Technical Report 2

Building and Plant Energy Analysis Report

Delaware County Community College

STEM Center

Media, PA

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Mechanical Option

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Table of Contents

List of Figures

List of Tables

Executive Summary

(Photos Provided by Burt Hill)

The Delaware County Community College Science, Technology, Engineering, and Mathematics (STEM) Center is a new addition to their Marple Campus, and is part of the two-building STEM Complex. At 105,000 square feet and four stories it is a focal point for the campus, and stands out with both architectural and sustainable features.

The purpose of this report is to analyze the energy consumption using a computer-based approach for simulation. In this case, Trane TRACE™ 700 Version 6.2 was utilized for modeling a block load to estimate the design load, annual energy consumption, and operating costs. These results were also compared to those of the simulation performed by the Burt Hill design team.

Most information for input into TRACE™ was obtained from design documents generously provided by Burt Hill, which included drawings, schedules, and spreadsheets. The results of the simulation showed an overall design cooling load of 201.22 ft^2/ton and heating load of 40.51 Btuh/ft^2. These values, as well as the airflow rates, were very close to those in the design documentation.

In the way of energy consumption, TRACE™ was able to take into account the design loads and mechanical equipment to estimate the electricity and gas usage for the STEM Center. The yearly totals for the two came out to 2,009,362 kWh and 11,327 therms, respectively. Altogether, the building accounted for 7,991 MBtu/year of energy usage, the majority of which was electrical.

These energy results were used to calculate operating costs based on utility rates for the area of Media, PA, where the campus lies. Using those rates, the calculated total utility cost was \$177,826/year and \$1.70/ft^2-year. As a whole, this information will be very useful moving forward in the study of the Delaware County Community College STEM Center as a whole.

PART 1 – Design Load Estimation

Mechanical System Overview

The STEM Center uses just (2) roof-mounted 80,000 cfm custom air handling units, AHU-4 and AHU-5, which together condition the entire building. They are substantial in size due to high amount of ventilation and air conditioning required by the numerous laboratory spaces located in the building. Chilled water is produced for the building by a 650 ton electrical centrifugal chiller, (2) 40 hp primary chilled water pumps, and (2) 125 hp secondary chilled water pumps, all complete with variable frequency drives. For hot water, (2) new 250 BHP dual fuel heating hot water boilers, (2) primary hot water pumps, and (2) secondary hot water pumps are used, also complete with variable frequency drives. For condenser water, (2) 60 hp in-line water pumps are used.

For the estimation of the design load for the STEM Center, Trane TRACE™ 700 Version 6.2 was utilized. To simulate the air handling, AHU-4 and AHU-5 were modeled as one unit, treating the whole building as one system, for all 160 spaces. Both air handlers are identical in size and performance, therefore this assumption seemed reasonable for a block load simulation. Shown below in Figure 1 is a 3D view of the main distribution of air throughout the STEM Center.

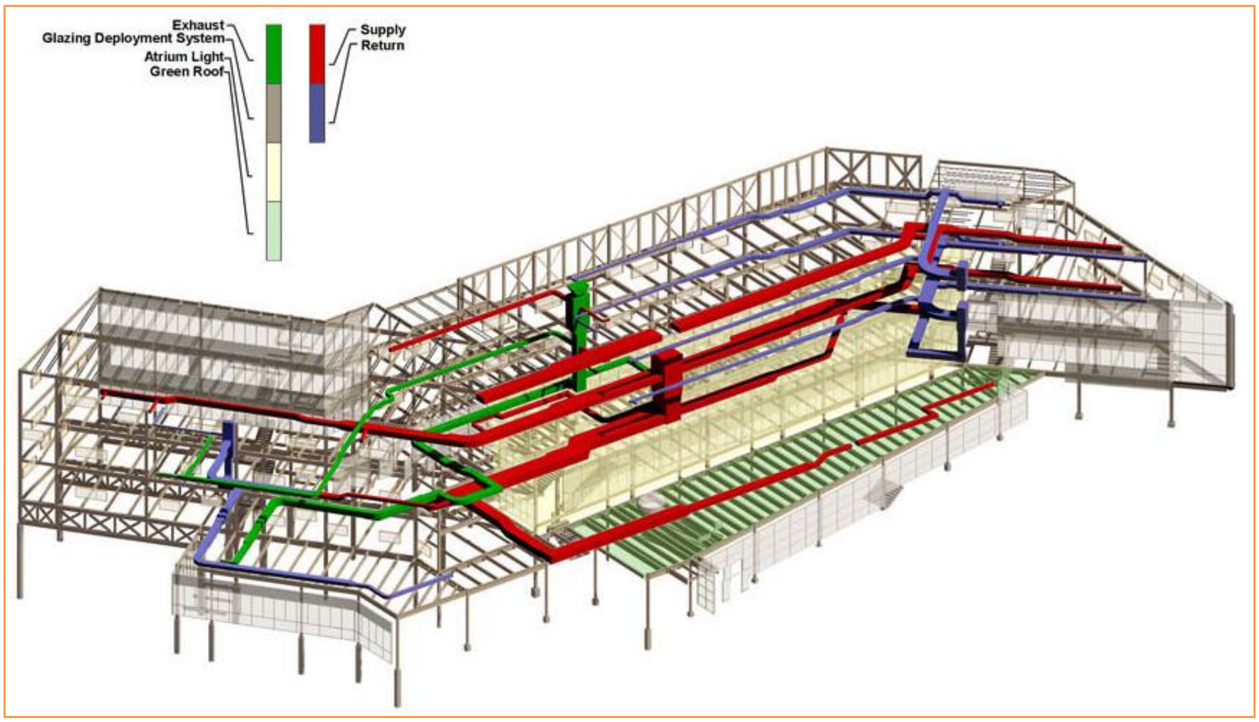

Figure 1: Air Distribution *(Provided by Burt Hill)*

All design data for the TRACE™ load simulation was taken from design documents generously provided by Burt Hill. This included the Autodesk Revit model, which was converted to a gbXML file for import into TRACE™. Along with the imported building room dimensions, U-values for floor, roof, wall, and window construction were determined also by provided design documents. These values can be seen in Appendix A TRACE™ Templates – Figure 6.

