SHA HEADQUARTERS

707 N. Calvert St. | Baltimore, MD

Technical Report Two

Building and Plant Energy Analysis

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Dr. Bahnfleth | October 27, 2010

Table of Contents

EXECUTIVE SUMMARY

The objective of Technical Report II is to determine the results of an entire building block load energy analysis of the Maryland State Highway Administration (SHA) Headquarters – 707 Building. Trane TRACE 700 Version 6.2 was utilized to calculate the office building load data, as well as the yearly energy consumption, of the 707 building. TRACE inputs were selected from the building design specifications and drawings as well as additional information provided by the design engineer.

The generated block load energy model for the 707 building calculated the total annual energy consumption for cooling and heating loads to be 44.305 MBtu/year. The total load calculated by the design engineer was 42.232 MBtu/year, which indicates that the load energy consumptions are within 4.9% of each other. The annual utility cost that was totaled for the consumed electricity and natural gas was $200,808 or 1.17 $/sf. In order to provide a redesigned mechanical system with reduced energy consumptions, the current features of the building's utility usage must be analyzed.

MECHANICAL SYSTEM SUMMARY

The 707 building's mechanical system is comprised of two low pressure central station air handling units (AHUs) serving the central core of the building and one high pressure central station AHU serving the central core of the building. Cooling is provided by a chilled water plant, utilizing a centrifugal chiller and an updraft cooling tower, while heating is provided by two low pressure steam boilers and a steam-to-hot water heat exchanger. Overall, the components of the system include 3 constant volume built-up AHUs, 534 perimeter induction units with no operating fans on the 6 office levels, 18 VAV boxes that serve individual areas, a chilled water/hot water indoor unit, and a chilled water/steam indoor unit.

SYSTEM DESIGN LOAD ESTIMATION

To simulate the design load energy consumption of the Maryland State Highway Administration (SHA) 707 Building located in Baltimore, MD, Trane TRACE 700 Version 6.2 was implemented. Operator experience and previously performed analyses were determinants for using TRACE for this energy study. A yearlong energy evaluation was executed to find the peak design heating and cooling loads of the system. A schematic of the system is located in Appendix B.

Block Load Elements

There are multiple advantages for a block load analysis to be performed, including model calculation time reduction, manageable model file sizes, and accurate results. The inputs, such as room areas, equipment characteristics, and building construction materials, were taken from the building design specifications and drawings; additional information was provided by the design engineer.

Load Sources and Modeling Information

Occupants, ventilation, infiltration, artificial lights, electrical and mechanical equipment, ambient conduction/convection and direct solar gain are the core load sources for the 707 building model. TRACE data templates are located in Appendix A.

Design Occupancy and Ventilation

As design occupancy was provided for each space in the 707 building, the ASHRAE recommended occupancies were not utilized. The low-rise office schedule in TRACE was used to determine the fraction of cooling needed during the weekdays; Table 1 depicts these times and percentages. TRACE produced all ventilation rates used in the energy analysis in accordance with ASHRAE Standard 62.1 - 2007.

Table 1: Weekday Cooling Design for People Loads

Start Time	End Time	Percentage
Midnight	7 a.m.	0
7 a.m.	8 a.m.	30
8 a.m.	11 a.m.	100
11 a.m.	Noon	80
Noon	1 p.m.	40
1 p.m.	2 p.m.	80
2 p.m.	5 p.m.	100
5 p.m.	6 p.m.	30
6 p.m.	9 p.m.	10
9 p.m.	Midnight	5

Infiltration

0.2 cfm/ft^2 of the wall for cooling and 0.4 cfm/ft^2 of the wall for heating are the typical infiltration rates used for office space in the 707 simulation.

Electrical Loads

Since it is required to "use lights and equipment electrical loads on a W/sf basis," the typical office space heat gain from recessed fluorescent, non-vented 80% load to space lighting was calculated to be 1.45 W/ft^2 by the design engineer. The lighting schedule of a low-rise office building was selected in TRACE; the weekday schedule timings and percentages can be seen in Table 2 below. The miscellaneous loads were 1 W/ft^2 to account for medium sized computer loads in the open office space.

Table 2: Weekday Cooling Design for Lighting Loads

Start Time	End Time	Percentage
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

Weather Information

The weather data was taken from the 2009 ASHRAE Handbook of Fundamentals (HOF), and they represent the 0.4% and 99.6% values, respectively. Below, Table 3 shows these values used in the building analysis. Actual weather conditions that were used in TRACE are displayed in the TRACE schedules in Appendix C. The entire Baltimore, MD weather data from ASHRAE 2009 HOF can also be found in Appendix C.

Table 3: ASHRAE Weather Data – Baltimore, MD

ASHRAE Values	Summer Design Cooling (0.4%)	Winter Design Heating (99.6%)
OA Dry Bulb (°F)	93.9	12.9
OA Wet Bulb (°F)	78.1	-

System Load Analysis Results

Below, Table 4 indicates cooling, heating, supply, and ventilation rates for the TRACE block load compared to the original loads calculated by the design engineer. The block load values are greater than those of the original calculations; this is most likely due to the simplified load estimations and assumptions of the block load. Specific information for every single room/space must be known and analyzed exactly to obtain the most accurate cooling and heating loads for 707. Nonetheless, even with the simplifications that were made for the block load, the findings show a plausible portrayal of the loads that the design engineer calculated.

Table 4: Block Loads vs. Original Loads and Ventilation

	Cooling (ft^2/ton)	Heating (Btu/h*ft^2)	Supply Air (cfm/ft^2)	Ventilation Air (cfm/ft^2)
707 Block Load	405.4	27.9	0.85	0.15
707 Original	535.2	21.6	0.37	0.14

SYSTEM ENERGY CONSUMPTION & OPERATING COSTS

A year-long energy simulation was composed by the TRACE model that was used to find the building design cooling and heating loads. Cooling is provided by a chilled water plant operated by electricity, while heating is provided by two low pressure steam boilers and a steam-to-hot water heat exchanger.

System Energy Classification

According to the energy analysis results, the 707 building consumes 1,743,765 kWh of energy annually. The breakdown of this energy consumption is shown in both Table 5 and Figure 1 below. Typical for an office building in this region, space heating and lighting are large energy consumers. Since there are no fans within any of the 534 induction units for the cooling system, the amount of energy expended is reduced when compared to a standard office building.

