Rami Moussa
Mechanical Option
Advisor: Professor Treado
10/23/10

Peirce Hall, Kenyon College

Technical Report 2:

Building and Plant Energy Analysis Report

Table of Contents

Executive Summary

The purpose of this report is to analyze the components of the Peirce Hall mechanical system that influence and provide service for heating and cooling loads and ventilation rates. In this analysis a Trane Trace 700 model was created to approximate characteristics of the mechanical system such as heating and cooling capacities, energy consumption of major system components, utility costs, and emission rates. A design model was provided by Syska Hennessy Group, Inc. to compare calculated values with. This model however, did not contain energy analysis information.

The Peirce Hall mechanical system is composed of 7 air handling units, 1 major fan coil unit and a collection of unit and cabinet unit heaters. Systems were assigned to the same zones as in design documents. However, some zones may have been designed to be served by a different unit through the design process and gotten changed in the design model. Therefore there are some inconsistencies between the design model and analysis model that resulted in larger and smaller supply requirement between systems. These results can be most easily found in Table A.2 Computed vs. design Document Load and Ventilation Indices.

Due to the multiuse functionality of Peirce Hall, many spaces required their own occupancy and air flow specification for internal loads to be calculated to reasonable accuracy. Spaces were more individually designed to analyze zone characteristics. A 250 occupant dining hall may have been adjacent to a kitchen, servery, and lobby. The block cooling load was approximated to within 10% of the design model and the heating load within 3.5%.

Service information was not able to be obtained from Kenyon College, so general data by the name “Northern Power Company,” from templates provided in Trane Trace were used. The annual utility cost per square foot was calculated to be 1.378 $/ft^2. Pollutant emission data can be found on pages 9 and 10.

Design Load Estimation

System Overview

Peirce Hall at Kenyon College in Gambier, Ohio uses a variety of cooling and heating systems to serve the multipurpose facility's diverse spatial types. Due to the large variety of types of spaces adjacent to one another, spaces were unable to be zoned together and the building had to be analyzed in a space by space manor. Zones were considered to be conditioned at all hours in the design model hence, were similarly modeled in the analysis model. 4 air handling units serve as the means for cooling in the building and 3 additional air handling units provide makeup and ventilation air for kitchens and the basement. Steam is supplied to unit heaters and cabinet unit heaters to serve as the primary providers of heat to spaces. Production of steam is assumed to be coal fueled.

Exterior and Interior Design Conditions

Gambier, Ohio is a small town in central Ohio. Yearly weather data from Columbus, Ohio was used to approximate the climate of Gambier, as it is located just 55 miles to the Northeast. Conditions used for analysis are 0.4% and 99.6% cooling and heating dry bulb temperatures and can be viewed in Table 1. Interior design temperatures for the majority of spaces including dining rooms, offices, the computer lab, and music room use the same interior conditions. Kitchens have a higher cooling dry bulb temperature and a lower heating dry bulb as recommended by 2009 ASHRAE Handbook of Fundamentals.

Interior Design Temperatures			
Space Type	Cooling [°F]	Heating [°F]	RH [%]
General	75	72	50
Kitchen	78	70	50

Table 1. Interior Design Temperatures

The Peirce Hall project was not simply new construction, but a renovation, expansion, and addition. Hence existing construction types and materials are used in conjunction with newer, much more efficient materials. Due to differences in construction materials between the existing and newly constructed building envelope components, separate thermal resistances were necessary to reasonably analyze building envelope loads. Material properties can be found in Table 2. Infiltration rates were assumed to be "Neutral, Tight Construction" allowing 0.3 air changes per hour.

Thermal Properties of Existing and New Envelope Components				
Envelope Component	U-Value by Construction Type		Shading Coefficient	
	Existing	New	Existing	New
Exterior Wall	0.36	0.085		
Window	0.95	0.29	0.95	0.44
Roof	0.1	0.068		

Table 2. Thermal Properties of Existing and New Envelope Components

Interior Loads

Peirce Hall's primary use for Kenyon College is as a dining hall. As a result, the loads generated within spaces such as occupant and lighting loads impacted cooling requirements significantly. Most occupancy values were taken from the architectural design drawings. These values were occasionally substituted with values that were more realistic to the intended use of the space. An example of this scenario is in lower dining lobby. Here, what would be considered a corridor with 0 occupants contains sitting areas that can host up to 32 occupants. Interior load contributions from occupants are based on activity levels in spaces. Load values can be found below in Table 3.

Occupant Load Contribution		
Space Type	Sensible [Btu/h]	Latent [Btu/h]
Cafeteria	275	275
Kitchen	275	275
Mechanical Room	250	200
Class Room	250	200
Office Space	250	200
Rest Room	245	155
Storage	245	155

Table 3. Occupant Load Contribution

Heat emitted by lighting was assumed to be the input wattage to lamps. Therefore constructed lighting power densities were used to approximate internal heat gains from lighting. Additional miscellaneous loads were necessary to account for large appliances in some spaces. Offices use a medium load density of 1 Watt per square foot (W/SF) and the computer lab uses a medium/heavy load density of 1.5 W/SF to represent general office equipment. Spaces with more demanding electrical equipment like the pub support, kitchen, servery, and dish room use a 2 W/SF load density.

