Technical Report 2

Calvin G. Douglass, LEED® AP

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This document contains an energy use analysis of Manassas Park Elementary School, located in Manassas Park, Virginia. This analysis was created by entering block load inputs into a whole building load and energy simulation software. The results of the analysis were compared to the proposed design energy usage estimation created by professional design engineers at 2rw. Expected results from a comparable baseline building were also included in this analysis to clarify the estimated energy savings of Manassas Park Elementary School. Generalized cost and pollution values were also calculated to supplement the aforementioned information; results are contained within this report.

The Pennsylvania State University
Architectural Engineering: Mechanical
Advisor: Dr. Freihaut
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Executive Summary

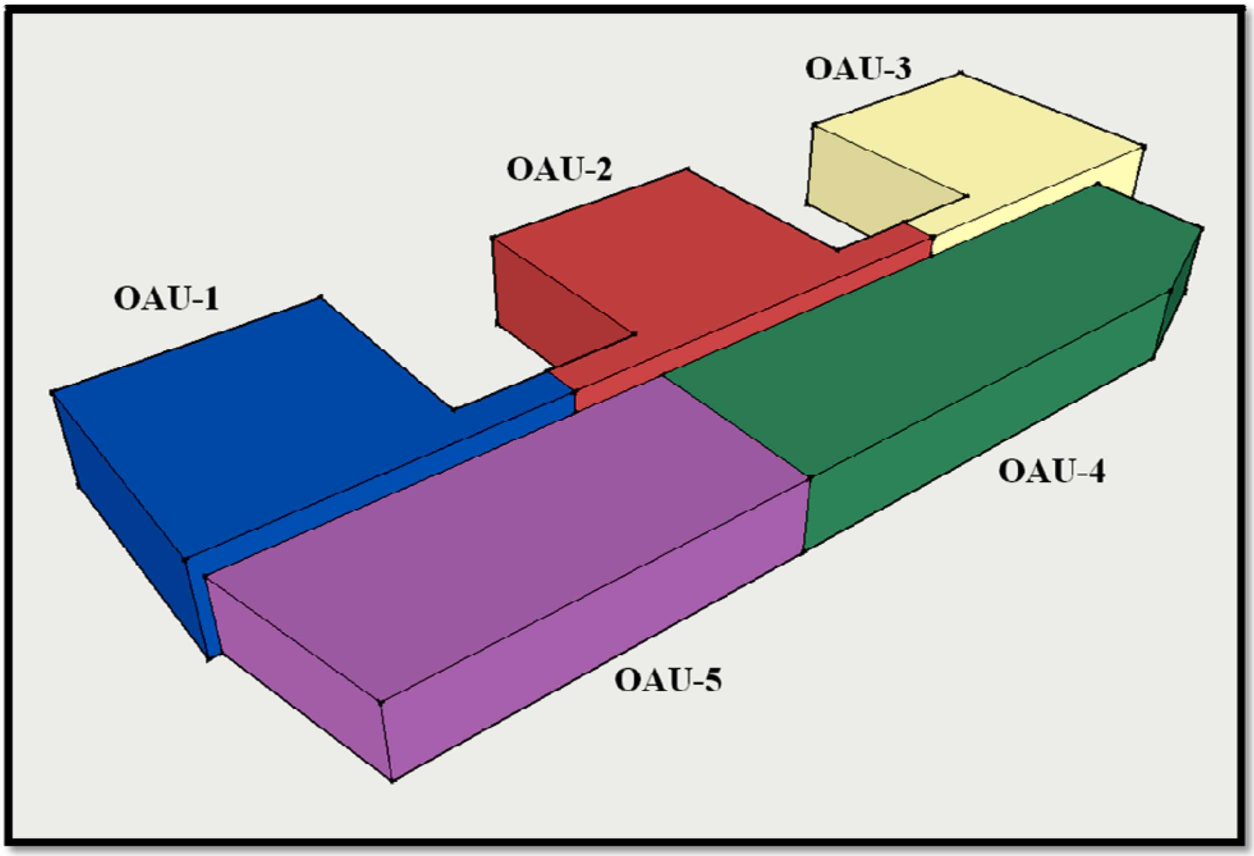
The purpose of this document is to report and discuss results from a whole building block load energy analysis describing predicted energy use (and associated values) for Manassas Park Elementary School. Associated values include predicted energy costs and total building pollutant outputs. These results have been compared to values proposed by professional design engineers from MPES, as well as to various expected values from a comparable baseline building. The whole building block load energy analysis described in this report was created using an energy modeling software called Trane Trace 700. The values that were reported from the professional engineers at 2rw Consultants were calculated from an energy modeling software called eQuest.

The results from the block building analysis performed for this discussion are reasonable; they fall within a range between the values calculated by professional design engineers and the values of a comparable baseline building. The total energy consumption calculated for Manassas Park Elementary School is 7003.7 mmbtu/year, with 4,632.4 mmbtu/year coming from natural gas and 2371.3 mmbtu/year (equivalent) coming from electricity. Further details on the results of the block building energy analysis can be reviewed on page 6 in Table 3: *Energy Analysis Results Summary*.

Mechanical Systems Overview

Manassas Park Elementary School utilizes an interesting conditioning system designed to maximize occupant comfort and to minimize energy consumption. It utilizes 5 constant volume Outside Air Units (OAU's), which have sensible wheels, desiccant wheels, direct fired gas heat exchangers and air-cooled direct expansion cooling coils with which they supply 100% outside air at 72˚ Fahrenheit and 50% relative humidity to the building. Before this air enters any occupied spaces, it is intercepted by heat pumps, which further condition the air to its supply temperature. These heat pumps reject their heat to a 200-well geothermal system which is capable of handling a load of 4,000,000 BTU's per hour (4,000 MBH). Figure 1, below, shows the relationships between the buildings zones and their respective pre-conditioners/ventilators. This figure was created using Google Sketchup 7 for the assistance of this system zone explanation:

Figure 1: OAU Zones



Because of the buildings symmetries, outside air units 1, 2, and 3 are identically designed and specified. These symmetries were also taken advantage of in the creation of the block energy analysis performed for this report; floor 1 of pod 1 was analyzed in detail, and the results of that analysis were multiplied by 9 to represent the remaining floors of pod 1 along with all three floors of pods 2 and 3. The outdoor air unit schedule provided information that was used as inputs for the block energy analysis. This schedule can be seen in Table 1, below.

Table 1: Outdoor Air Unit Schedule

Mark	Supply Air (CFM)	Supply Fan Power (HP)	Exhaust Fan Power (HP)	Enthalpy Wheel Power (HP)	Sensible Wheel Power (HP)	Cooling Coil Cap (MBH)	Gas Fired Cap (MBH)	Pre-Filter Efficiency
OAU-1,2,3	3360	5	3	0.25	0.25	128.5	123	30%
OAU-4	9330	15	7.5	0.5	0.25	365.3	341	30%
OAU-5	4650	7.5	3	0.25	0.25	188.3	170	30%

Design Load Estimation

For this section of the report, it was suggested that students utilize one of the following whole building load and energy simulation programs to perform a block load analysis: "EnergyPlus, eQuest, Trace, HAP, IES, [or] ASHRAE RTSM". Trane Trace 700 Version 6.2 was ultimately chosen for this analysis because it provided the best resources for help, and it came highly recommended from a well respected Penn State colleague, Justin Herzing.

Information from the architectural, electrical, and mechanical design documents was used to build the Trane Trace 700 model.

Load Sources and Modeling Information

The main load sources in the building are occupants, ventilation, infiltration, artificial lights, electrical equipment, mechanical equipment, ambient conduction/convection and direct solar gain.

Design Occupancy and Ventilation

All ventilation rates used in this energy analysis were taken from the design schedules as provided by the mechanical engineer. Design occupancy was not explicitly available for Manassas Park Elementary School, so ASHRAE recommended occupancies were used in this analysis.

Infiltration

Manassas Park Elementary School was assumed to have an infiltration rate at 0.3 air changes per hour for this analysis. This infiltration value is representative of a well constructed building that has a slightly higher air pressure than the ambient outdoor air.

Electrical Loads

The requirements for this technical report specified that students should "use lights and equipment electrical loads on a Watt per square foot basis".

The average lighting power density of the building is 0.67 Watts per square foot, where some spaces have a lighting power density as high as 1.12 Watts per square foot and others have a lighting power density as low as 0.53 Watts per square foot. Because the electrical loads in the school varied so drastically from space to space, actual lighting inputs were used. This was done because Manassas Park Elementary School is only a 123,000 square foot building, and fixture counts were readily available (minimizing time and energy inputs by the author). This extra step should prove to provide a more accurate energy model.

Weather Data

Indoor and outdoor air conditions for heating and cooling in Manassas, VA were used for this analysis. These values were taken from the 2005 ASHRAE Handbook of Fundamentals, and they represent the 0.4% and 99.6% values, respectively. Manassas is very close to Manassas Park, VA, and weather patterns are comparable. Table 2, below, shows the values used in this analysis[1].