Table 5: Energy Consumption Breakdown

	Energy (kBtu/yr)	Total Energy (%)
Lighting	2951.2	35
Space Heating	2533.5	30
Receptacles	1986.7	24
Space Cooling	566.2	7
Heat Rejection	310.4	4

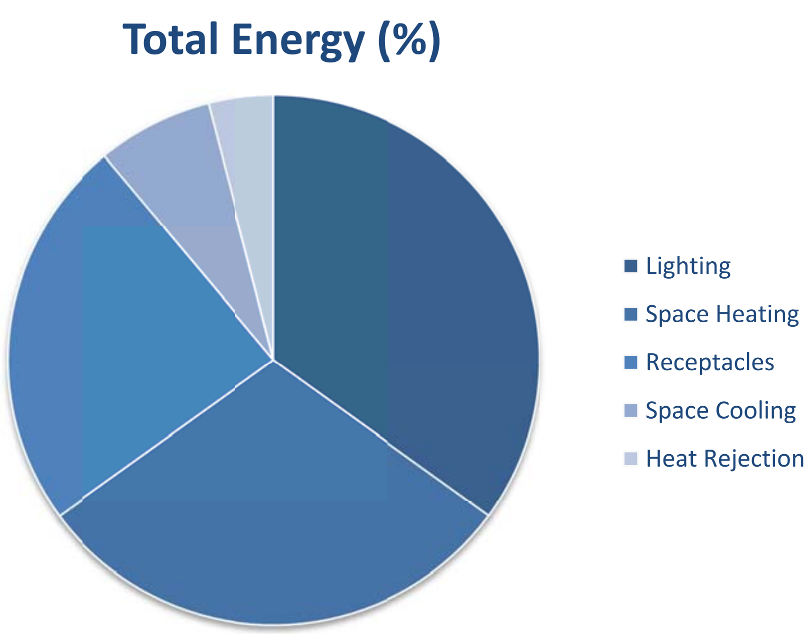

Figure 1: Energy Consumption Pie Chart

A monthly breakdown of the electrical and natural gas energy consumption can be seen in Figures 2 and 3, respectively. Typically, winter months and peak summer months consume the most energy, since the building is most heavily heated and cooled during those times. Since the heating system runs on natural gas and not electricity, Figure 2 shows the greatest electrical energy use during the summer months when the maximum AHU use occurs. Similarly, Figure 3 displays peaks in energy of the natural gas usage in the winter months.

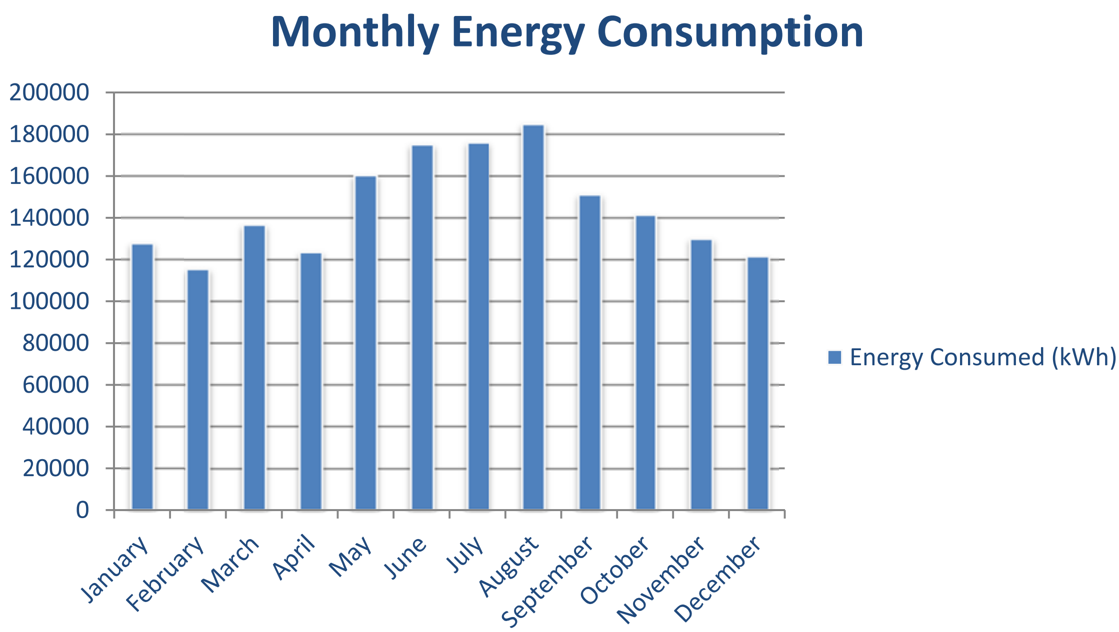

Figure 2: Monthly Electrical Energy Consumption Chart

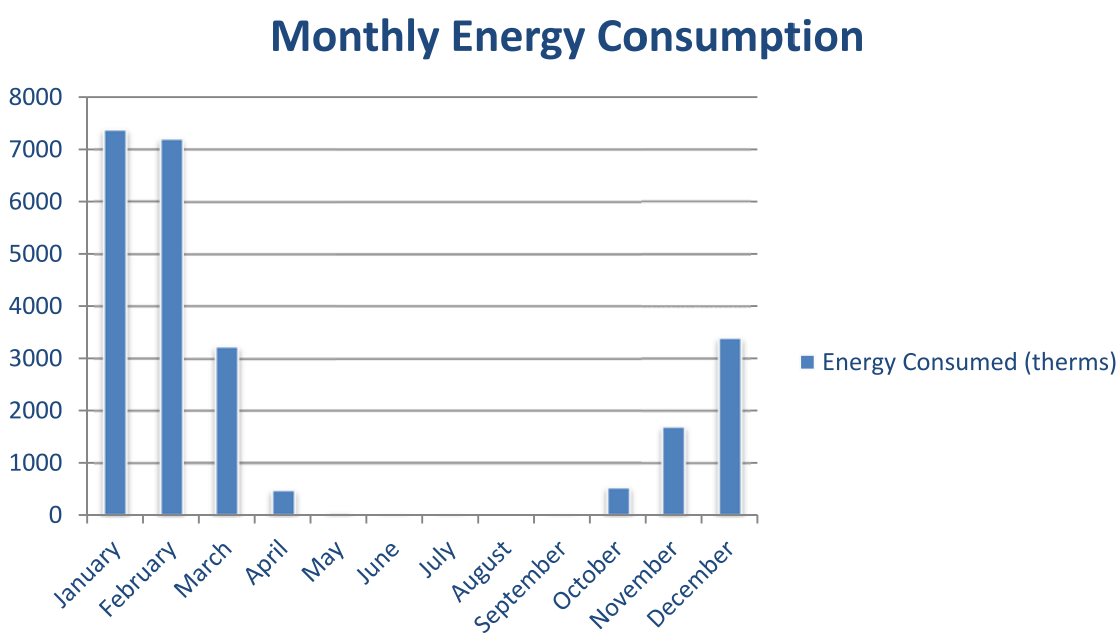

Figure 3: Monthly Natural Gas Energy Consumption Chart

Building Energy Cost Analysis

Knowing the monthly energy usages, an annual building operating cost analysis can be performed. Tables 5 and 6 display the utility rates for both electricity and natural gas, respectively, from the Baltimore Gas and Electric Company (BGE) website. These values were manually inserted into TRACE in the form of utility schedules, seen in Table 7, so that the energy consumption could be calculated in a yearlong energy simulation. Table 7 below shows the schedule of BGE Off-Peak, Mid-Peak, and Peak rates.