Ventilation and Exhaust Rates

Ventilation rates used in the original system design for Peirce Hall air handling units were very generous. Values are a mix of occupant and area based and can be found in the following table. Highly occupied spaces include space types such as the pub, dining areas, lounges, and the kitchen. Medium occupancy spaces include preparation areas, the computer lab, and the servery area.

Ventilation Rates	
Space Type	Rate
High Occupancy	20 [cfm/person]
Medium Occupancy	15 [cfm/ft^2]
Storage	0.15 [cfm/ft^2]
Circulation	0.05 [cfm/ft^2]

Table 4. Ventilation Rates

Results and Analysis

A design load calculation was previously prepared by Syska Hennessy Group, Inc. One discrepancies that distinguishes the analysis model from the design model is the population values used in select spaces. Rather than using occupancy statistics from the design energy model, most were taken from the architectural design drawings. The difference in total population between models is 123 occupants where the analysis model is designed for the larger occupancy. Major occupancy differences can be found in Table 5. The greatest differences in space occupancy occur in the spaces designed for the largest occupancy. The provided model was most likely designed to anticipate that the space would never be fully occupied. In the case of the main dining hall, The Great Hall, the provided model greatly over compensates for the architectural design occupancy. This could also be an attempt to estimate the most realistic occupancy possible.

Major Area Populations			
Room Name	Area [ft^2]	Design Population	
		Analysis	Design
Pub	4001	265	110
Servery	5002	193	104
Student Org. Lounge	359	24	8
Great Hall	4148	277	350

Table 5. Major Area Populations

A comparison of computed loads versus design document load and ventilation indices can be found in Table A.2. An overall comparison of heating and cooling loads can be found below in Table 6.

Overall Plant Requirements						
Load Type	Cooling [ft^2/ton]		Difference	Heating [MBH]		Difference
	Analysis	Design		Analysis	Design	
Block	265.7	242.5	9.57%			
Peak	278.7	252	10.60%	4.483	4.329	3.56%

Table 6. Overall Plant Requirements

Annual Energy Consumption and Operation Costs

Basis of Analysis

Cost rates for utilities could not be obtained from Kenyon College for Peirce Hall's energy model. Therefore the Northern Power Company template provided by Trane Trace 700 has been used for this analysis. A summary of this template's values can be viewed in Table 7. The price of coal is assumed to be the 2.26 dollars per million Btu, representing the June 2010 price from the U.S. Energy Information Administration *2010 Monthly Energy Review*.

Utility Cost Rates	
Utility Type	Cost [$/kW]
Electric Demand On Peak	8.13
Electric Consumption On Peak	0.0319
Gas On Peak	0.466
Water	0.0001
Electric Demand Off Peak	5.87
Electric Consumption Off Peak	0.024

Table 7. Utility Cost Rates

Details on the modeled performance statistics of the scroll type electric chiller and the provided coal steam system are located in Figure A.3.

Annual Cost by System

A cost analysis was not set up in the design model, however was performed on the analysis to study the operation and consumption costs resulting from use of electricity and coal. From the energy requirements displayed in Table 8, it is clealy evident that more heating is required than cooling in Peirce Hall. Gambier, Ohio is a very cool climate in winter months and the existing exterior wall's poor insulating characteristics expel a great amount of heat. In terms of dollar value, the cost of heating is double that of cooling. Therefore, during cold months large rises in heating costs are expected, where during hot months there are lower rises in electric costs. This energy and cost relationship is displayed in Table 9, Chart 1, and Graph 1.

Overall Utility Expenses		
Utility	Energy 10^6 [Btu/yr]	Cost/yr [$/yr]
Coal	7,423.90	16,778.00
Electricity	5,415.00	75,066.00
Total	12,838.90	91,844.00
Annual Cost/ft^2 [$/ft^2]		**1.378**