Table 2: ASHRAE 2009 Weather Data – Manassas, VA

ASHRAE Values	Summer Design Cooling - 0.4%	Winter Design Heating - 99.6%
OA Dry Bulb (˚F)	92.7	10.6
OA Wet Bulb (˚F)	74.0	~

[1] The actual weather data sheet used for this information can be reviewed in Appendix B.

IA Dry Bulb (˚F)	74	70
Clearness Number	0.85	0.85
Ground Reflectance	0.2	0.2

Results

Results calculated as part of the whole building load and energy simulation analysis are a reasonable representation of what a reasonable elementary school building should consume. Table 3, below, shows results of this analysis, and compares the results side by side to both the building energy as estimated by the design engineers (proposed building) and a comparable baseline building. The energy consumption values used for the proposed building were estimated by professional design engineers using eQuest.

The style chosen to represent these results roughly emulates the style used for the LEED-NC 2.2 Submittal Template for EA Credit 1: Optimize Energy Performance. The relevant portion of the LEED-NC 2.2 Submittal that was actually submitted for EA Credit 1: Optimize Energy Performance can be reviewed in Appendix A.

Table 3: Energy Analysis Results Summary

End Use	Energy Type	Units	Analysis Building Results Estimation	Proposed Building Results	Baseline Building Results
Interior Lighting	Electricity	Energy Use (kWh)	105,321.0	119,320.0	311,811.0
		Demand (kW)	-	78.5	147.0
Exterior Lighting	Electricity	Energy Use (kWh)	10,000.0	9,854.0	24,110.0
		Demand (kW)	-	2.8	6.8
Space Heating	Electricity	Energy Use (kWh)	82,920.0	50,861.0	26,249.8
		Demand (kW)	-	116.8	25.8
Space Heating - Gas	Natural Gas	Energy Use (therms)	39,365.8	-	-
		Demand (MBH)	-	-	-
Space Cooling	Electricity	Energy Use (kWh)	152,526.0	71,690.0	402,868.2
		Demand (kW)	-	110.6	267.1
Pumps	Electricity	Energy Use (kWh)	-	41,199.0	5,954.3
		Demand (kW)	-	9.5	1.6
Heat Pump Supplemental	Electricity	Energy Use (kWh)	-	38.0	9,156.5
		Demand (kW)	-	1.5	61.1
Fans - Interior	Electricity	Energy Use (kWh)	84,805.0	266,200.0	101,162.0
		Demand (kW)	-	98.3	61.5
Space Heating - Gas	Natural Gas	Energy Use (therms)	-	5,556.0	36,942.5
		Demand (MBH)	-	630.0	3,550.0
Service Water Heating	Electricity	Energy Use (kWh)	-	23,134.0	23,163.8
		Demand (kW)	-	13.9	13.9
Receptacle Equipment	Electricity	Energy Use (kWh)	19,370.0	93,180.0	93,180.0
		Demand (kW)	-	40.2	40.2
Pumps/Auxiliary	Electricity	Energy Use (kWh)	142,605.0	-	-
		Demand (kW)	-	-	-
Refrigeration	Electricity	Energy Use (kWh)	-	49,932.0	49,932.0
		Demand (kW)	-	13.7	13.7
Service Water Heating - Gas	Natural Gas	Energy Use (therms)	-	3,148.0	3,858.5
		Demand (MBH)	-	320.0	390.0
Cooking	Electricity	Energy Use (kWh)	-	44,181.0	44,181.0
		Demand (kW)	-	35.0	35.0
Elevators and Escalators	Electricity	Energy Use (kWh)	-	9,839.0	9,839.0

		Demand (kW)	-	4.2	4.2
Cooking - Gas	Natural Gas	Energy Use (therms)	-	3,424.0	3,424.0
		Demand (MBH)	-	270.0	270.0
Total Corrected Gas Usage	Natural Gas	Energy Use (therms)	46,324.1	12,128.0	44,225.0
Total Corrected Electricity Usage	Electricity	Energy Use (kWh)	694,982.1	781,173.0	1,106,495.5
Total Corrected Energy Usage	~	mmbtu/year	7,003.7	3,878.2	8,197.9
Energy Usage as a Percent of Baseline	~	~	85.4%	47.3%	100.0%
Energy Usage as a Percent of Proposed	~	~	180.6%	100.0%	211.4%
Energy Usage as a Percent of Estimated	~	~	100.0%	55.4%	117.1%
Correction Factor:	1.18				

The most notable values in comparing the building loads that were estimated as part of this analysis and the building loads that were estimated by the design engineers are those that are contained within the last 4 rows of the above table. Specifically, the summarized results in the above table show that the results for the building loads that were estimated as part of this analysis are 180.6% of those that were estimated by the design engineers.

These results came as no surprise. A series of engineering decisions were made during the modeling process that were expected manipulate the results to values slightly greater than the values that would be expected in a comparable tangible building. Most notably, natural ventilation and solar shading were designed to make a significant impact on the total energy consumption of Manassas Park Elementary School; these technologies were *neglected*[2] from the block energy analysis performed for this report, which should have driven the results of this analysis to much higher values than those presented by the professional design engineers. Contrariwise, roof surface area was *neglected*[3] from the block energy analysis performed for this report, which should have decreased the results of this analysis to values that are closer to (yet not in synergy with) the resulting values in the professional design engineers model (resulting directly from less total exterior surface area, which affects solar gain as well as convective and conductive heat transfer to and/or from the ambient outdoor air). This expected outcome is evident in the results of this analysis presented above in Table 3. There exists the possibility that these two “assumptions” had a relatively equal but opposite effect on the energy model, with the terminal result on the model being tabulated as negligible. This unlikely yet plausible scenario could be used to show that there are indeed some modeling errors, even though the final results of this model are as expected.

[2] Natural ventilation and solar shading were neglected from the block building load and energy simulation analysis due to the analyzing engineer’s unfamiliarity’s with the load estimation software. Reasonable explanations of these estimation techniques were unsuccessfully investigated for the benefit of this report.

[3] Roof surface area was not utilized in the block building load and energy simulation analysis due to the initial assumption of building pod floor symmetries. One floor of pod 1 was analyzed, and the results of which were multiplied by nine to account for the remaining two floors of pod 1, as well as all three floors of pod 2 and pod 3.

Possible Errors

The myriad of possible error scenarios that existed throughout the execution of this specific analysis can be grouped in three main categories: Modeler error, modeling software error, and miscommunication between the modeler and the modeling software.

The modeler that performed this specific analysis was relatively new to the program, and had never modeled this type of system before[4]. This could lead to many further errors; all of which with possible detrimental effects to the models end results.

Although rare, modeling software packages may still contain intrinsic errors. They were ultimately created by humans, which are by no means perfect.

Miscommunication between the modeler and the modeling software is also a possible source of error. If the modeling software perceives a specific building characteristic or system input differently than the modeler had initially intended, the results may become unfavorably skewed.

Operating Costs

The operating costs of the building were calculated using an averaged rate structure. This rate was calculated by taking averaged annual costs from the professional design engineers' cost analysis and dividing them by the average annual energy totals from the professional design engineers' energy analysis. The resultant number was in the form of dollars per unit of energy, and can be reviewed below in Table 4.

Table 4: Averaged Energy Costs

Energy Type	Averaged Energy Cost	Units
Electricity	0.075911308	dollars/kWh
Natural Gas	1.313679057	dollars/therm

Manassas Park Elementary Schools annual energy costs were calculated using these averaged energy rates, and the results can be found in Table 5, below. This table shows the results for the building estimation performed in this analysis, the results for the building estimation performed by the professional design engineers, and the results for a comparable baseline building.

[4] Rigorous attempts were made by the modeler to correctly model the systems of Manassas Park Elementary School; the Trane Trace 700 helpline was regularly used throughout the modeling process to efficiently increase the accuracy of the models end results.

Table 5: Energy Cost Analysis Results Summary

Energy Type	Analysis Building Results			Proposed Building Results			Baseline Building Results		
	Energy Use	Units	Cost	Energy Use	Units	Cost	Energy Use	Units	Cost
Electricity	694,982.1	kWh	$ 52,757	781,173.0	kWh	$ 59,182	1,106,495.5	kWh	$ 84,163
Natural Gas	46,324.1	therms	$ 60,855	12,128.0	therms	$ 16,244	44,224.0	therms	$ 56,960
Total	7,003.7	mmbtu	$ 113,612	3,878.2	mmbtu	$ 75,426	8,197.9	mmbtu	$ 141,123
Energy Price as a Percent of Baseline	~	%	80.5%	~	%	53.4%	~	%	100.0%
Energy Usage as a Percent of Proposed	~	%	150.6%	~	%	100.0%	~	%	187.1%
Energy Usage as a Percent of Estimated	~	%	100.0%	~	%	66.4%	~	%	124.2%

Energy Usage vs. Cost - Discrepancy Discussion

Table 3 showed that building **loads** calculated as part of this analysis were 180.6% of the **loads** calculated during the professional design engineers' load analysis. However, Table 5 (above) showed that building **energy costs** calculated as part of this analysis were 150.6% of the **energy costs** calculated during the professional design engineers' load analysis, or roughly 83.4% of the difference between the **loads** calculated in this analysis and the **loads** calculated during the professional design engineers' load analysis. Also, the building consumed 694,982.1 kWh annually and only 46,324.1 therms annually. The fact that the difference between these two numbers was over an order of magnitude was initially troubling; however, upon further investigation, a reasonable explanation was quickly established.