Table 5: BGE Electric Rates

	Demand Charge ($/kW)	Peak ($/kWh)	Mid-Peak (cents/kWh)	Off-Peak (cents/kWh)
Electricity	3.95	0.1155	0.0927	0.0882

Table 6: BGE Natural Gas Rates

	Up to first 10,000 therms ($/therm)	Above 10,000 therms ($/therm)
Natural Gas	0.198	0.095

Table 7: Schedule of BGE Rates

Start Time	End Time	Rate
11 p.m.	7 a.m.	Off-Peak
7 a.m.	10 a.m.	Mid-Peak
10 a.m.	8 p.m.	Peak
8 p.m.	11 p.m.	Mid-Peak

The total annual utility cost that was totaled for the consumed electricity and natural gas is $200,808 or 1.17 $/sf. TRACE's monthly breakdown of this analysis is shown in Figure 4. As displayed below, the highest monthly cost occurred in August. The reasoning for the drastic cost differentiations between the winter and summer months is most likely due to the low natural gas rate.

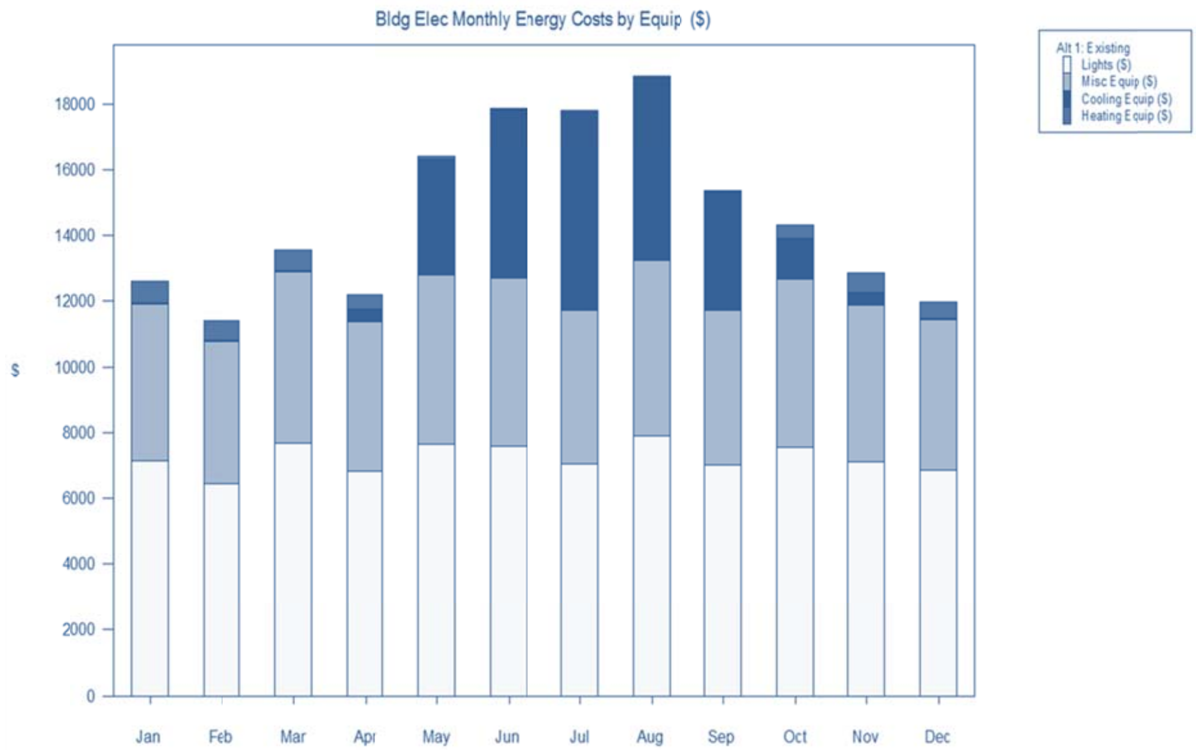

Figure 4: Monthly Building Electricity Costs by Equipment Chart

Environmental Impact Analysis

As well as the energy consumption assessment, the environmental impact of the emissions from the building is another vital element to consider. Average annual carbon dioxide, sulfur dioxide, nitrogen oxide emissions, and particulates were calculated manually. Using the given regional emissions coupled with the delivered electric energy for the 707 building location and emissions profiles associated with the boiler, the annual existing emissions footprint was determined. The assessed emissions summaries for the 707 building are shown in Tables 8 and 9, below.

Table 8: Combustion Emissions Produced by Electricity

Emission	Eastern Emission Factors (lbm/kWh)	Total Electricity Usage (kWh)	Total Emissions for Delivered (lbm/yr)
CO_2	1.64	1,743,765	2,859,775
SO_X	8.57E-3		14,944
NO_X	3.00E-3		5,231
PM10	9.16E-5		160

According to the RegionalGridemissionfactors2007.pdf,

> The PM factors are for direct emissions and do not include the effect of particulate formation in the atmosphere from chemical reactions of sunlight with emissions of NOx, SO_X, [and CO_2]. The PM composition and emission levels are complex functions of boiler firing configuration, boiler operation, pollution control equipment, and fuel properties.

Table 9: Combustion Emissions Produced by Natural Gas

Emission	Natural Gas ($lbm/1000ft^3$)	Natural Gas Usage (MBtu/year)	Conversion Factor (Btu/ft^3)	Total Emissions for Delivered (lbm/yr)
CO_2	11.6	44.305	1010	508,850
SO_X	1.22			53,517
NO_X	1.64E-2			719
PM10	8.17E-4			36

As learned in the Penn State Building Thermal Load Simulation and Energy Utilization Estimation course, only about 30% of original electricity produced is delivered to a building, where an efficient boiler delivers the energy more directly. The emissions from electricity are significantly greater than those from the natural gas because the majority of the building energy comes from electricity.