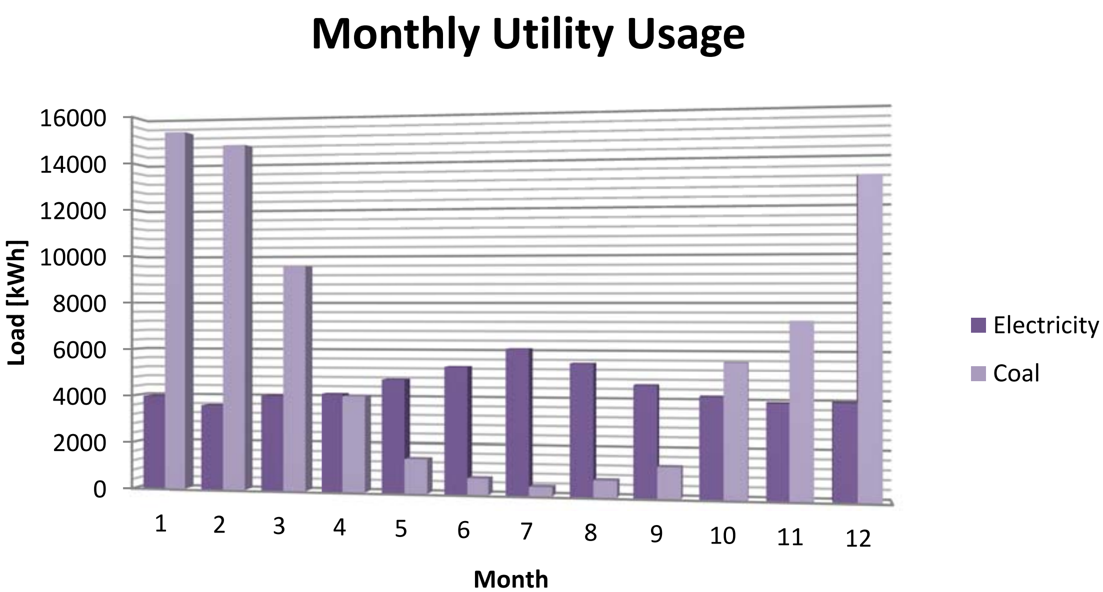
Table 8. Overall Utility Expenses

Electrical Cost Break Down			
Load	Energy 10^6 [Btu/yr]	Cost/yr [$/yr-ft^2]	Load Base %
Primary Heating*	7,587.90	0.27	59.10%
Primary Cooling**	438.05	0.09	3.41%
Cooling Tower	121.01	0.03	0.94%
Supply Fans	1,051.92	0.22	8.19%
Pumps	9.78	0.00	0.08%
Lighting	3,492.55	0.73	27.20%
Receptacle	137.65	0.03	1.07%

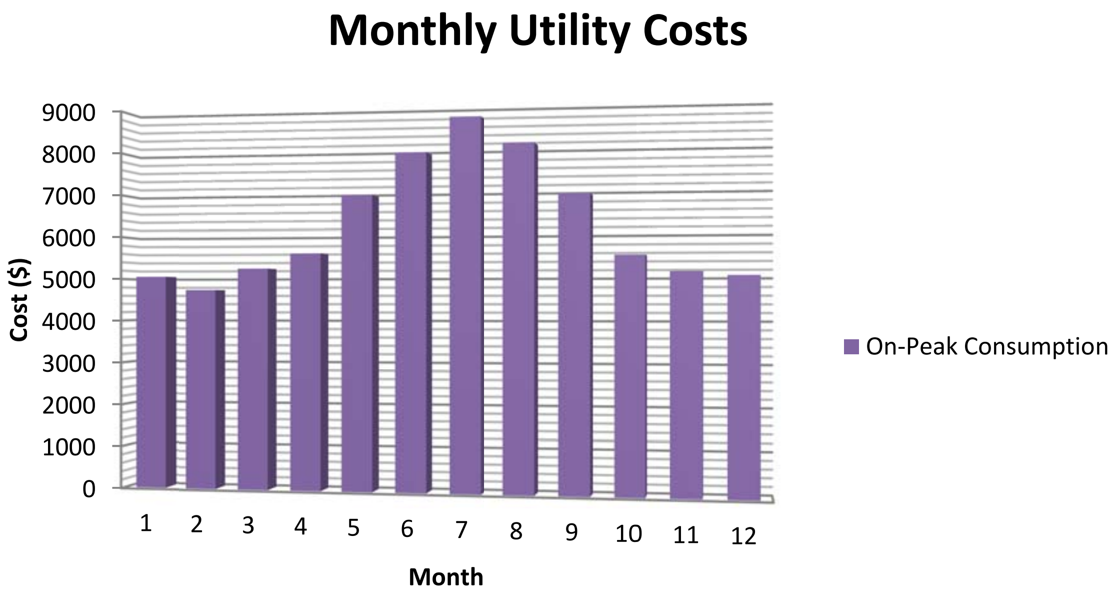
*Primary Heating Cost/yr Includes Coal Cost

** Excludes Cooling Tower Load

Table 9. Annual Utility Cost Breakdown



Graph 1. Monthly Utility Usage



Graph 2. Monthly Utility Cost

Of the electrical systems, lighting systems drew more power than the next leading load, supply fan power, by a factor of three. High lighting loads can be attributed largely to the 1500 and 1200W dining space luminaires. The load from pumps seems very low since cooling is required in the facility all year. However since heating relies more heavily on medium pressure steam, pumping loads are minimal.