Table 6 (below) displays a value that will be referred to as the "Leveling Energy Factor", which was derived for the purpose of this explanation.

Table 6: Leveling Energy Factors for Electricity and Natural Gas

Energy Type	Leveling Energy Factor	Units
Electricity	293.08	kwh/mmbtu
Natural Gas	10.00	therm/mmbtu

As the units suggest, the Leveling Energy Factor is simply a numerical representation of how many units of a particular energy type are in one standard mmbtu of *equivalent* energy. This number can be used to illustrate why the **energy use differences** between the model created for this analysis and the model created by the professional design engineers are greater than the **energy consumption cost differences** between the model created for this analysis and the model created by the professional design engineers.

Notice that the Leveling Energy Factor for electricity is almost 30 times larger than the Leveling Energy Factor for natural gas. This can be used to explain why such a large electric consumption has a relatively small effect on the building as a whole[5].

Table 7, below, compares the average energy cost per electric *equivalent* mmbtu to the average energy cost per natural gas mmbtu.

Table 7: Price per mmbtu or mmbtu equivalent for Electricity and Natural Gas

Energy Type	Averaged Energy Cost	Units
Electricity	$ 22.25	dollars/electric mmbtu
Natural Gas	$ 13.14	dollars/natural gas mmbtu

These numbers were calculated by multiplying the averaged energy cost (in dollars/kWh or dollars/therm) by the specific unit's respective Leveling Energy Factor. The averaged energy cost (in units of dollars/mmbtu) will be useful in later analyses as it shows that energy purchased in the form of natural gas is cheaper on a price per unit energy basis than energy purchased in the form of electricity.

Pollution Estimation

When source energy factors are applied to the analyzed building, the following results are obtained:

Table 8: VA Emission Factors and MPES Annual Pollutant Emissions

Pollutant	lb/kWh in VA	lb/1000ft^3	lb/therm	Analysis Building lb/year	Proposed Building lb/year	Baseline Building lb/year
CO_{2e}	1.40E+00	1.21E+02	1.21E+01	1,533,496.99	1,240,391.00	2,084,216.20
CO_2	1.33E+00	1.20E+02	1.20E+01	1,480,215.82	1,184,496.09	2,002,339.02
CH_4	2.52E-03	2.30E-03	2.30E-04	1,762.01	1,971.35	2,798.54
N_2O	2.81E-05	2.20E-03	2.20E-04	29.72	24.62	40.82
NO_X	2.67E-03	9.40E-03	9.40E-04	1,899.15	2,097.13	2,995.91
SO_X	8.04E-03	6.00E-04	6.00E-05	5,590.44	6,281.36	8,898.88
CO	9.74E-04	4.00E-02	4.00E-03	862.21	809.37	1,254.63
TNMOC	8.77E-05	5.50E-03	5.50E-04	86.43	75.18	121.36
Lead	1.02E-07	5.00E-07	5.00E-08	0.07	0.08	0.12
Mercury	3.24E-08	2.60E-07	2.60E-08	0.02	0.03	0.04
PM10	7.25E-05	7.60E-03	7.60E-04	85.59	65.85	113.83
Solid Waste	1.47E-01	0.00E+00	0.00E+00	102,162.37	114,832.43	162,654.84

The energy emissions factors reported in Table 8, above, come from tables that can be viewed in Appendix C.

[5] The building analysis conducted for this report showed that the building consumed 694,982.1 kWh of electricity annually and only 4,632.41 therms annually. However, when these numbers are divided by their respective Leveling Energy Factors, it becomes evident that the building consumes 2371.3 equivalent mmbtu's of electricity and 4632.4 mmbtu's of natural gas.

Resources:

ASHRAE Standard 62.1-2004
ASHRAE Standard 62.1-2007
ASHRAE Standard 62.1-2004 Users Manual
ASHRAE Standard 90.1-2004
ASHRAE Standard 90.1-2007
ASHRAE Standard 90.1-2004 Users Manual
ASHRAE Handbook of Fundamentals
ASHRAE Handbook of HVAC Systems and Equipment
Source Energy and Emission Factors for Energy Use in Buildings – M. Deru and P. Torcellini (2007)

Gregory Smithmyer
Justin Herzing

Appendix A: LEED 2.2 Submittal – EA Credit 1

Table 1.8.1 - Baseline Performance - Performance Rating Method Compliance

End Use	Process?	Baseline Design Energy Type	Units of Annual Energy & Peak Demand	Baseline (0° rotation)	Baseline (90° rotation)	Baseline (180° rotation)	Baseline (270° rotation)	Baseline Design	
Interior Lighting	☐	Electricity	Energy Use (kWh)	311,811	311,811	311,811	311,811	311,811	CLEAR
			Demand (kW)	147	147	147	147	147	
Exterior Lighting	☐	Electricity	Energy Use (kWh)	24,110	24,110	24,110	24,110	24,110	CLEAR
			Demand (kW)	6.8	6.8	6.8	6.8	6.8	
Space Heating	☐	Electricity	Energy Use (kWh)	24,935	26,589	27,470	26,005	26,249.8	CLEAR
			Demand (kW)	24.8	25.8	26.6	26.1	25.8	
Space Cooling	☐	Electricity	Energy Use (kWh)	401,429	401,984	393,192	414,869	402,868.5	CLEAR
			Demand (kW)	266.5	263.7	267.1	271	267.1	
Pumps	☐	Electricity	Energy Use (kWh)	6,054	5,760	5,880	6,123	5,954.3	CLEAR
			Demand (kW)	1.6	1.6	1.6	1.6	1.6	
Heat Pump Supplemental	☐	Electricity	Energy Use (kWh)	8,782	8,587	9,637	9,620	9,156.5	CLEAR
			Demand (kW)	60.7	61.2	61.1	61.3	61.1	
Fans - Interior	☐	Electricity	Energy Use (kWh)	101,351	98,797	101,025	103,475	101,162	CLEAR
			Demand (kW)	62.3	59.7	60.4	63.6	61.5	
Space Heating - Gas	☐	Natural Gas	Energy Use (therms)	36,850	35,443	36,988	38,489	36,942.5	CLEAR
			Demand (MBH)	3,860	3,240	3,240	3,860	3,550	
Service Water Heating	☐	Electricity	Energy Use (kWh)	23,157	23,169	23,170	23,159	23,163.8	CLEAR
			Demand (kW)	13.9	13.9	13.9	13.9	13.9	
Receptacle Equipment	☒	Electricity	Energy Use (kWh)	93,180	93,180	93,180	93,180	93,180	CLEAR
			Demand (kW)	40.2	40.2	40.2	40.2	40.2	
Pumps/Auxiliary	☒	Natural Gas	Energy Use (therms)	0	0	0	0	0	CLEAR
			Demand (MBH)						
Refrigeration	☒	Electricity	Energy Use (kWh)	49,932	49,932	49,932	49,932	49,932	CLEAR
			Demand (kW)	13.7	13.7	13.7	13.7	13.7	
Service Water Heating - Gas	☐	Natural Gas	Energy Use (therms)	3,856	3,857	3,861	3,860	3,858.5	CLEAR
			Demand (MBH)	390	390	390	390	390	
Cooking	☒	Electricity	Energy Use (kWh)	44,181	44,181	44,181	44,181	44,181	CLEAR
			Demand (kW)	35	35	35	35	35	
Elevators & Escalators	☒	Electricity	Energy Use (kWh)	9,839	9,839	9,839	9,839	9,839	CLEAR
			Demand (kW)	4.2	4.2	4.2	4.2	4.2	
Cooking - Gas	☒	Natural Gas	Energy Use (therms)	3,424	3,424	3,424	3,424	3,424	CLEAR
			Demand (MBH)	270	270	270	270	270	
Baseline Energy Totals:		Total Annual Energy Use	(MBtu/year)	8,162	8,019	8,158	8,386	8,181	
		Annual Process Energy	(MBtu/year)					1,015	

Note: Process Cost accounts for 18% of Baseline Performance. Process cost must equal at least 25% of Baseline Performance, or the narrative at the end of this form must document why this building's process costs are less than 25%

Appendix B: ASHRAE Weather Data

2005 ASHRAE Handbook - Fundamentals (IP)

Design conditions for MANASSAS MUNI (AWOS), VA, USA

Station Information

Station name	WMO#	Lat	Long	Elev	StdP	Hours +/- UTC	Time zone code	Period
1a	*1b*	*1c*	*1d*	*1e*	*1f*	*1g*	*1h*	*1i*
MANASSAS MUNI (AWOS)	**724036**	**38.72N**	**77.52W**	**194**	**14.593**	**-5.00**	**NAE**	**9201**