Modeling Information

Load Sources and Schedules

The loads taken into account in a program like TRACE™ include lighting, electrical and mechanical equipment, occupancy, ventilation, infiltration, and direct solar gain. All supply and ventilation rates were taken from design documentation and mechanical drawings M-900 and M-901, which showed space-by-space air balances.

For load schedules, the TRACE™ template for typical College was used for Lighting Loads, Miscellaneous Loads, People Activity, Ventilation, and Infiltration. This was deemed suitable for a building such as the STEM Center that was primarily used for academic purposes on a daily basis with minimal after-hour activity. For this schedule, the highest rates occur between 8 AM and 5 PM, and a detailed look at the schedule can be found in Appendix A – Figure 10.

Indoor and Outdoor Air Conditions for Heat and Cooling

From the ASHRAE Handbook of Fundamentals 2009, and using weather data for Philadelphia, PA (within 10 miles of the Delaware County Community College Marple Campus), the indoor and outdoor air conditions were determined to be as shown below in Table 1.

	Heating Dry Bulb Temperature (F)	Cooling Dry Bulb Temperature (F)	Cooling Wet Bulb Temperature (F)
	99.6%	0.4%	0.4%
Philadelpha, PA	**11**	**93.1**	**75.7**

Table 1: Design Air Conditions

For the interior design, a value of 75°F was used for room temperature and 58°F for supply air temperature. Also, an assumption of 0.11 air changes per hour was made based on information provided in design documents.

Lighting and Equipment Electrical Loads

To determine the load created by lighting and equipment in the building, ASHRAE Standard 90.1 was used. ASHRAE Standard 90.1 Section 9 Lighting provides Lighting Power Density (LPD) values for building types and individual space types. For a School/University building type, 1.2 W/ft^2 is listed as typical, and was initially inserted into TRACE™ for all spaces in the model. However, several room types found in ASHRAE Standard 90.1 Table 9.6.1 have a LPD greater than 1.2 W/ft^2. These values were used for the appropriate spaces in the TRACE™ model, and are listed in Table 2. This provides a generous and conservative, but still accurate, approximation for the artificial lighting load of the building as a whole.

Common Space Type	Spaces Applied To	LPD (W/SF)
Classroom	Classrooms, Computer Labs, etc.	1.4
Lobby	Ground Floor Lobbies	1.3
Laboratory	All Science Labs, Preparation Rooms, etc.	1.4
Electrical/Mechanical	All Electrical, Mechanical Rooms	1.5
Building Space Type		
School/University	All Other Spaces Types	1.2

Table 2: Lighting Power Density Values

Miscellaneous loads were also accounted for based on the TRACE™ default values for "Standard Office Equipment" and "Standard School Equipment", and these were applied to all classrooms, laboratories, office spaces, and other similar room types.

Design Occupancy

The STEM Center has a broad range of academic spaces, including laboratories, classrooms, offices, and conference/collaboration rooms. The number of occupants per each individual space was provided in design documentation and put in TRACE™. The building occupancy for design totaled 1,688 people, the majority of which came from classrooms and labs. For sensible and latent loads for typical activity categories, the TRACE™ default templates were used and shown below in Table 3.

Activity	Sensible Load (BTU/hr)	Latent Load (BTU/hr)
Auditorium	225	105
Classroom	250	200
Conference Room	245	155
General Office Space	250	200
Laboratory	250	250

Table 3: Occupant Loads

Load Simulation Analysis

Simulation Results

Upon simulation of the TRACE™ energy model, the results very closely matched those of the design as documented. Shown in Table 4 are the comparison between the modeled data and design data, including the percent difference of each category, the greatest of which was for the supply air (3.579%) and least of which was for the ventilation supply (0.396%). The air flow totals reflect a general ventilation rate of about 42% outside air. Although certain rooms in the building such as laboratories and preparation rooms require more delicate air conditioning considerations, those considerations do not call for 100% outside air. A substantial exhaust system much like the one implemented in the STEM Center is required to maintain high quality of air in such areas.

	Cooling (SF/ton)	Heating (BTUh/SF)	Total Supply (cfm/SF)	Ventilation Supply (cfm/SF)
Computed	201.220	40.510	1.328	0.557
Design Documented	197.310	40.696	1.282	0.559
% Difference	1.982	0.457	3.579	0.396

Table 4: Computed and Design Load Comparison

Although the compared data are relatively close to each other, particularly the air rates, there exists some error, which can be due to a handful of different reasons. Many slight simplifications and assumptions were made through entering data into TRACE™, including a conservative overcompensation for internal loads. As a whole, when conducting an energy model, only a certain amount of accuracy can be obtained, and so error will occur. Based on the closeness of the computed and designed load values, it can be concluded that reasonable assumptions were made for the block load simulation.

PART 2 – Annual Energy Consumption and Operating Costs

Energy Consumption Analysis

The second portion of this analysis involved a more in-depth look at the energy consumption and subsequent economics. The same TRACE™ file as previously discussed was used, which included the same ventilation rates and overall building information. Additional information was applied in regards to the systems and plants. The plants selected in TRACE™ were a water-cooled chiller and a gas-fired boiler, which were discussed in Part 1 and were designed at 700 tons, and 12,000 MBh, respectively. Once again, schedules were based on the template for typical College building, an example of which is shown in Appendix A – Figure 10.