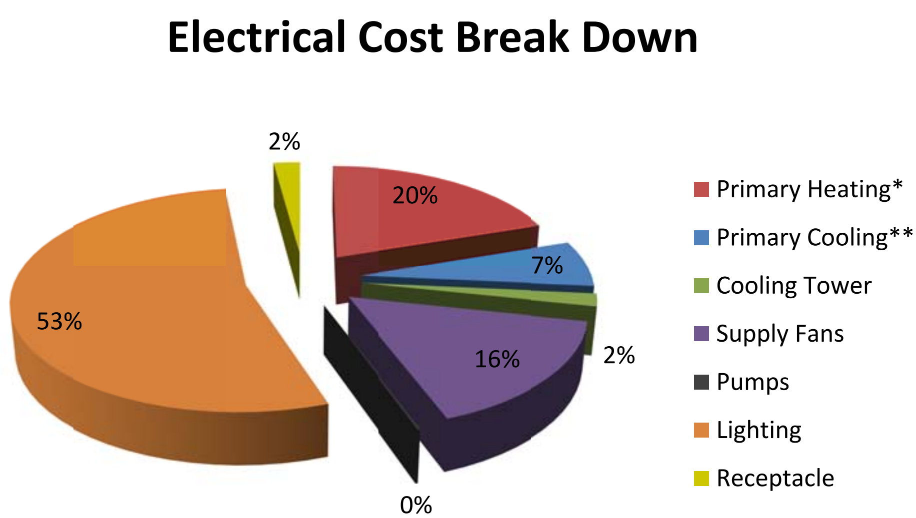


Chart 1. Electrical Cost Breakdown

System Emission Rates

With any production of energy via combustion, there will be by products that are potentially harmful to the environment. It is important to know how harmful a system can be and an emission study can often be helpful. The origin of the power supply should be examined first. Below, in Table 10 are the emission rates of pollutants created by local power generation in various regions of the United States. Ohio lies in the Eastern region. The pounds of pollutant created per year by Peirce Hall relative to the buildings yearly consumption rates can be found in Table 11.

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

Pollutant (lb)	National	Eastern	Western	ERCOT	Alaska	Hawaii
CO_{2e}	1.67E+00	1.74E+00	1.31E+00	1.84E+00	1.71E+00	1.91E+00
CO_2	1.57E+00	1.64E+00	1.22E+00	1.71E+00	1.55E+00	1.83E+00
CH_4	3.71E-03	3.59E-03	3.51E-03	5.30E-03	6.28E-03	2.96E-03
N_2O	3.73E-05	3.87E-05	2.97E-05	4.02E-05	3.05E-05	2.00E-05
NO_x	2.76E-03	3.00E-03	1.95E-03	2.20E-03	1.95E-03	4.32E-03
SO_x	8.36E-03	8.57E-03	6.82E-03	9.70E-03	1.12E-02	8.36E-03
CO	8.05E-04	8.54E-04	5.46E-04	9.07E-04	2.05E-03	7.43E-03
TNMOC	7.13E-05	7.26E-05	6.45E-05	7.44E-05	8.40E-05	1.15E-04
Lead	1.31E-07	1.39E-07	8.95E-08	1.42E-07	6.30E-08	1.32E-07
Mercury	3.05E-08	3.36E-08	1.86E-08	2.79E-08	3.80E-08	1.72E-07
PM10	9.16E-05	9.26E-05	6.99E-05	1.30E-04	1.09E-04	1.79E-04
Solid Waste	1.90E-01	2.05E-01	1.39E-01	1.66E-01	7.89E-02	7.44E-02

Table 10. Total Emission Factors for Delivered Electricity (Table 3 of National Renewable Energy Laboratory, *Source Energy and Emission Factors for Energy Use in Buildings*, M. Deru and P. Torcellini, 2007.)

Eastern Interconnection Emissions for Delivered Electricity	
Pollutant	Mass of Emitted Pollutant (lbm)
CO_{2E}	2,760,654.42
CO_2	2,601,996.12
N_2O	61.40
NO_x	4,759.75
SO_x	13,597.02
PM10	146.92

Table 11. Eastern Interconnection Emissions for Delivered Electricity

Next the pollutants emitted by the system should be considered. In the energy analysis run in Trane Trace, the steam plant was modeled as a coal fueled steam boiler. After running the analysis 74,239 therms was determined to be the total consumption value. With this and the assumption that 1 lb of bituminous coal produces 12.465 kBtu of energy (as defined by Energy Star) emitted pollutants can be calculated with Table 12. Results of these calculations can be found in Table 13.