Building Energy and Cost Analysis Results

The generated block load energy model for the 707 building calculated the total annual energy consumption for cooling and heating loads to be 44.305 MBtu/year. The total load calculated by the design engineer was 42.232 MBtu/year, which indicates that the load energy consumptions are within 4.9% of each other. No energy cost analysis was run by the design engineer, therefore results could not be compared.

An estimated operating cost was determined by using individual utility consumptions. The total annual utility cost that was totaled for the consumed electricity and natural gas is $200,808 or 1.17 $/sf. The final operating cost per square foot will provide a unit of measurement that can be used to compare the building's energy performance to the redesign. The same combustion emissions analysis for the operation of the redesign will be performed in order to quantify the emissions footprint enhancements of the redesigned building.

REFERENCES

ANSI/ASHRAE (2007), Standard 62.1-2007, Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., Atlanta, GA, 2007.

ANSI/ASHRAE (2007), Standard 90.1-2007, Energy Standard for Buildings Except Low-Rise Residential Buildings. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., Atlanta, GA, 2007.

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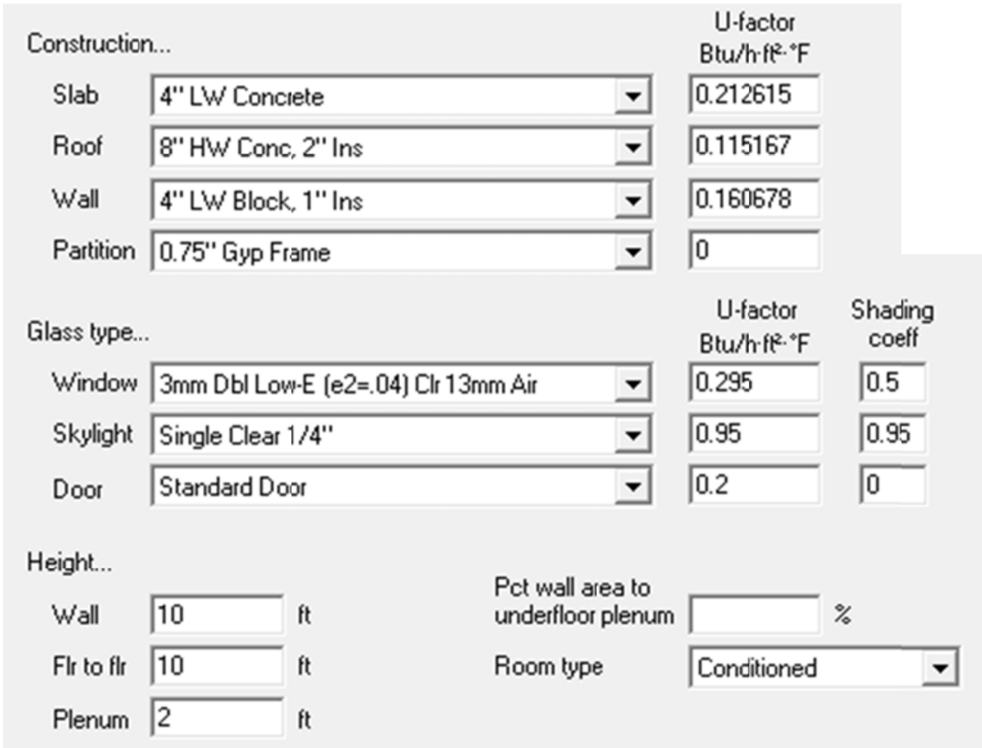
APPENDIX A – TRACE DATA TEMPLATES



Construction...

		U-factor Btu/h·ft²·°F
Slab	4" LW Concrete	0.212615
Roof	8" HW Conc, 2" Ins	0.115167
Wall	4" LW Block, 1" Ins	0.160678
Partition	0.75" Gyp Frame	0

Glass type...

		U-factor Btu/h·ft²·°F	Shading coeff
Window	3mm Dbl Low-E (e2=.04) Clr 13mm Air	0.295	0.5
Skylight	Single Clear 1/4"	0.95	0.95
Door	Standard Door	0.2	0

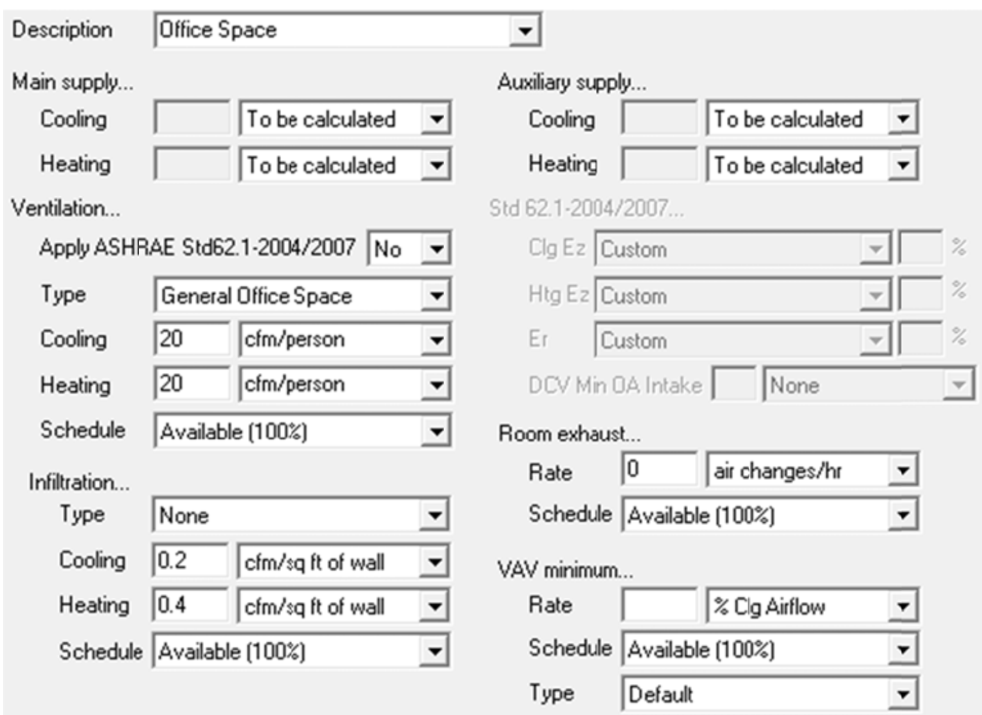
Height...