Energy Results

Shown below in Table 5 are the results of the energy modeling conducted by TRACE™. As anticipated, the auxiliary loads from fans and pumps resulted in a significant percentage (48.6%) of the total building energy usage. This particular load category was greatly higher than that of the heating and cooling system and may be the result of an oversimplification along the way. Still, however, the amount of energy usage by each category is reasonable, and all add up to a total building energy usage of **7,991 mBtu/year**.

	Electric (kWh)	Gas (kBtu)	Water (1000 gal)	% of Total Building Energy	Total Building Energy (kBtu/yr)
Heating					
Primary Heating		1,132,702			1,192,318
Heating Accessories	37,888				387,969
Heating Subtotal	**37,888**	**1,132,702**	**0**	**15.8%**	**1,580,287**
Cooling					
Cooling Compressor	72,830				248,570
Tower/Cond Fans	109,988		530		375,389
Condenser Pump	339,682				1,159,335
Cooling Accessories	2,847				9,717
Cooling Subtotal	**525,348**	**0**	**530**	**22.4%**	**1,793,011**
Auxiliary					
Supply Fans	759,974				2,953,792
Pumps	377,136				1,287,166
Aux Subtotal	**1,137,110**	**0**	**0**	**48.6%**	**3,880,957**
Lighting	**282,857**	**0**	**0**	**12.1%**	**965,391**
Receptacles	**26,160**	**0**	**0**	**1.1%**	**89,284**
TOTAL	**2,009,362**	**1,132,702**	**530**	**100%**	**7,990,655**

Table 5: Energy Usage Breakdown

Energy Consumption Breakdown

A report for monthly energy use was compiled and showed a general peak of electrical energy usage in the summer months and a peak of fuel energy usage in the winter months. Though these graphs are not as perfectly normally distributed as would be assumed, they still provide evidence of the general pattern of energy usage based on necessary heating and cooling loads throughout the year. The highest therm consumption occurs in January and February, and likewise the highest amount of kilowatt-hours is in August. The numerical breakdown of monthly energy consumption is shown in Table 6, and Figures 2 and 3 display the pattern of energy usage in kWh and therms, respectively.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Electric (kWh)	145,839	124,847	173,958	158,933	183,830	187,078	173,508	197,374	168,150	175,545	165,230	155,070	2,009,362
Gas (therms)	1,980	1,943	1,339	808	491	416	344	435	435	804	1,009	1,323	11327
Water (1000 gal)	7	5	17	25	61	83	105	101	60	31	22	12	587

Table 6: Monthly Energy Consumption

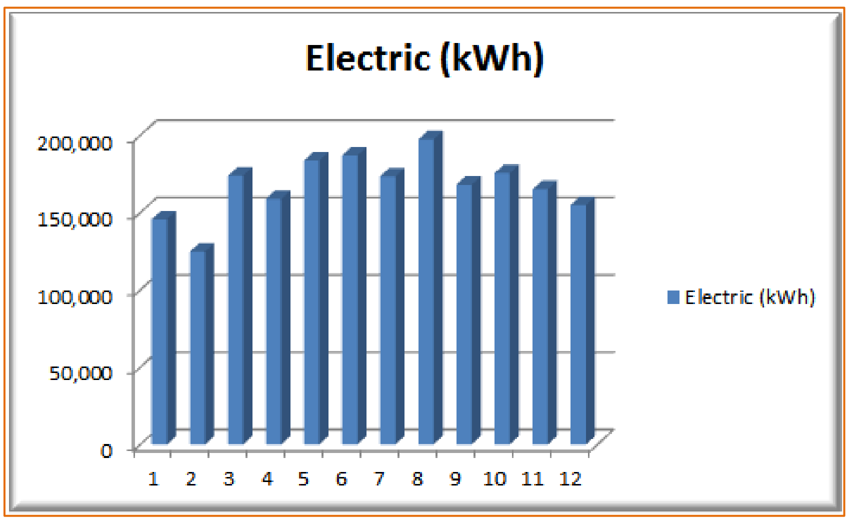

Figure 2: Electrical Energy Consumption

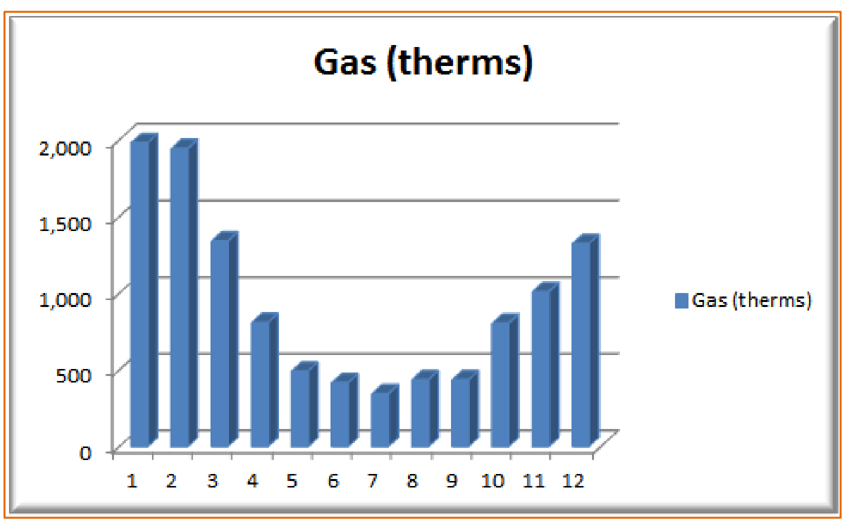

Figure 3: Gas Consumption

The electrical energy total was also broken down by usage, including cooling, heating, fans, lighting, and general equipment, as per the data outputs from TRACE™. This breakdown is represented graphically in Figure 4, and once again it can be seen that a substantial amount of energy is used for auxiliary purposes (41.5%), as well as for cooling systems (40.99%).