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

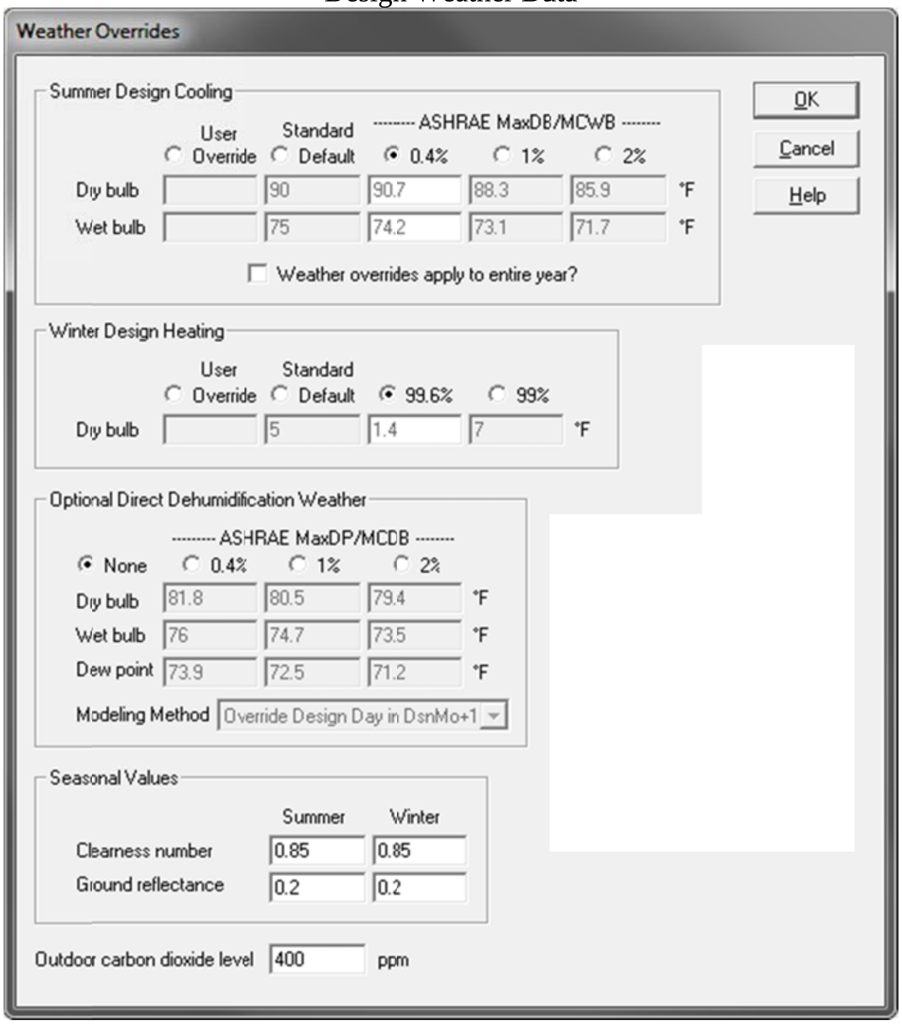
Pollutant (lb)	Commercial Boiler					
	Bituminous Coal *	Lignite Coal **	Natural Gas	Residual Fuel Oil	Distillate Fuel Oil	LPG
	1000 lb	1000 lb	1000 ft^3 ***	1000 gal	1000 gal	1000 gal
CO_{2e}	2.74E+03	2.30E+03	1.23E+02	2.56E+04	2.28E+04	1.35E+04
CO_2	2.63E+03	2.30E+03	1.22E+02	2.55E+04	2.28E+04	1.32E+04
CH_4	1.15E-01	2.00E-02	2.50E-03	2.31E-01	2.32E-01	2.17E-01
N_2O	3.68E-01	ND †	2.50E-03	1.18E-01	1.19E-01	9.77E-01
NO_X	5.75E+00	5.97E+00	1.11E-01	6.41E+00	2.15E+01	1.57E+01
SO_X	1.66E+00	1.29E+01	6.32E-04	4.00E+01	3.41E+01	0.00E+00
CO	2.89E+00	4.05E-03	9.33E-02	5.34E+00	5.41E+00	2.17E+00
VOC	ND †	ND †	6.13E-03	3.63E-01	2.17E-01	3.80E-01
Lead	1.79E-03	6.86E-02	5.00E-07	1.51E-06	ND †	ND †
Mercury	6.54E-04	6.54E-04	2.60E-07	1.13E-07	ND †	ND †
PM10	2.00E+00	ND †	8.40E-03	4.64E+00	1.88E+00	4.89E-01