Annual Heating and Humidification Design Conditions

Coldest month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
2	*3a*	*3b*	*4a*	*4b*	*4c*	*4d*	*4e*	*4f*	*5a*	*5b*	*5c*	*5d*	*6a*	*6b*
1	**10.6**	**16.0**	**-1.9**	**5.0**	**16.4**	**2.5**	**6.3**	**21.3**	**25.5**	**35.1**	**22.6**	**36.0**	**3.0**	**330**

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest month	Hottest month DB range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	*8*	*9a*	*9b*	*9c*	*9d*	*9e*	*9f*	*10a*	*10b*	*10c*	*10d*	*10e*	*10f*	*11a*	*11b*
7	**20.9**	**92.7**	**74.0**	**90.4**	**73.4**	**88.0**	**72.2**	**76.5**	**88.0**	**75.2**	**86.2**	**74.0**	**84.5**	**8.1**	**200**

Dehumidification DP/MCDB and HR									Enthalpy/MCDB					
0.4%			1%			2%			0.4%		1%		2%	
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB
12a	*12b*	*12c*	*12d*	*12e*	*12f*	*12g*	*12h*	*12i*	*13a*	*13b*	*13c*	*13d*	*13e*	*13f*
73.0	**123.3**	**82.2**	**72.1**	**119.4**	**81.4**	**70.5**	**113.0**	**79.8**	**32.2**	**88.0**	**31.0**	**86.7**	**29.9**	**84.0**

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
14a	*14b*	*14c*	*15*	*16a*	*16b*	*16c*	*16d*	*17a*	*17b*	*17c*	*17d*	*17e*	*17f*	*17g*	*17h*
21.8	**18.8**	**16.4**	**82.0**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**

Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18a	*18b*	*18c*	*18d*	*18e*	*18f*	*18g*	*18h*	*18i*	*18j*	*18k*	*18l*
0.4%	**67.6**	**59.9**	**70.1**	**56.2**	**81.8**	**61.7**	**85.4**	**66.3**	**90.3**	**70.7**	**93.3**	**74.2**
1%	**65.6**	**60.4**	**65.7**	**54.0**	**75.6**	**57.5**	**82.9**	**63.2**	**88.1**	**69.0**	**91.7**	**73.6**
2%	**63.3**	**57.5**	**62.7**	**51.4**	**72.2**	**55.0**	**80.1**	**61.7**	**85.6**	**68.1**	**90.4**	**73.4**

%	Jul		Aug		Sep		Oct		Nov		Dec	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18m	*18n*	*18o*	*18p*	*18q*	*18r*	*18s*	*18t*	*18u*	*18v*	*18w*	*18x*
0.4%	**96.7**	**75.4**	**94.8**	**75.2**	**93.0**	**71.9**	**82.4**	**67.0**	**73.1**	**59.3**	**71.4**	**58.1**
1%	**94.5**	**74.4**	**92.9**	**74.7**	**90.8**	**70.7**	**81.2**	**65.2**	**71.4**	**57.1**	**65.8**	**55.1**
2%	**93.0**	**74.3**	**91.3**	**74.1**	**88.1**	**70.0**	**78.9**	**64.0**	**69.6**	**58.4**	**62.7**	**54.2**

Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19a	*19b*	*19c*	*19d*	*19e*	*19f*	*19g*	*19h*	*19i*	*19j*	*19k*	*19l*
0.4%	**62.4**	**65.4**	**58.7**	**67.2**	**62.1**	**79.5**	**67.2**	**81.4**	**72.4**	**86.6**	**76.6**	**88.6**
1%	**60.0**	**63.9**	**55.9**	**63.1**	**60.0**	**74.2**	**65.9**	**79.7**	**71.2**	**85.1**	**75.7**	**86.9**
2%	**58.4**	**62.9**	**52.8**	**60.6**	**57.0**	**66.9**	**64.4**	**75.4**	**69.6**	**82.2**	**75.1**	**86.3**

%	Jul		Aug		Sep		Oct		Nov		Dec	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19m	*19n*	*19o*	*19p*	*19q*	*19r*	*19s*	*19t*	*19u*	*19v*	*19w*	*19x*
0.4%	**78.8**	**90.6**	**78.2**	**90.1**	**75.1**	**85.8**	**69.4**	**78.8**	**64.5**	**68.1**	**60.2**	**67.2**
1%	**77.8**	**89.7**	**77.2**	**88.5**	**74.0**	**84.0**	**68.1**	**77.2**	**63.3**	**66.8**	**57.6**	**64.2**
2%	**77.0**	**88.7**	**76.3**	**87.2**	**72.9**	**82.7**	**66.3**	**74.6**	**61.3**	**65.7**	**55.4**	**61.3**

Monthly Mean Daily Temperature Range

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20a	*20b*	*20c*	*20d*	*20e*	*20f*	*20g*	*20h*	*20i*	*20j*	*20k*	*20l*
18.2	**20.1**	**22.0**	**25.0**	**24.3**	**21.7**	**20.9**	**21.2**	**22.6**	**25.9**	**22.0**	**19.2**

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

Appendix C: Emission Factor Data

Table 10 Emission Factors for On-Site Combustion in Other Equipment (lb of pollutant per unit of fuel)

Pollutant (lb)	Stationary Reciprocating Engine			Small Turbine		Residential Furnace *
	Natural Gas	Distillate Fuel Oil	Gasoline	Natural Gas	Distillate Fuel Oil	Natural Gas
	1000 ft^3 **	1000 gal	1000 gal	1000 ft^3 **	1000 gal	1000 ft^3 **
CO_{2e}	1.37E+02	2.27E+04	1.76E+04	1.25E+02	2.29E+04	1.21E+02
CO_2	1.16E+02	2.25E+04	1.72E+04	1.22E+02	2.28E+04	1.20E+02
CH_4	8.38E-01	1.20E+00	8.31E+00	5.26E-02	2.58E-01	2.30E-03
N_2O	3.41E-03	6.11E-01	5.51E-01	4.54E-03	6.11E-01	2.20E-03
NO_X	3.56E+00	4.76E+02	3.02E+02	3.51E-01	4.02E+01	9.40E-02
SO_X	6.32E-04	3.24E+01	4.18E+00	6.32E-04	3.24E+01	6.00E-04
CO	2.29E+00	1.26E+02	1.22E+03	1.75E-01	2.66E+00	4.00E-02
VOC	2.06E-03	1.22E+01	2.56E+01	2.06E-03	4.08E-01	5.50E-03
Lead	5.00E-07	ND †	ND †	5.00E-07	1.40E-08	5.00E-07
Mercury	2.60E-07	ND †	ND †	2.60E-07	1.20E-09	2.60E-07
PM10	1.66E-02	1.49E+01	2.40E+00	2.64E-02	5.19E+00	7.60E-03

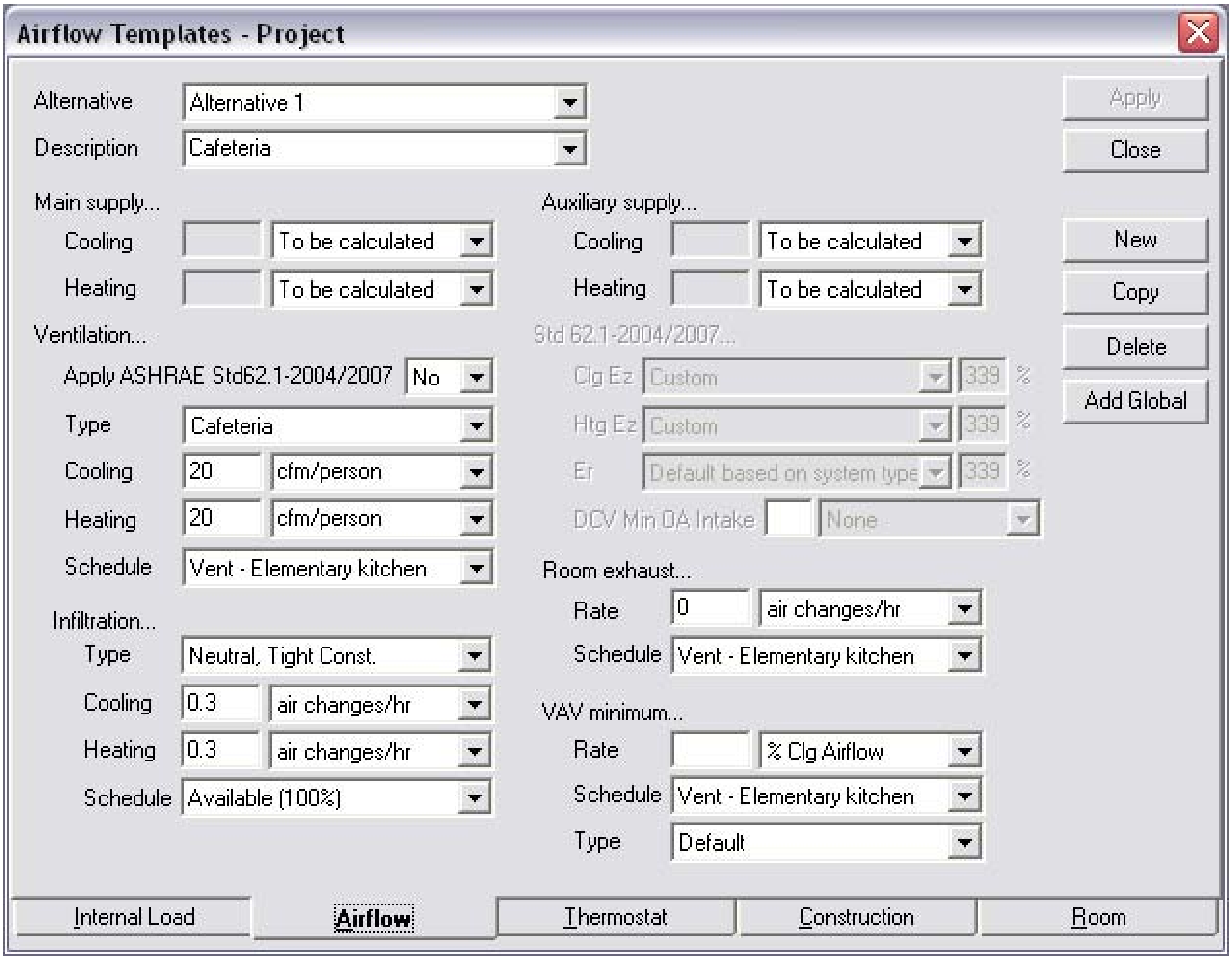
* data from EPA's AP-42, volume 1, 5th edition, 1995 (EPA 2005b)
** Gas volume at 60°F and 14.70 psia.
† no data available