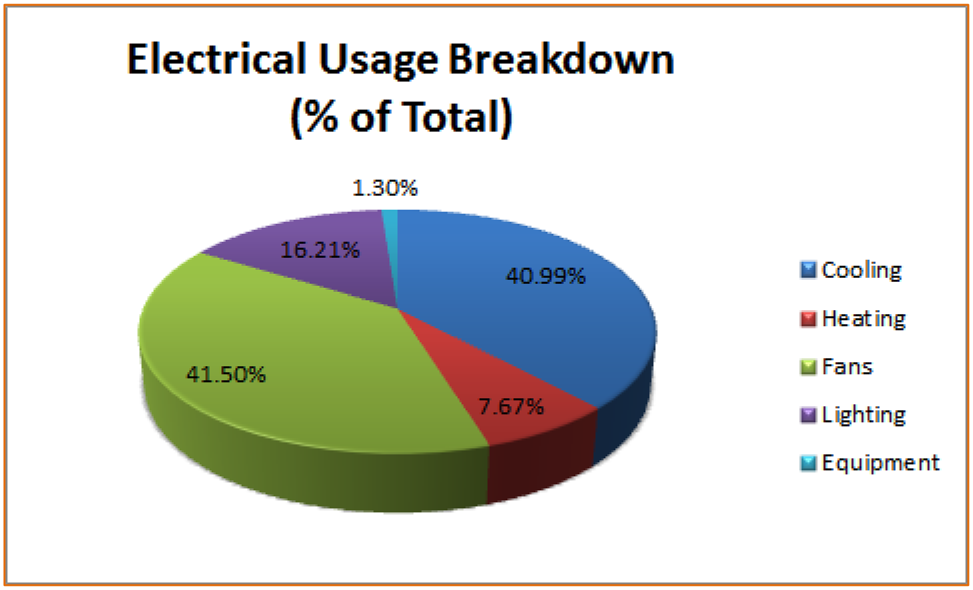

Figure 4: Electrical Usage Breakdown

Results Comparison

For the mechanical system design by Burt Hill, an energy simulation was conducted using IES (Integrated Environmental Solutions) software. This program was selected largely due to its versatility in providing graphical features and overall ability to model the building loads, specifically those produced by the solar gain from the south side glass curtain wall that is present at all floors. The results for the IES simulation had been generously provided, and upon comparison it was seen that the TRACE™ simulation produced comparable data. Shown in Table 6 is a juxtaposition of the overall modeling results, showing the similarity of the values. Arguably, an amount of the roughly 8% error can be attributed to the difference in software used, as each method of energy modeling can vary to some degree.

	TRACE	IES
Energy (kBtu/yr)	7,990,655	7,834,878
Utility Cost ($/yr)	177,826	164,139
Utility Cost ($/SF-yr)	1.70	1.57

Table 7: TRACE™ and IES Results Comparison

Operating Cost Analysis

The costs compared in Table 7 are based off of the basic utility rates provided in the design documentation, which were an electrical cost of $0.089/kWh and a gas fuel cost of $1.347/therm. With these rates, the monthly utility costs were calculated and are shown in Table 8 and graphically in Figure 5.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Electric $	12,980	11,111	15,482	14,145	16,361	16,650	15,442	17,566	14,965	15,624	14,706	13,801	178,833
Gas $	2,667	2,618	1,804	1,089	661	560	463	586	586	1,083	1,359	1,782	15,257

Table 8: Monthly Utility Costs

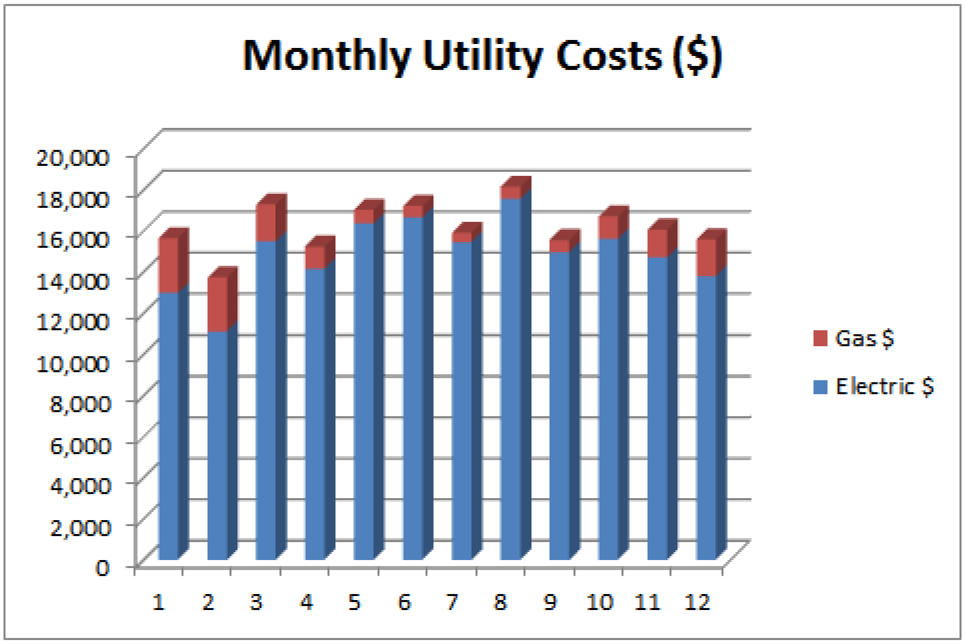

Figure 5: Monthly Utility Costs

These show that it is the electrical cost that accounts for the majority of the utility bill, much more than the gas cost. Although no utility bills from Delaware County Community College were available for comparison, this distribution is reasonable for a month-by-month distribution.