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

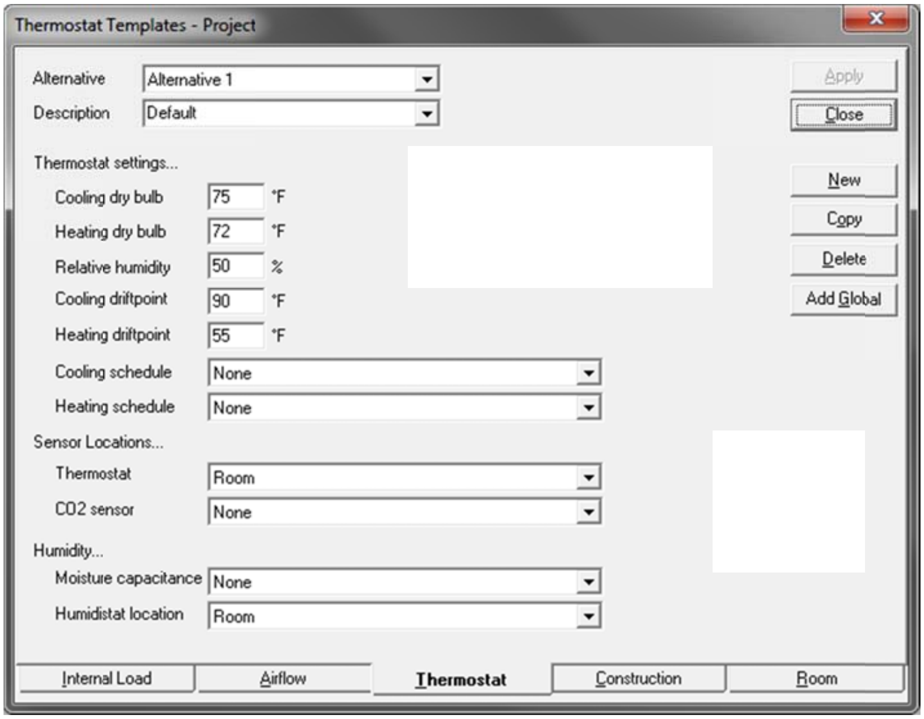
Appendix

A.1 Model Design Information

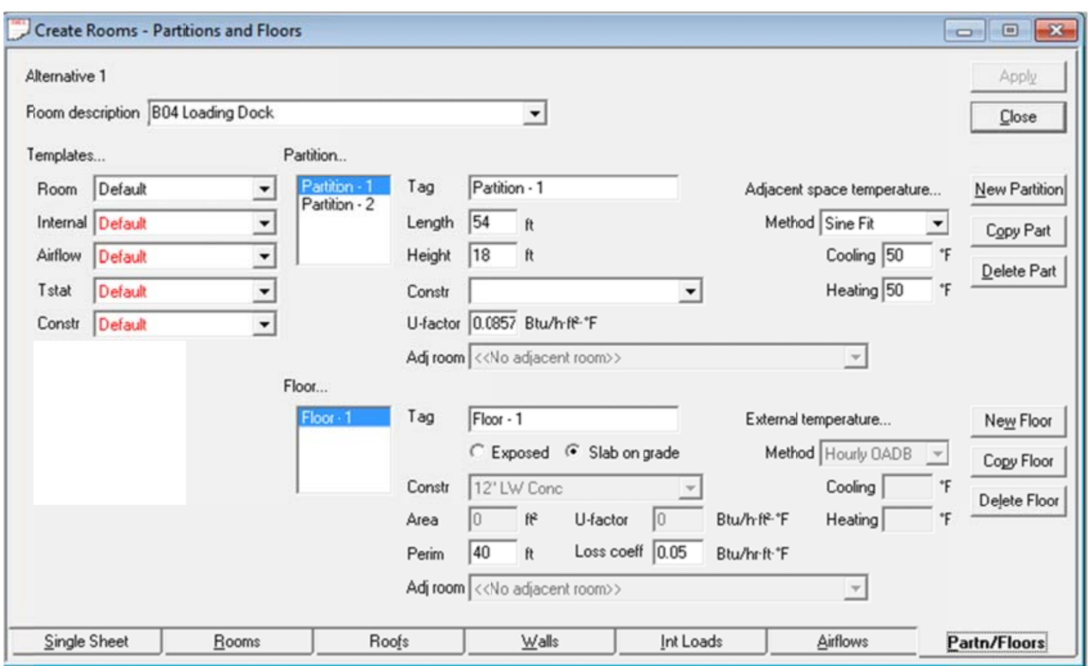