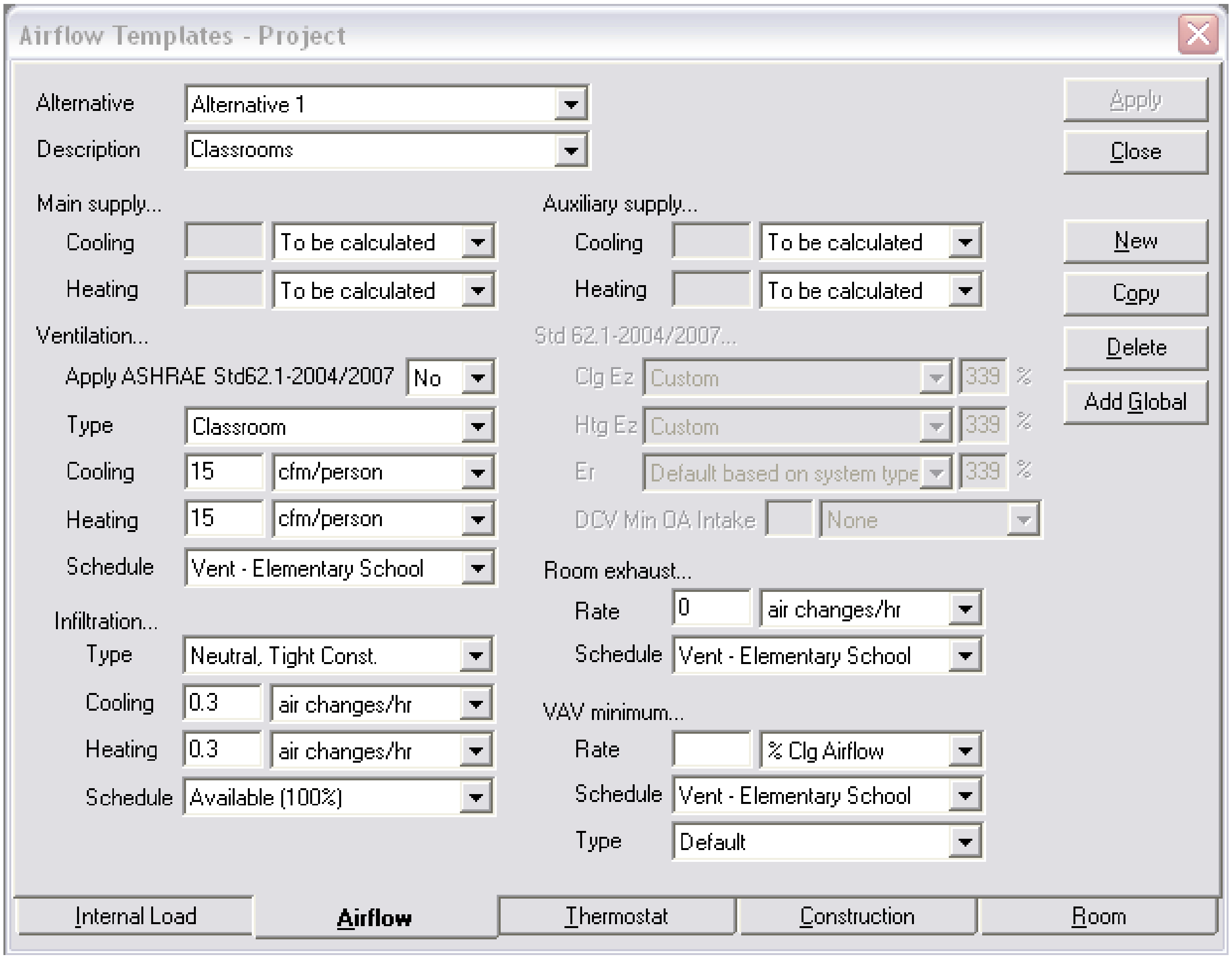
Table B-10 (page 2) Total Emission Factors for Delivered Electricity by State (lb of pollutant per kWh of electricity)

Pollutant (lb)	MT	NC	ND	NE	NH	NJ	NM	NV	NY	OH	OK	OR	PA
CO_{2e}	1.99E+00	1.47E+00	2.68E+00	1.81E+00	8.60E-01	9.31E-01	2.43E+00	1.88E+00	1.03E+00	2.20E+00	2.08E+00	4.85E-01	1.55E+00
CO_2	1.87E+00	1.41E+00	2.61E+00	1.71E+00	8.05E-01	8.61E-01	2.29E+00	1.76E+00	9.61E-01	2.10E+00	1.93E+00	4.40E-01	1.48E+00
CH_4	4.17E-03	2.37E-03	2.41E-03	3.70E-03	2.19E-03	2.79E-03	5.38E-03	4.81E-03	2.59E-03	3.71E-03	5.67E-03	1.83E-03	2.70E-03
N_2O	5.29E-05	3.11E-05	5.92E-05	4.94E-05	1.53E-05	1.76E-05	6.50E-05	3.75E-05	1.68E-05	4.73E-05	5.09E-05	1.04E-05	3.22E-05
NO_X	3.33E-03	2.83E-03	3.71E-03	3.09E-03	1.44E-03	1.32E-03	4.00E-03	2.89E-03	1.72E-03	4.14E-03	3.02E-03	5.21E-04	2.91E-03
SO_X	5.88E-03	8.26E-03	1.00E-02	4.79E-03	5.47E-03	6.34E-03	7.30E-03	1.21E-02	6.23E-03	1.19E-02	8.88E-03	3.03E-03	8.88E-03
CO	7.40E-04	4.31E-04	1.07E-03	6.09E-04	1.13E-03	6.69E-04	8.66E-04	7.39E-04	1.75E-03	6.38E-04	8.67E-04	2.72E-04	6.01E-04
TNMOC	6.02E-05	5.25E-05	5.34E-05	5.23E-05	8.62E-05	6.92E-05	7.27E-05	6.23E-05	6.38E-05	5.41E-05	8.01E-05	3.90E-05	5.46E-05
Lead	1.99E-07	1.16E-07	4.23E-07	1.87E-07	4.57E-08	4.27E-08	2.37E-07	1.09E-07	5.59E-08	1.76E-07	1.61E-07	2.05E-08	1.17E-07
Mercury	4.08E-08	2.40E-08	7.52E-08	3.73E-08	2.60E-08	1.44E-08	4.75E-08	2.27E-08	3.99E-08	3.59E-08	3.27E-08	4.59E-09	2.70E-08
PM10	1.14E-04	6.55E-05	3.03E-04	1.01E-04	5.47E-05	5.14E-05	1.36E-04	8.97E-05	6.87E-05	9.87E-05	1.16E-04	2.87E-05	7.14E-05
Solid Waste	3.01E-01	1.78E-01	3.33E-01	2.88E-01	5.65E-02	6.23E-02	3.65E-01	1.68E-01	6.18E-02	2.71E-01	2.49E-01	3.25E-02	1.78E-01