Wall	10	ft
Flr to flr	10	ft
Plenum	2	ft

Pct wall area to underfloor plenum: %

Room type: Conditioned

Construction Information for 707



Description: Office Space

Main supply...

Cooling		To be calculated
Heating		To be calculated

Auxiliary supply...

Cooling		To be calculated
Heating		To be calculated

Ventilation...

Apply ASHRAE Std62.1-2004/2007	No	
Type	General Office Space	
Cooling	20	cfm/person
Heating	20	cfm/person
Schedule	Available (100%)	

Std 62.1-2004/2007...

Clg Ez	Custom	%
Htg Ez	Custom	%
Er	Custom	%
DCV Min OA Intake		None

Infiltration...

Type	None	
Cooling	0.2	cfm/sq ft of wall
Heating	0.4	cfm/sq ft of wall
Schedule	Available (100%)	

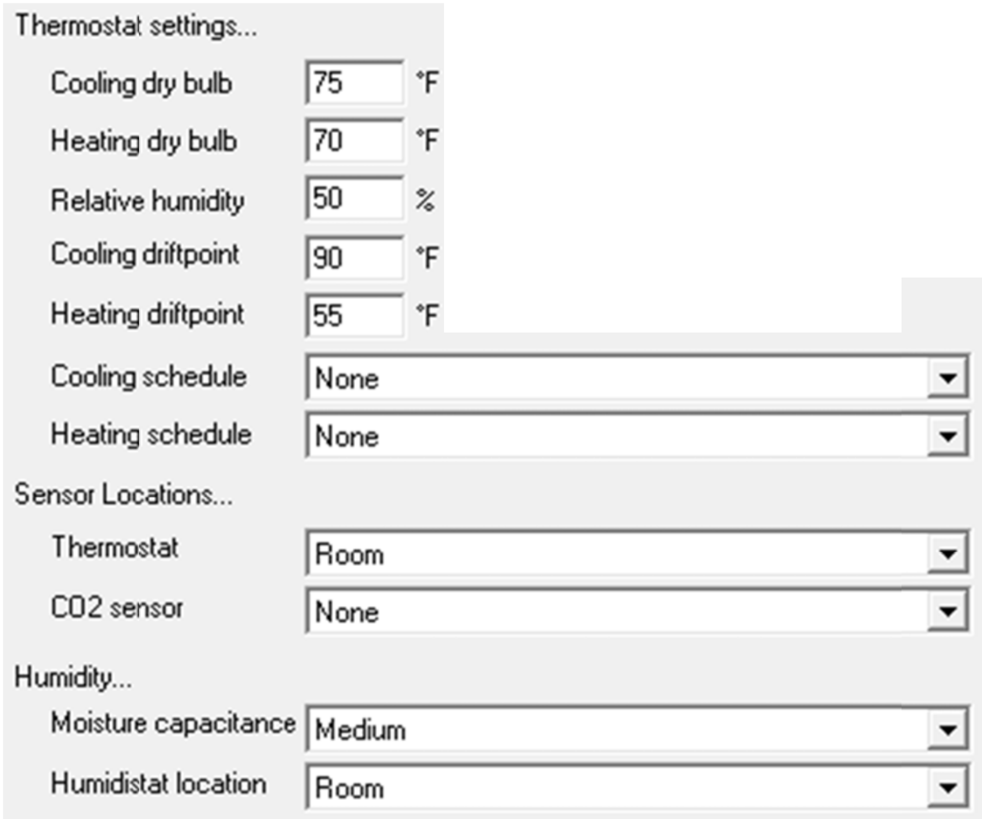
Room exhaust...

Rate	0	air changes/hr
Schedule	Available (100%)	

VAV minimum...

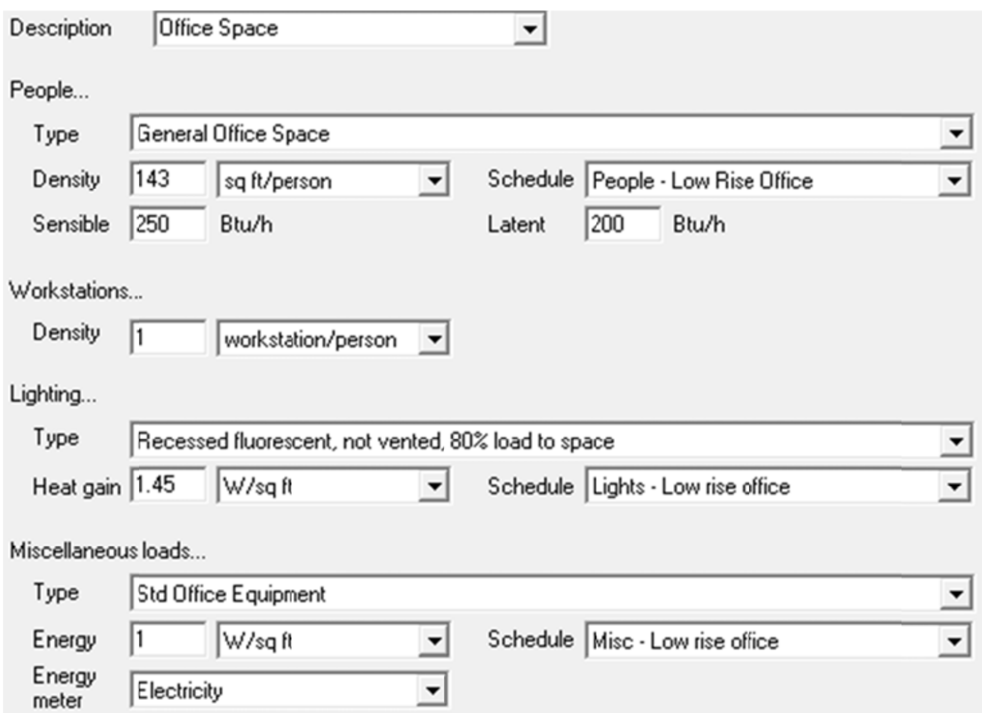
Rate		% Clg Airflow
Schedule	Available (100%)	
Type	Default	