Design Weather Data



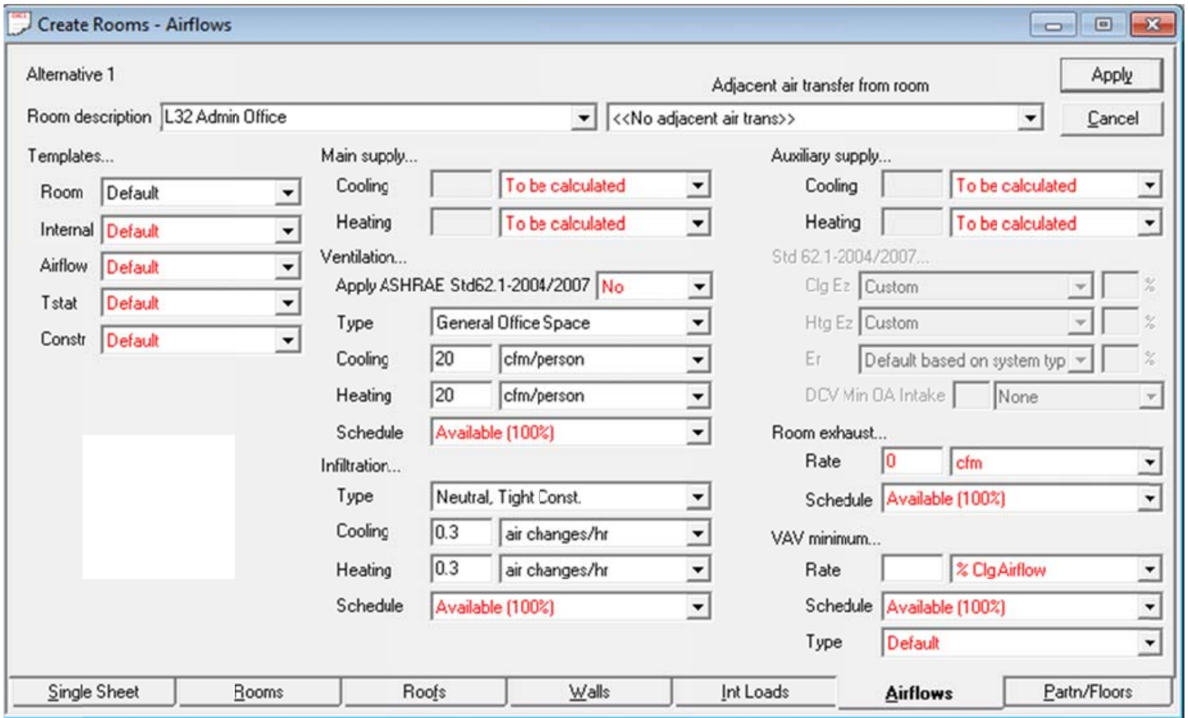
General Indoor Temperature Settings



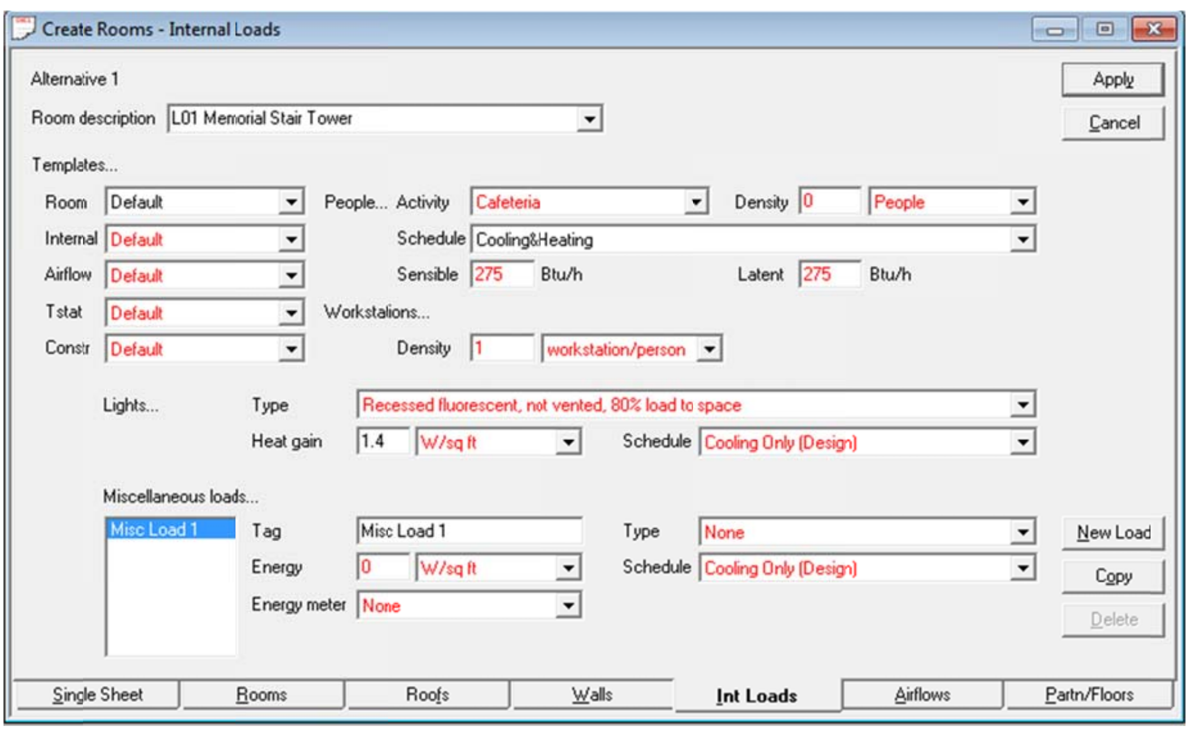
Sample Slab-on-Grade Floor and Grade Wall