Pollutant (lb)	RI	SC	SD	TN	TX	UT	VA	VT	WA	WI	WV	WY	
CO_{2e}	1.18E+00	1.00E+00	1.45E+00	1.46E+00	1.99E+00	2.62E+00	1.40E+00	1.88E-02	4.11E-01	2.03E+00	2.41E+00	2.67E+00	
CO_2	1.04E+00	9.57E-01	1.36E+00	1.40E+00	1.85E+00	2.51E+00	1.33E+00	1.78E-02	3.82E-01	1.92E+00	2.31E+00	2.52E+00	
CH_4	5.65E-03	1.72E-03	3.02E-03	2.43E-03	5.80E-03	4.21E-03	2.52E-03	2.25E-05	1.13E-03	4.13E-03	3.85E-03	5.42E-03	
N_2O	2.04E-05	2.12E-05	3.91E-05	3.28E-05	4.37E-05	5.53E-05	2.81E-05	1.70E-06	1.05E-05	5.32E-05	5.08E-05	7.30E-05	
NO_X	7.91E-04	1.90E-03	2.45E-03	2.77E-03	2.42E-03	5.00E-03	2.67E-03	1.38E-04	6.13E-04	3.51E-03	4.62E-03	4.58E-03	
SO_X	9.90E-03	5.73E-03	3.97E-03	7.32E-03	1.05E-02	1.47E-02	8.04E-03	1.13E-04	1.70E-03	6.60E-03	1.35E-02	7.05E-03	
CO	8.52E-04	3.22E-04	5.26E-04	4.14E-04	9.77E-04	6.89E-04	9.74E-04	5.90E-05	1.80E-04	7.13E-04	6.50E-04	9.00E-04	
TNMOC	9.92E-05	4.89E-05	4.12E-05	4.17E-05	8.22E-05	5.78E-05	8.77E-05	1.02E-04	3.74E-05	8.26E-05	5.26E-05	7.43E-05	
Lead	6.87E-09	7.66E-08	1.47E-07	1.24E-07	1.49E-07	2.08E-07	1.02E-07	6.33E-10	3.21E-08	1.97E-07	1.92E-07	2.77E-07	
Mercury	4.09E-09	1.62E-08	3.01E-08	2.50E-08	2.96E-08	4.15E-08	3.24E-08	1.03E-09	6.62E-09	4.01E-08	3.87E-08	5.54E-08	
PM10	7.02E-05	4.61E-05	8.12E-05	6.75E-05	1.37E-04	1.14E-04	7.25E-05	7.67E-06	2.46E-05	1.11E-04	1.05E-04	1.49E-04	
Solid Waste	1.31E-02	1.17E-01	2.26E-01	1.91E-01	1.82E-01	3.20E-01	1.47E-01	2.83E-04	4.96E-02	3.03E-01	2.95E-01	4.26E-01	