Environmental Impact Analysis

The STEM Center was also analyzed for emissions and environmental impact based on the energy consumed. The main concern was for the production of CO_2, NO_x, SO_x, and particulates on a yearly basis. A detailed calculation for a broad range of pollutants was conducted based on information found in the June 2007 Technical Report by M. Deru and P. Torcellini entitled "Source Energy and Emission Factors for Energy Use in Buildings" (pages 18, 28). This information, provided by the National Renewable Energy Laboratory, is included in table form in Appendix B Emission Factors – Figures 11 and 12. A full calculation of the total building environmental impact breakdown for each harmful emission is shown in Table 9 (and in larger print in Appendix B – Table 10). A very high amount of Carbon Dioxide is emitted (more than 3 million pounds) and additionally the amount SO_x gas is substantial as well. The amount of CO_2 results from both forms of energy consumption, while SO_x is produced almost exclusively by the electrical usage. The pollution from the gas combustion leads to considerable values of NO_x and Carbon Monoxide on top of the relatively very high CO_2 produced. This total amount of pollutant emission is cause for concern and provides significant room for improvement in the way of the environmental effect of the mechanical system design for the STEM Center.

Pollutant	Pollutant lbs/kWh	kWh/year	Subtotal (kWh) Pollutant lbs/year	Pollutant lbs/1000 ft^3	Gas 1000 ft^3/year	Subtotal (therms) Pollutant lbs/year	TOTAL Pollutants
CO2e	1.55	2,009,362	3,114,511.10	123	1,132.7	139,322.10	3,253,833.20
CO2	1.48	2,009,362	2,973,855.76	122	1,132.7	138,189.40	**3,112,045.16**
CH4	0.0027	2,009,362	5,425.28	0.0025	1,132.7	2.83	5,428.11
N2O	0.0000322	2,009,362	64.70	0.0025	1,132.7	2.83	67.53
NOx	0.00291	2,009,362	5,847.24	0.111	1,132.7	125.73	**5,972.97**
SOx	0.00888	2,009,362	17,843.13	0.000632	1,132.7	0.72	**17,843.85**
CO	0.000601	2,009,362	1,207.63	0.0933	1,132.7	105.68	1,313.31
TNMOC	0.0000546	2,009,362	109.71	0.00613	1,132.7	6.94	116.65
Lead	0.000000117	2,009,362	0.24	0.0000006	1,132.7	0.00	0.24
Mercury	0.000000027	2,009,362	0.05	0.00000026	1,132.7	0.00	0.05
PM10	0.0000714	2,009,362	143.47	0.0084	1,132.7	9.51	152.98
Solid Waste	0.178	2,009,362	357,666.44				**357,666.44**