Typical Office Airflows



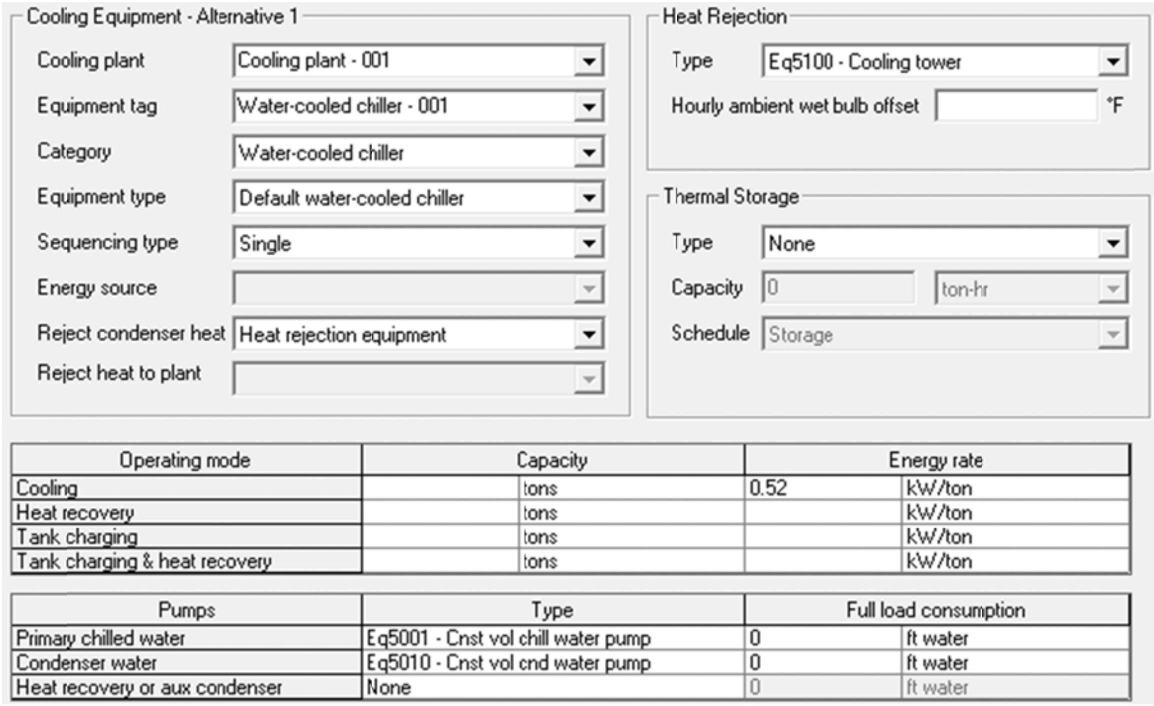
Thermostat settings...		
Cooling dry bulb	75	°F
Heating dry bulb	70	°F
Relative humidity	50	%
Cooling driftpoint	90	°F
Heating driftpoint	55	°F
Cooling schedule	None	
Heating schedule	None	
Sensor Locations...		
Thermostat	Room	
CO2 sensor	None	
Humidity...		
Moisture capacitance	Medium	
Humidistat location	Room	

Thermostat Settings for 707 Office Space



Description	Office Space			
People...				
Type	General Office Space			
Density	143	sq ft/person	Schedule	People - Low Rise Office
Sensible	250	Btu/h	Latent	200 Btu/h
Workstations...				
Density	1	workstation/person		
Lighting...				
Type	Recessed fluorescent, not vented, 80% load to space			
Heat gain	1.45	W/sq ft	Schedule	Lights - Low rise office
Miscellaneous loads...				
Type	Std Office Equipment			
Energy	1	W/sq ft	Schedule	Misc - Low rise office
Energy meter	Electricity			

Typical Office Internal Loads



Cooling Equipment - Alternative 1

Cooling plant: Cooling plant - 001
Equipment tag: Water-cooled chiller - 001
Category: Water-cooled chiller
Equipment type: Default water-cooled chiller
Sequencing type: Single
Energy source:
Reject condenser heat: Heat rejection equipment
Reject heat to plant:

Heat Rejection

Type: Eq5100 - Cooling tower
Hourly ambient wet bulb offset: °F

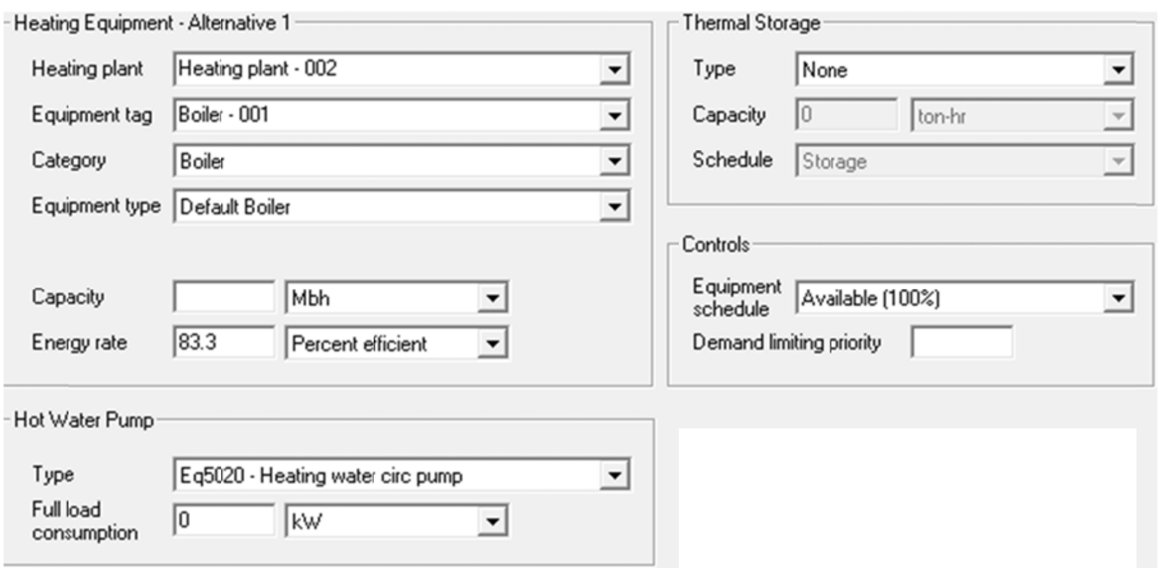
Thermal Storage

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

Operating mode	Capacity		Energy rate	
Cooling		tons	0.52	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	Eq5001 - Cnst vol chill water pump	0	ft water
Condenser water	Eq5010 - Cnst vol cnd water pump	0	ft water
Heat recovery or aux condenser	None	0	ft water

Cooling Plant Summary



Heating Equipment - Alternative 1

Heating plant: Heating plant - 002
Equipment tag: Boiler - 001
Category: Boiler
Equipment type: Default Boiler