Appendix D: Sample Trane Trace 700 Inputs

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Heating
To be calculated
Auxiliary supply...
Cooling
To be calculated
Heating
To be calculated
New
Copy
Delete
Add Global
Ventilation...
Apply ASHRAE Std62.1-2004/2007
No
Type
Classroom
Cooling
15
cfm/person
Heating
15
cfm/person
Schedule
Vent - Elementary School
Std 62.1-2004/2007...
Clg Ez
Custom
339
%
Htg Ez
Custom
339
%
Er
Default based on system type
339
%
DCV Min OA Intake
None
Room exhaust...
Rate
0
air changes/hr
Schedule
Vent - Elementary School
Infiltration...
Type
Neutral, Tight Const.
Cooling
0.3
air changes/hr
Heating
0.3
air changes/hr
Schedule
Available (100%)
VAV minimum...
Rate
% Clg Airflow
Schedule
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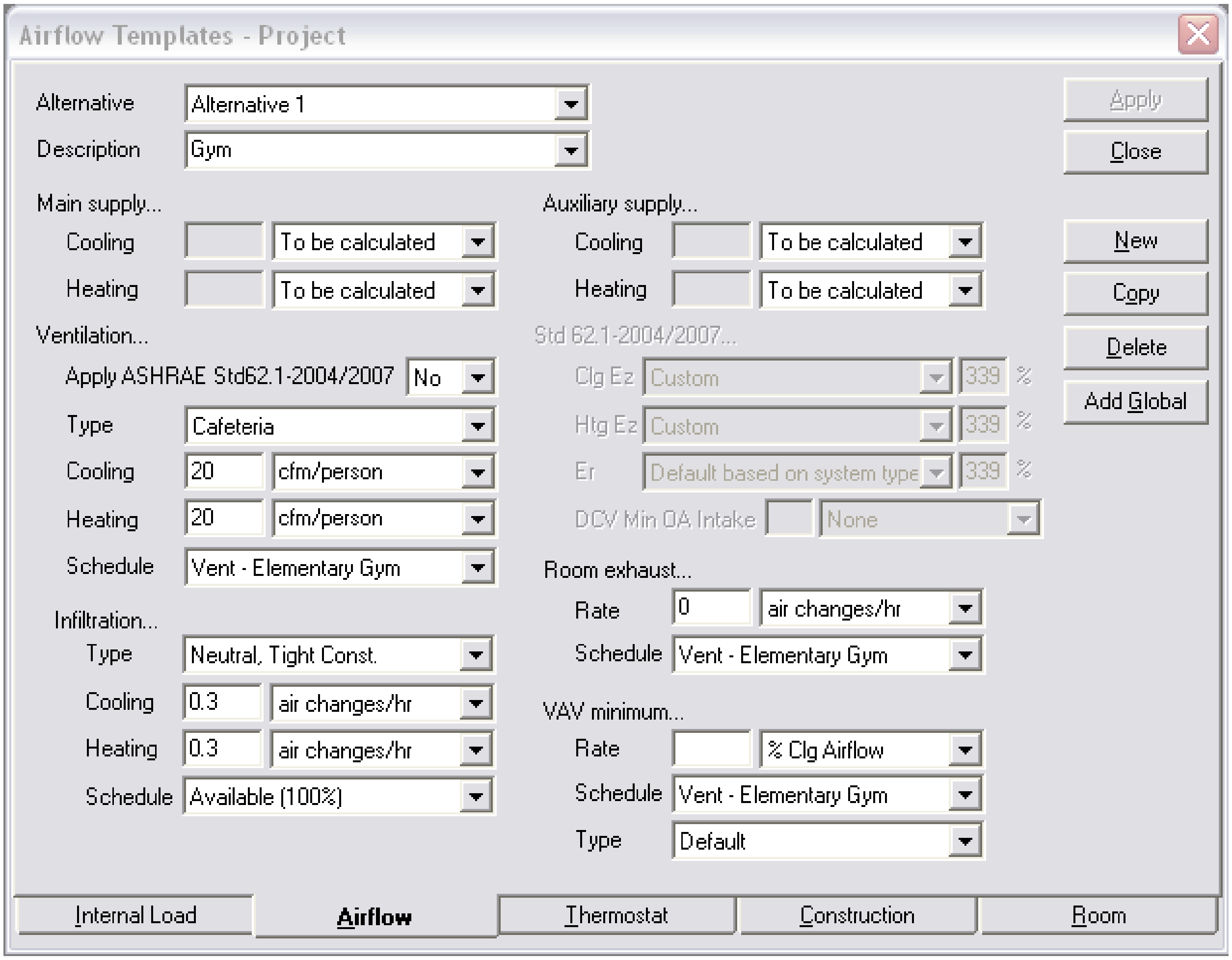
Type
Default
Internal Load
Airflow
Thermostat
Construction
Room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To be calculated
Heating
To be calculated
Auxiliary supply...
Cooling
To be calculated
Heating
To be calculated
Ventilation...
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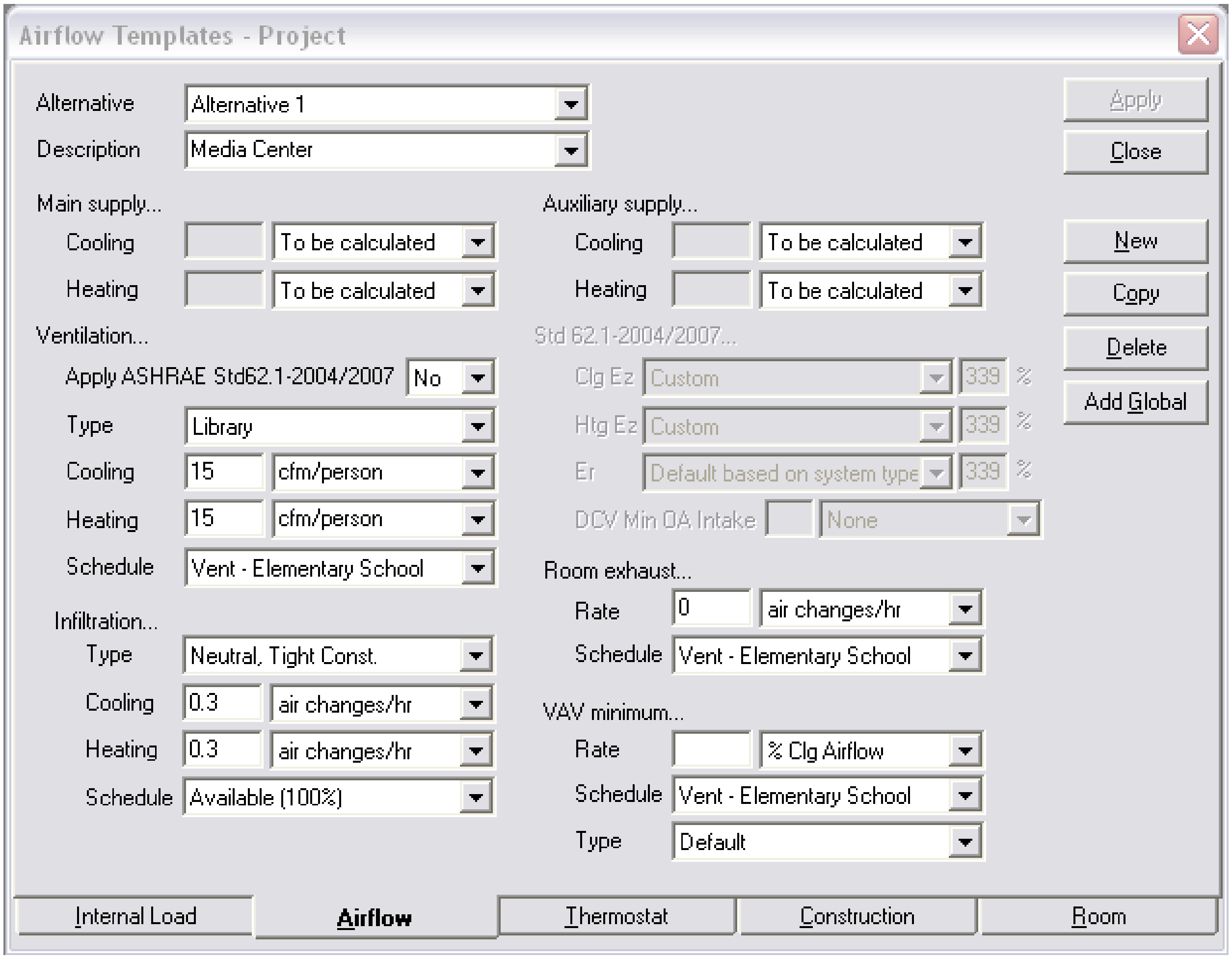
No
Type
Cafeteria
Cooling
20
cfm/person
Heating
20
cfm/person
Schedule
Vent - Elementary Gym
Std 62.1-2004/2007...
Clg Ez
Custom
339
%
Htg Ez
Custom
339
%
Er
Default based on system type
339
%
DCV Min OA Intake
None
Room exhaust...
Rate
0
air changes/hr
Schedule
Vent - Elementary Gym
Infiltration...
Type
Neutral, Tight Const.
Cooling
0.3
air changes/hr
Heating
0.3
air changes/hr
Schedule
Available (100%)
VAV minimum...
Rate
% Clg Airflow
Schedule
Vent - Elementary Gym
Type
Default
Internal Load
Airflow
Thermostat
Construction
Room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Heating
To be calculated
Auxiliary supply...
Cooling
To be calculated
Heating
To be calculated
Ventilation...
Apply ASHRAE Std62.1-2004/2007
No
Type
Library
Cooling
15
cfm/person
Heating
15
cfm/person
Schedule
Vent - Elementary School
Std 62.1-2004/2007...
Clg Ez
Custom
339
%
Htg Ez
Custom
339
%
Er
Default based on system type
339
%
DCV Min OA Intake
None
Room exhaust...
Rate
0
air changes/hr
Schedule
Vent - Elementary School
Infiltration...
Type
Neutral, Tight Const.
Cooling
0.3
air changes/hr
Heating
0.3
air changes/hr
Schedule
Available (100%)
VAV minimum...
Rate
% Clg Airflow