Table 9: Annual Emissions Footprint

Appendix A: TRACE™ Templates

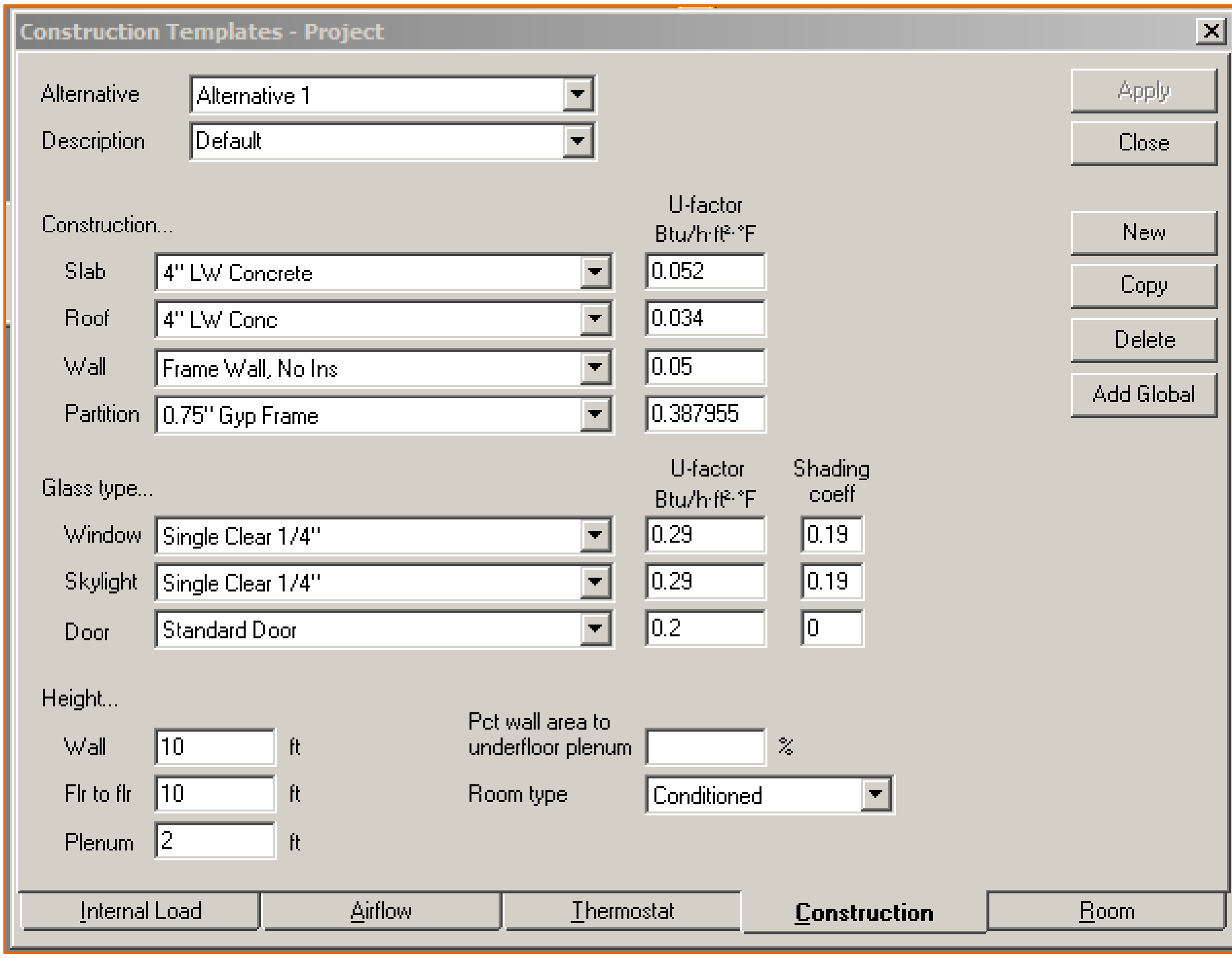

Figure 6: Room Construction Template

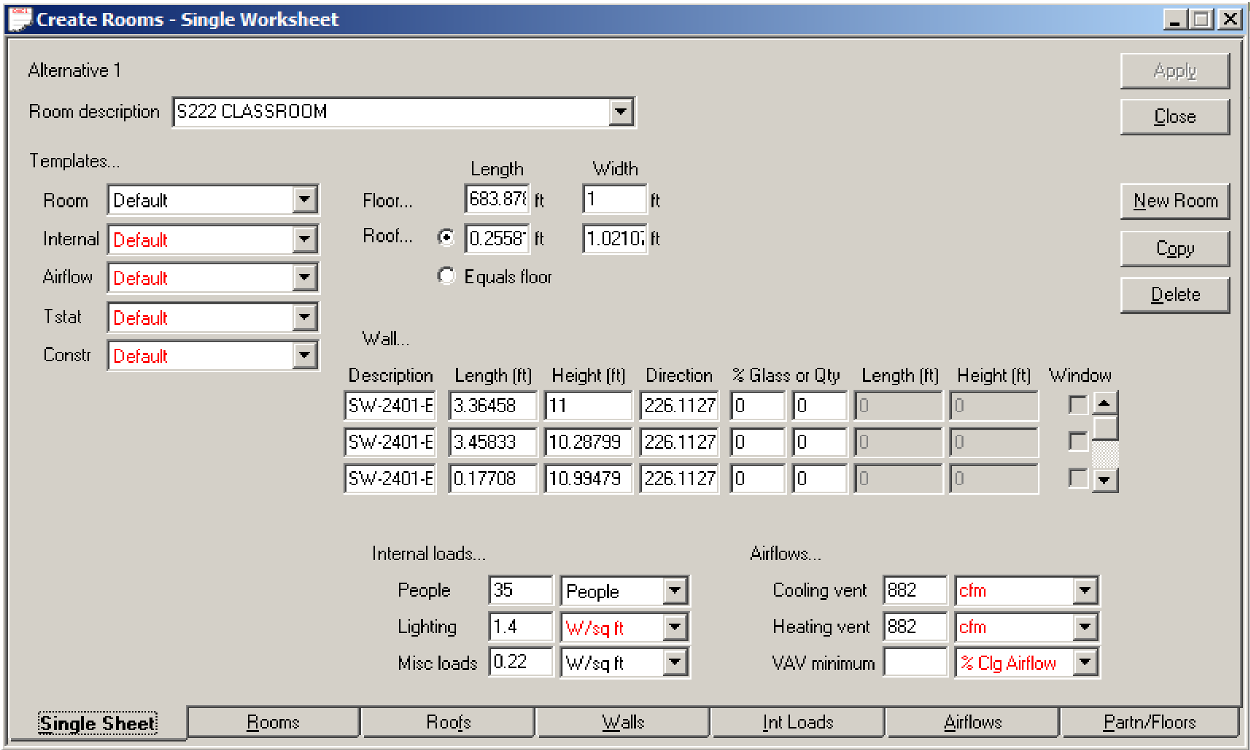

Figure 7: Typical Room - Classroom

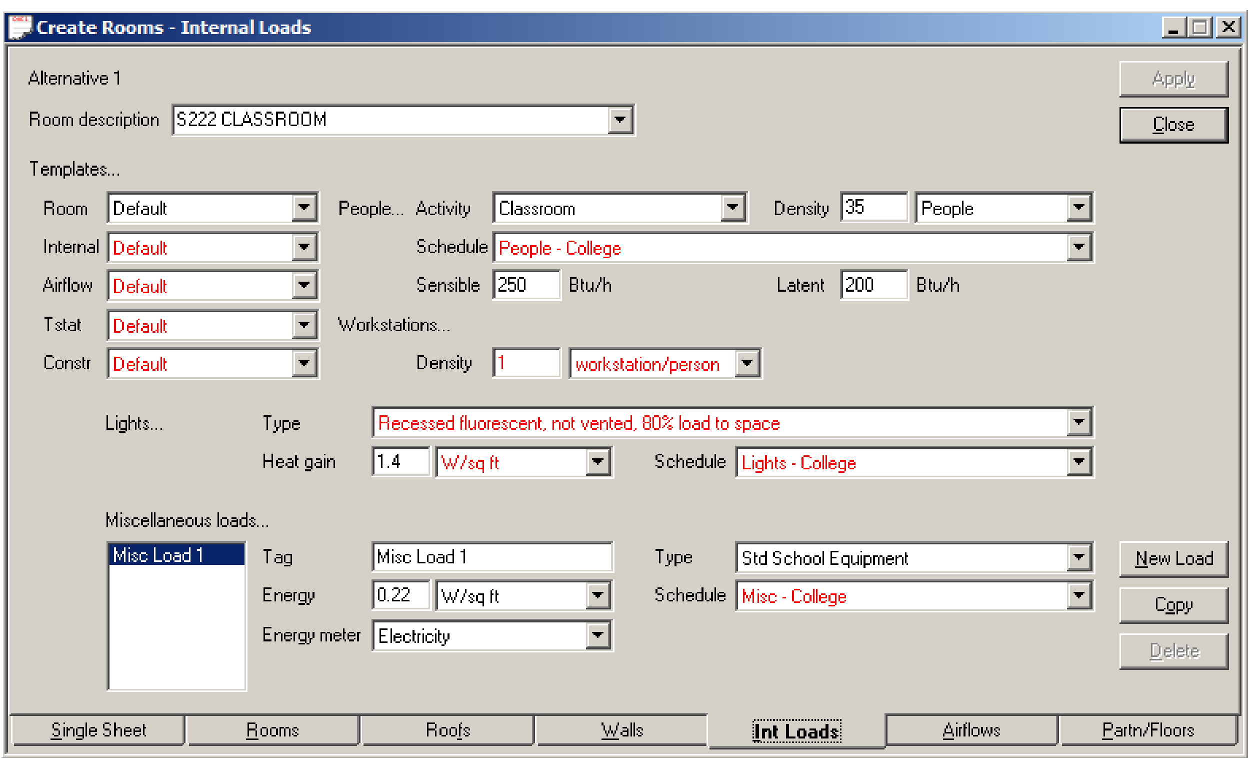

Figure 8: Typical Internals Loads - Classroom

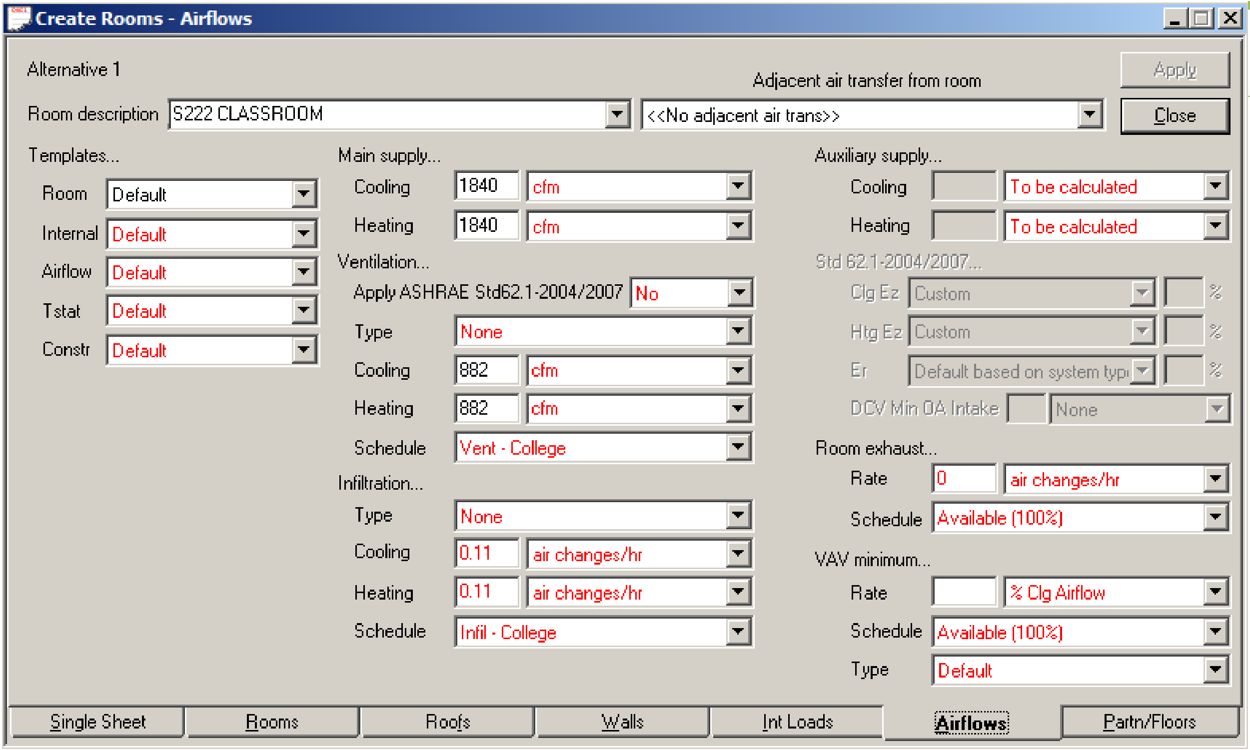

Figure 9: Typical Airflows - Classroom

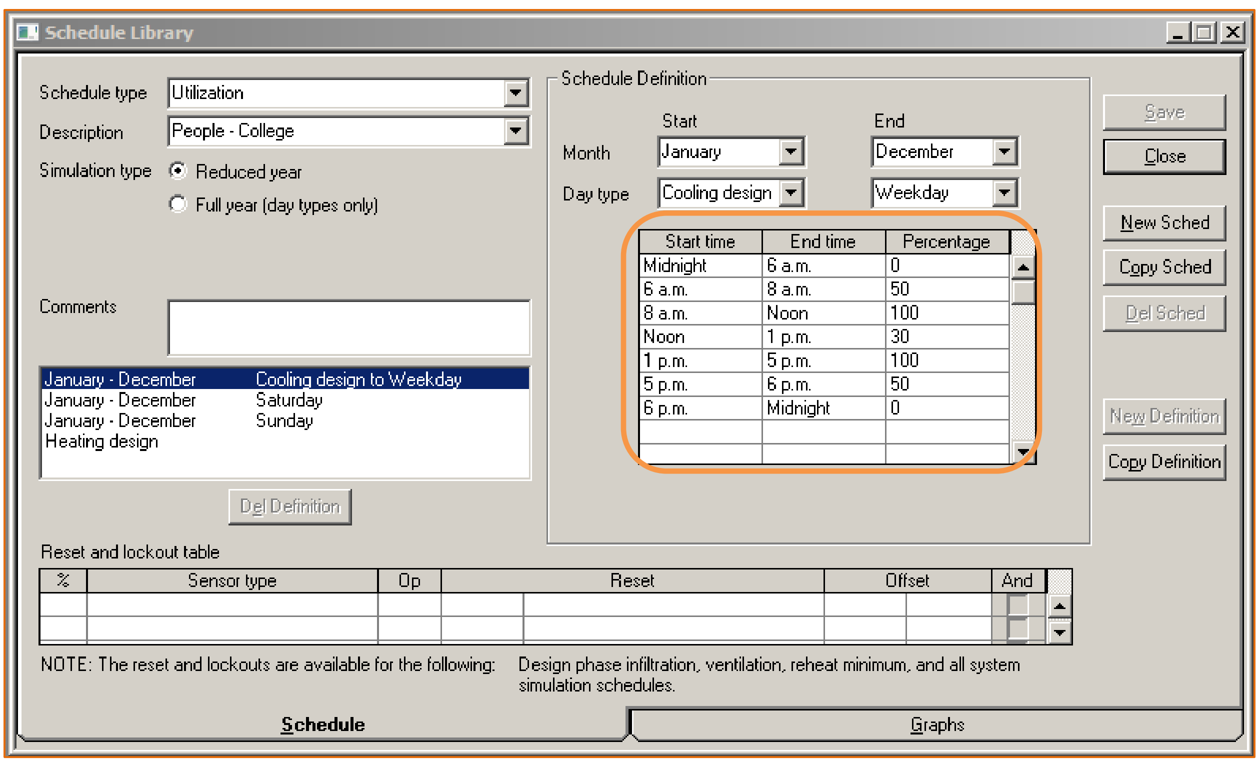

Figure 10: Typical Schedule – People – College

Appendix B: Emission Factors

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

Figure 11: Emission Factors for Delivered Electricity

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

Pollutant (lb)	Commercial Boiler					
	Bituminous Coal *	Lignite Coal **	Natural Gas	Residual Fuel Oil	Distillate Fuel Oil	LPG
	1000 lb	1000 lb	1000 ft^3 ***	1000 gal	1000 gal	1000 gal
CO_{2e}	2.74E+03	2.30E+03	1.23E+02	2.58E+04	2.28E+04	1.35E+04