Capacity: Mbh
Energy rate: 83.3 Percent efficient

Thermal Storage

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

Controls

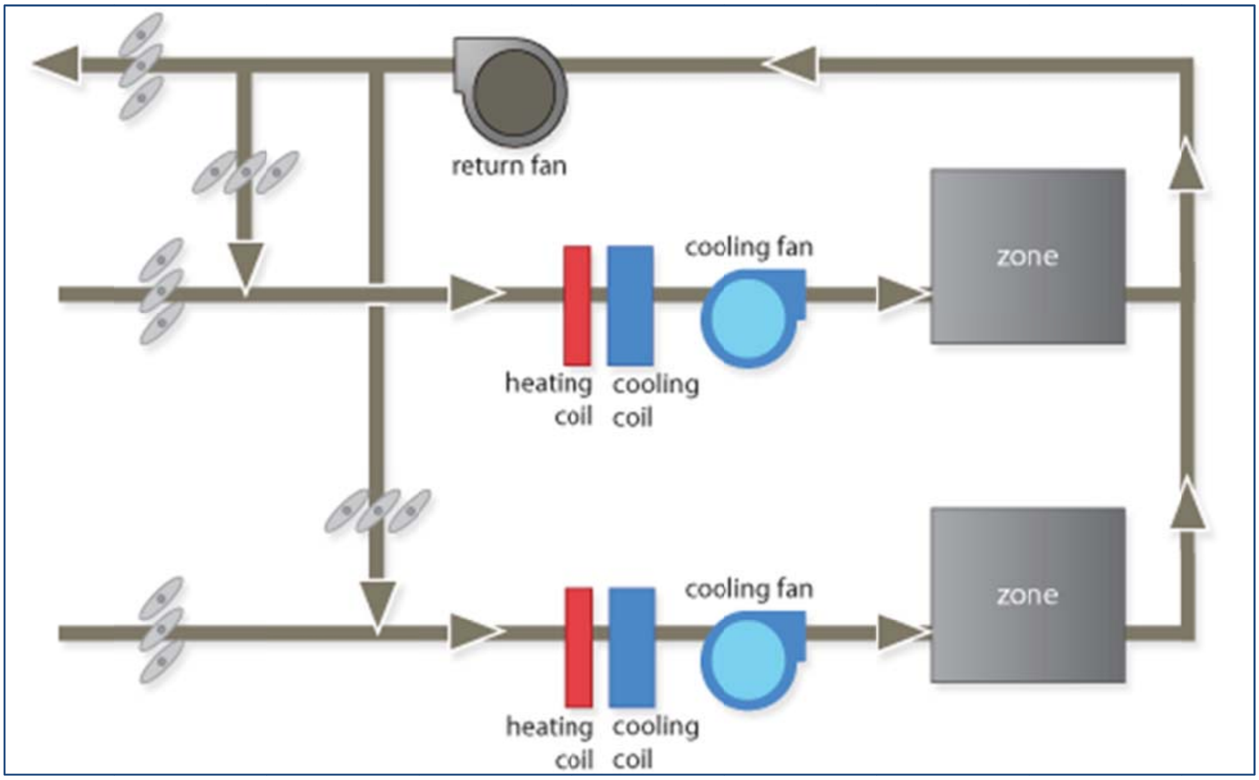
Equipment schedule: Available (100%)
Demand limiting priority:

Hot Water Pump

Type: Eq5020 - Heating water circ pump
Full load consumption: 0 kW

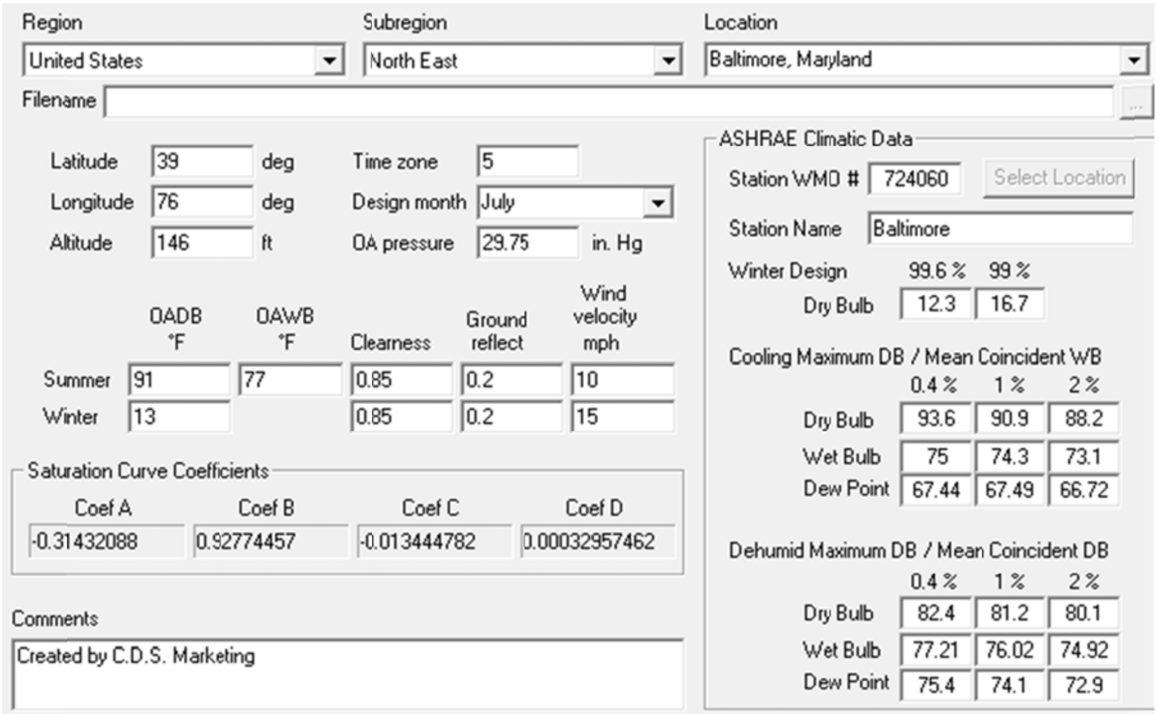
Heating Plant Summary

APPENDIX B – TRACE SYSTEM SCHEMATIC



System Schematic

APPENDIX C – WEATHER INFORMATION



Weather Conditions for Baltimore, MD

2009 ASHRAE Handbook - Fundamentals (IP)

BALTIMORE BLT-WASHNGTN INT'L, MD, USA WMO#: 724060

Lat: 39.17N Long: 76.68W Elev: 154 StdP: 14.61 Time Zone: -5.00 (NAE) Period: 82-06 WBAN: 93721