Schedule
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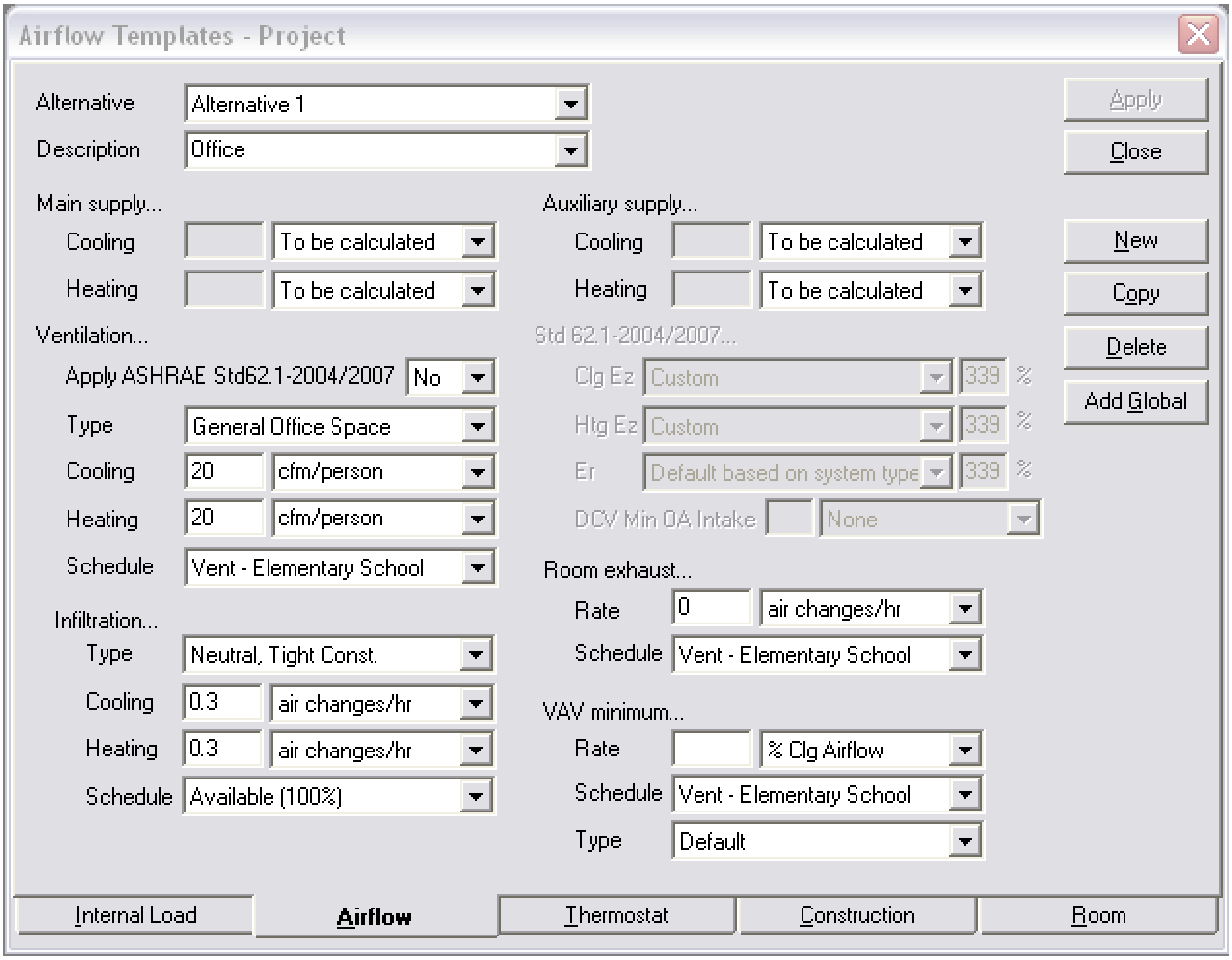
Type
Default
Internal Load
Airflow
Thermostat
Construction
Room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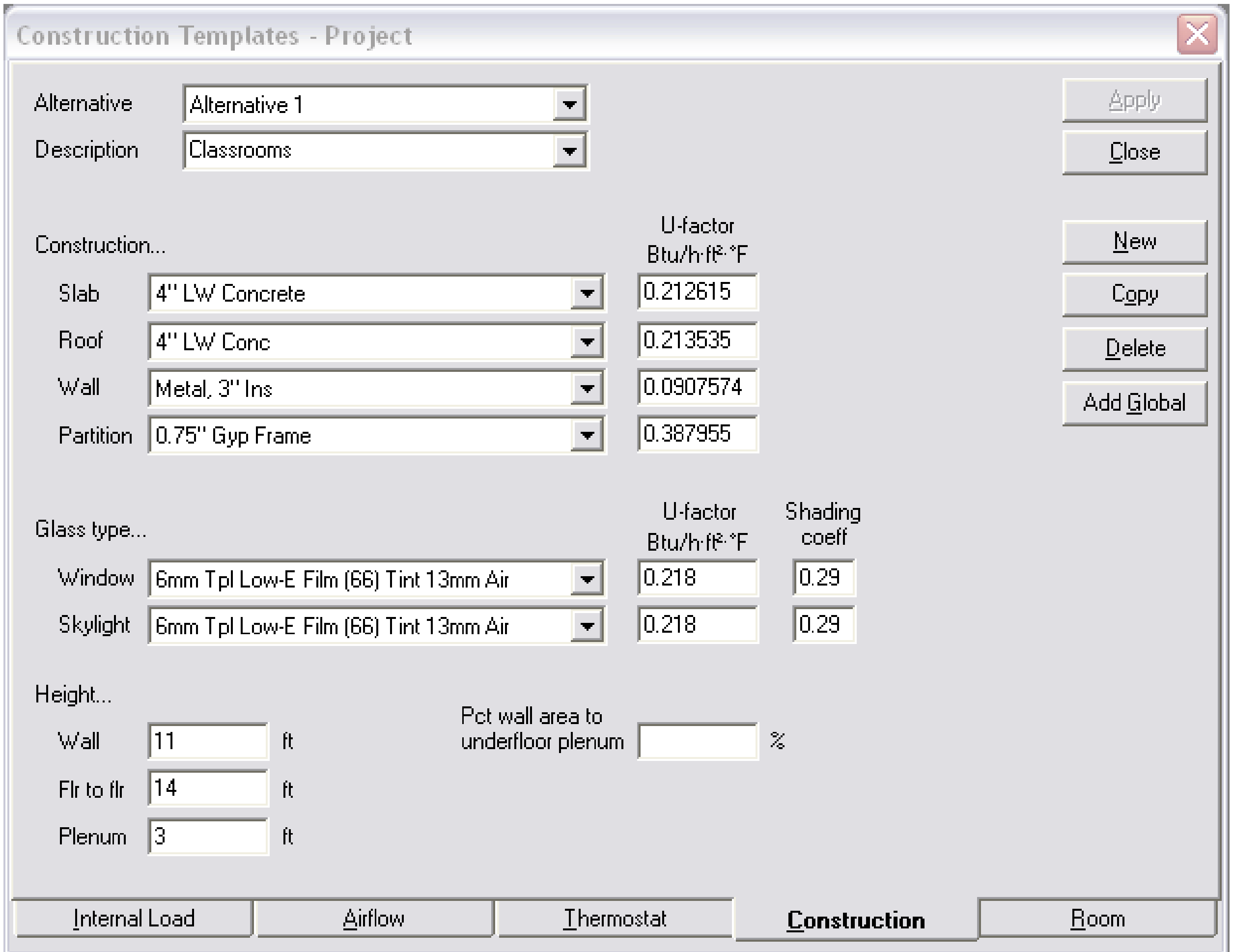
To be calculated
Heating
To be calculated
Auxiliary supply...
Cooling
To be calculated
Heating
To be calculated
Ventilation...
Apply ASHRAE Std62.1-2004/2007
No
Type
General Office Space
Cooling
20
cfm/person
Heating
20
cfm/person
Schedule
Vent - Elementary School
Std 62.1-2004/2007...
Clg Ez
Custom
339
%
Htg Ez
Custom
339
%
Er
Default based on system type
339
%
DCV Min OA Intake
None
Room exhaust...
Rate
0
air changes/hr
Schedule
Vent - Elementary School
Infiltration...
Type
Neutral, Tight Const.
Cooling
0.3
air changes/hr
Heating
0.3
air changes/hr
Schedule
Available (100%)
VAV minimum...
Rate
% Clg Airflow
Schedule
Vent - Elementary School
Type
Default
Internal Load
Airflow
Thermostat
Construction
Room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Alternative 1
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Classrooms
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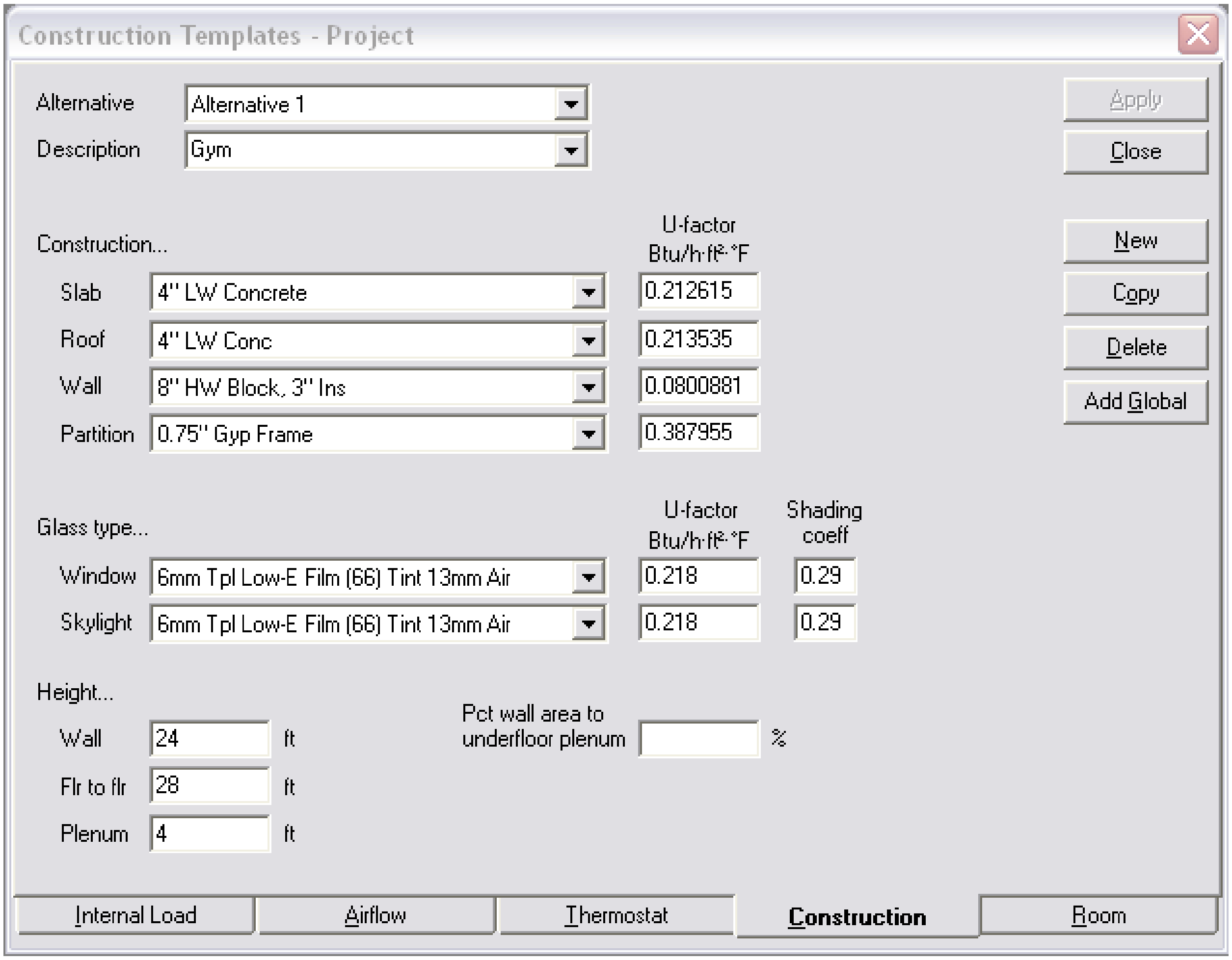
Delete
Add Global
Construction...
U-factor
Btu/h·ft²·°F
Slab
4" LW Concrete
0.212615
Roof
4" LW Conc
0.213535
Wall
Metal, 3" Ins
0.0907574
Partition
0.75" Gyp Frame
0.387955
Glass type...
U-factor
Btu/h·ft²·°F
Shading
coeff
Window
6mm Tpl Low-E Film (66) Tint 13mm Air
0.218
0.29
Skylight
6mm Tpl Low-E Film (66) Tint 13mm Air
0.218
0.29
Height...
Wall
11
ft
Flr to flr
14
ft
Plenum
3
ft
Pct wall area to
underfloor plenum
%
Internal Load
Airflow
Thermostat
Construction
Room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Alternative 1
Description
Gym
Apply
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New
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Construction...
U-factor
Btu/h·ft²·°F
Slab
4" LW Concrete
0.212615
Roof
4" LW Conc
0.213535
Wall
8" HW Block, 3" Ins
0.0800881
Partition
0.75" Gyp Frame
0.387955
Glass type...
U-factor
Btu/h·ft²·°F
Shading
coeff
Window
6mm Tpl Low-E Film (66) Tint 13mm Air
0.218
0.29
Skylight
6mm Tpl Low-E Film (66) Tint 13mm Air
0.218
0.29
Height...
Wall
24
ft
Flr to flr
28
ft
Plenum
4
ft
Pct wall area to
underfloor plenum
%
Internal Load
Airflow
Thermostat
Construction
Room