CO_2	2.63E+03	2.30E+03	1.22E+02	2.55E+04	2.28E+04	1.32E+04
CH_4	1.15E-01	2.00E-02	2.50E-03	2.31E-01	2.32E-01	2.17E-01
N_2O	3.68E-01	ND †	2.50E-03	1.18E-01	1.19E-01	9.77E-01
NO_x	5.75E+00	5.97E+00	1.11E-01	6.41E+00	2.15E+01	1.57E+01
SO_x	1.66E+00	1.29E+01	6.32E-04	4.00E+01	3.41E+01	0.00E+00
CO	2.89E+00	4.05E-03	9.33E-02	5.34E+00	5.41E+00	2.17E+00
VOC	ND †	ND †	6.13E-03	3.63E-01	2.17E-01	3.80E-01
Lead	1.79E-03	6.86E-02	5.00E-07	1.51E-06	ND †	ND †
Mercury	6.54E-04	6.54E-04	2.60E-07	1.13E-07	ND †	ND †
PM10	2.00E+00	ND †	8.40E-03	4.64E+00	1.88E+00	4.89E-01

* from the U.S. LCI data module: Bituminous Coal Combustion in an Industrial Boiler (NREL 2005)
** from the U.S. LCI data module: Lignite Coal Combustion in an Industrial Boiler (NREL 2005)
*** Gas volume at 60°F and 14.70 psia.
† no data available

Figure 12: Emission Factors for On-Site Boiler Combustion

			Subtotal (kWh)			Subtotal (therms)	TOTAL