Annual Heating and Humidification Design Conditions

Coldest Month	Heating DB 99.6%	Heating DB 99%	Humidification DP/MCDB and HR 99.6% DP	99.6% HR	99.6% MCDB	99% DP	99% HR	99% MCDB	Coldest month WS/MCDB 0.4% WS	0.4% MCDB	1% WS	1% MCDB	MCWS/PCWD to 99.6% DB MCWS	PCWD
1	12.9	17.3	-3.3	4.6	17.8	1.3	5.9	22.1	26.2	31.6	24.2	32.1	8.7	290

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest Month	Hottest Month DB Range	Cooling DB/MCWB 0.4% DB	0.4% MCWB	1% DB	1% MCWB	2% DB	2% MCWB	Evaporation WB/MCDB 0.4% WB	0.4% MCDB	1% WB	1% MCDB	2% WB	2% MCDB	MCWS/PCWD to 0.4% DB MCWS	PCWD
7	18.7	93.9	74.9	91.2	74.2	88.5	73.1	78.1	88.6	76.8	86.5	75.6	84.3	10.2	280

Dehumidification DP/MCDB and HR 0.4% DP	0.4% HR	0.4% MCDB	1% DP	1% HR	1% MCDB	2% DP	2% HR	2% MCDB	Enthalpy/MCDB 0.4% Enth	0.4% MCDB	1% Enth	1% MCDB	2% Enth	2% MCDB	Hours 8 to 4 & 55/69
75.3	133.3	82.1	74.1	127.9	80.8	73.0	123.1	79.8	41.5	89.1	40.2	86.5	39.1	84.5	723

Extreme Annual Design Conditions

Extreme Annual WS 1%	2.5%	5%	Extreme Max WB	Extreme Annual DB Mean Min	Mean Max	Standard deviation Min	Standard deviation Max	n-Year Return Period Values of Extreme DB n=5 years Min	n=5 years Max	n=10 years Min	n=10 years Max	n=20 years Min	n=20 years Max	n=50 years Min	n=50 years Max
22.4	19.2	17.3	84.6	5.1	98.0	6.3	3.3	0.6	100.3	-3.1	102.2	-6.7	104.0	-11.3	106.4

Monthly Climatic Design Conditions

			Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperatures, Degree-Days and Degree-Hours	Tavg		55.9	33.9	36.9	44.2	54.2	63.6	72.7	77.6	75.7	68.3	56.8	47.3	37.8
	Sd			10.07	8.67	9.29	8.30	7.49	6.31	5.08	5.20	6.95	7.72	8.51	9.29
	HDD50		1726	507	376	231	45	1	0	0	0	0	22	152	392
	HDD65		4567	964	787	649	339	119	12	0	2	45	275	532	843
	CDD50		3861	8	9	50	171	424	680	855	796	550	232	71	15
	CDD65		1228	0	0	4	15	77	242	390	333	145	21	1	0
	CDH74		11317	0	1	42	195	792	2240	3853	2963	1071	148	11	1
	CDH80		4315	0	0	8	57	267	849	1669	1125	317	23	0	0
Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures	0.4%	DB		65.2	69.3	80.0	86.9	90.9	94.6	98.0	96.9	92.6	83.2	75.3	68.5
		MCWB		57.7	56.2	62.2	66.7	71.5	74.5	76.5	75.9	72.8	68.9	63.6	60.2
	2%	DB		59.5	61.4	71.1	79.6	86.8	91.3	94.7	92.6	87.1	78.1	69.8	62.1
		MCWB		54.5	53.5	58.1	63.2	69.3	73.9	75.7	75.0	71.7	66.9	60.2	55.3
	5%	DB		53.0	55.5	64.7	74.1	82.6	88.2	91.8	89.2	83.4	74.0	65.3	56.4
		MCWB		46.8	47.5	54.1	60.3	67.9	73.0	74.9	73.8	70.1	64.3	58.7	51.0
	10%	DB		47.6	50.4	59.4	69.3	78.1	85.1	88.7	86.1	80.2	70.2	61.4	51.6
		MCWB		42.7	44.3	50.1	57.3	65.5	71.8	74.0	72.5	69.0	62.5	55.6	46.1
Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures	0.4%	WB		60.1	60.1	64.6	68.9	74.8	78.8	80.2	79.4	77.0	72.2	66.5	62.1
		MCDB		63.2	66.0	76.5	80.5	86.0	88.3	91.3	90.0	85.0	77.8	70.8	67.1
	2%	WB		55.0	53.7	60.2	65.7	72.1	76.5	78.4	77.5	75.0	69.8	63.5	57.2
		MCDB		58.6	58.7	68.8	75.7	82.8	85.9	89.4	88.0	82.1	75.5	67.9	61.0
	5%	WB		47.9	49.1	55.7	62.4	69.7	75.2	77.2	76.2	73.3	66.6	60.1	52.1
		MCDB		50.9	54.0	62.1	71.4	79.4	84.2	87.6	85.0	79.2	71.9	64.1	55.5
	10%	WB		43.3	45.1	51.5	59.3	67.4	73.7	76.0	74.9	71.7	63.8	56.7	47.0
		MCDB		47.2	50.2	58.5	67.2	75.4	81.7	85.2	82.5	77.2	68.8	60.6	50.6
Mean Daily Temperature Range		MDBR		15.5	16.7	18.4	20.3	20.2	19.6	18.7	18.3	18.6	19.8	18.6	16.0
	5% DB	MCDBR		22.7	24.8	26.8	27.7	26.2	23.2	22.4	21.7	22.1	23.8	23.5	22.7
		MCWBR		17.1	17.3	16.6	14.6	12.2	9.6	8.1	8.3	9.7	13.7	16.1	17.5
	5% WB	MCDBR		20.1	21.3	23.7	24.0	22.7	19.6	19.1	18.6	17.7	19.3	19.6	19.8
		MCWBR		17.2	17.0	16.5	14.0	11.7	9.2	8.2	8.2	9.1	12.5	16.2	17.4
Clear Sky Solar Irradiance	taub			0.319	0.353	0.411	0.417	0.474	0.546	0.552	0.580	0.421	0.370	0.342	0.317
	taud			2.373	2.188	1.997	2.036	1.892	1.746	1.769	1.681	2.164	2.286	2.350	2.446
	Ebn,noon			269	272	266	273	258	239	237	225	261	264	258	262
	Edh,noon			30	40	52	53	62	72	69	74	44	36	31	27

ASHRAE 2009 HOF Weather Data for Baltimore, MD