	-18,538.3	393,868	9.0	51.2
Reheat	-2,335.3	103,282	51.2	71.5
Humidif	-8,867.4	484,019	1.8	27.9
Opt Vent	0.0	0	0.0	0.0
Total	-31,289.1			

Project Name: 75 Ames Lab/Research
Dataset Name: 75AMES_TRACE.TRC

TRACE® 700 v6.2.8 calculated at 05:52 AM on 10/12/2012
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System Checksums

By ACADEMIC

AHU-5 — **Variable Volume Reheat (30% Min Flow Default)**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 16; Outside Air: OADB/WB/HR: 88 / 74 / 105

CLG Space Peak — Mo/Hr: 7 / 11; OADB: 82

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	0	0	0	0	0
Glass Solar	181,574	0	181,574	7	206,488	28
Glass/Door Cond	21,479	0	21,479	1	7,419	1
Wall Cond	1,292	753	2,045	0	1,348	0
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	0		0	0	0	0
Sub Total ==>	204,345	753	205,098	8	215,253	29
Internal Loads						
Lights	73,024	17,958	90,982	4	71,943	10
People	137,330	0	137,330	6	68,304	9
Misc	381,305	0	381,305	16	381,305	52
Sub Total ==>	591,659	17,958	609,617	25	521,552	71
Ceiling Load	2,268	-2,268	0	0	2,209	0
Ventilation Load	0	0	1,505,492	61	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-7,441	-7,441	0		
Sup. Fan Heat			143,502	6		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	798,273	9,001	2,456,267	100.00	739,013	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 9

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	0	0.00
Glass Solar	0	0	0.00
Glass/Door Cond	-112,788	-112,788	5.93
Wall Cond	-7,304	-11,211	0.59
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	0	0	0.00
Sub Total ==>	-120,092	-123,999	6.52
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-1,382	0	0.00
Ventilation Load	0	-783,564	41.22
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		16,708	-0.88
OA Preheat Diff.		-1,009,855	53.13
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-121,474	-1,900,709	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	81.7
Ra Plenum	75.4	70.4
Return	75.4	70.4
Ret/OA	87.5	9.0
Fn MtrTD	0.4	0.0
Fn BldTD	0.9	0.0
Fn Frict	2.7	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	32,761	11,199
Terminal	32,761	11,199
Main Fan	32,761	11,199
Sec Fan	0	0
Nom Vent	32,761	11,199
AHU Vent	32,761	11,199
Infil	0	0
MinStop/Rh	11,199	11,199
Return	31,723	10,807
Exhaust	31,723	10,807
Rm Exh	1,039	392
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	100.0	100.0
cfm/ft²	1.57	0.54
cfm/ton	160.05	
ft²/ton	101.70	
Btu/hr·ft²	117.99	-92.08
No. People	275	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	204.7	2,456.3	1,323.6	32,288	87.5	74.0	105.0	51.0	50.9	55.4
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	204.7	2,456.3								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	20,817		
Part	0		
Int Door	0		
ExFlr	0		
Roof	0	0	0
Wall	10,375	5,984	58
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-382.6	11,199	51.0	81.7
Aux Htg	0.0	0	0.0	0.0
Preheat	-1,534.3	32,761	9.0	51.0
Reheat	-259.1	11,199	51.0	71.8
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-1,916.9			

Project Name: 75 Ames Lab/Research
Dataset Name: 75AMES_TRACE.TRC

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