Pollutant	Pollutant lbs/kWh	kWh/year	Pollutant lbs/year	Pollutant lbs/1000 ft^3	Gas 1000 ft^3/year	Pollutant lbs/year	Pollutants
CO2e	1.55	2,009,362	3,114,511.10	123	1,132.7	139,322.10	3,253,833.20
CO2	1.48	2,009,362	2,973,855.76	122	1,132.7	138,189.40	**3,112,045.16**
CH4	0.0027	2,009,362	5,425.28	0.0025	1,132.7	2.83	5,428.11
N2O	0.0000322	2,009,362	64.70	0.0025	1,132.7	2.83	67.53
NOx	0.00291	2,009,362	5,847.24	0.111	1,132.7	125.73	**5,972.97**
SOx	0.00888	2,009,362	17,843.13	0.000632	1,132.7	0.72	**17,843.85**
CO	0.000601	2,009,362	1,207.63	0.0933	1,132.7	105.68	1,313.31
TNMOC	0.0000546	2,009,362	109.71	0.00613	1,132.7	6.94	116.65
Lead	0.000000117	2,009,362	0.24	0.0000006	1,132.7	0.00	0.24
Mercury	0.000000027	2,009,362	0.05	0.00000026	1,132.7	0.00	0.05
PM10	0.0000714	2,009,362	143.47	0.0084	1,132.7	9.51	152.98
Solid Waste	0.178	2,009,362	357,666.44				**357,666.44**

Table 10: Annual Emissions