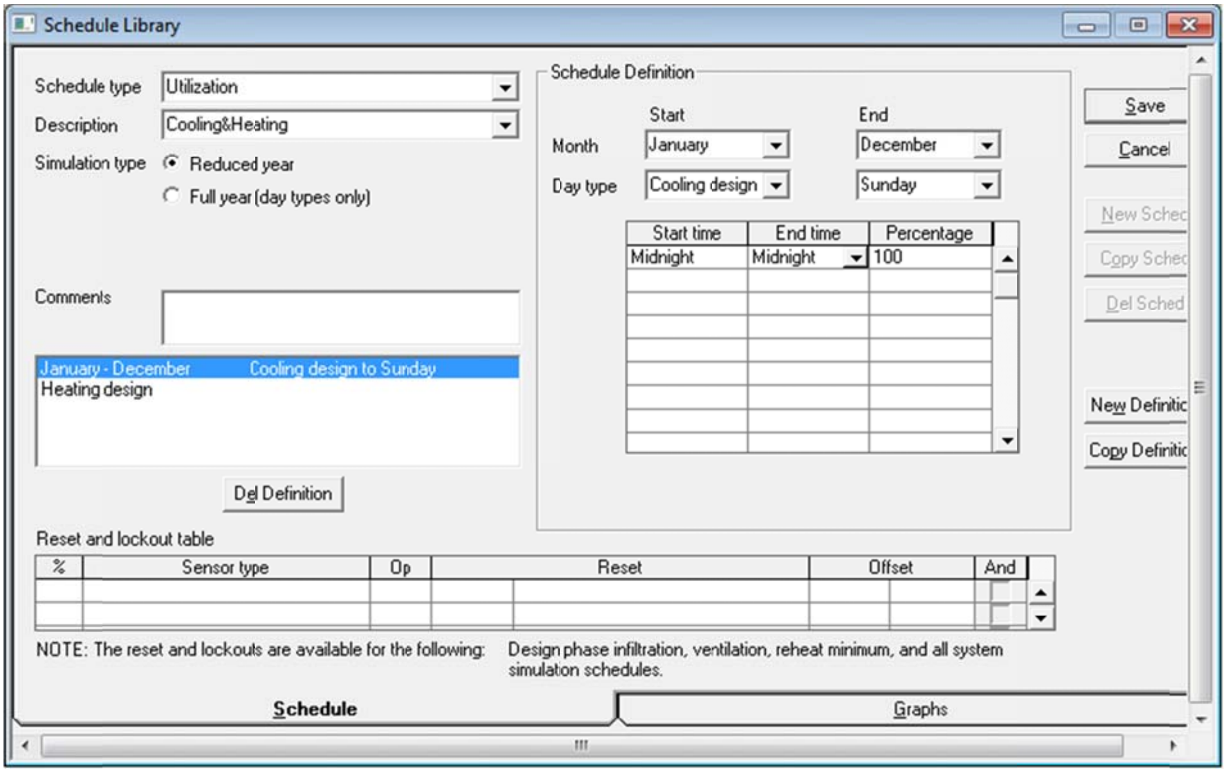
Sample Air Flow Template



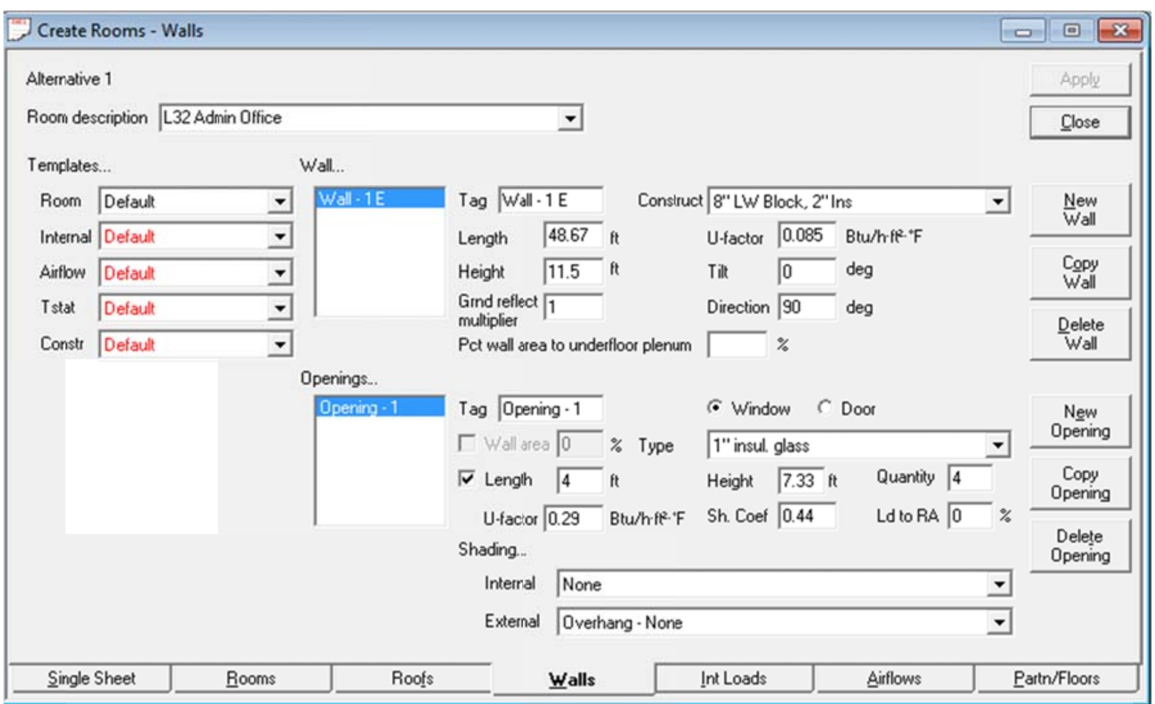
Sample Interior Load Template



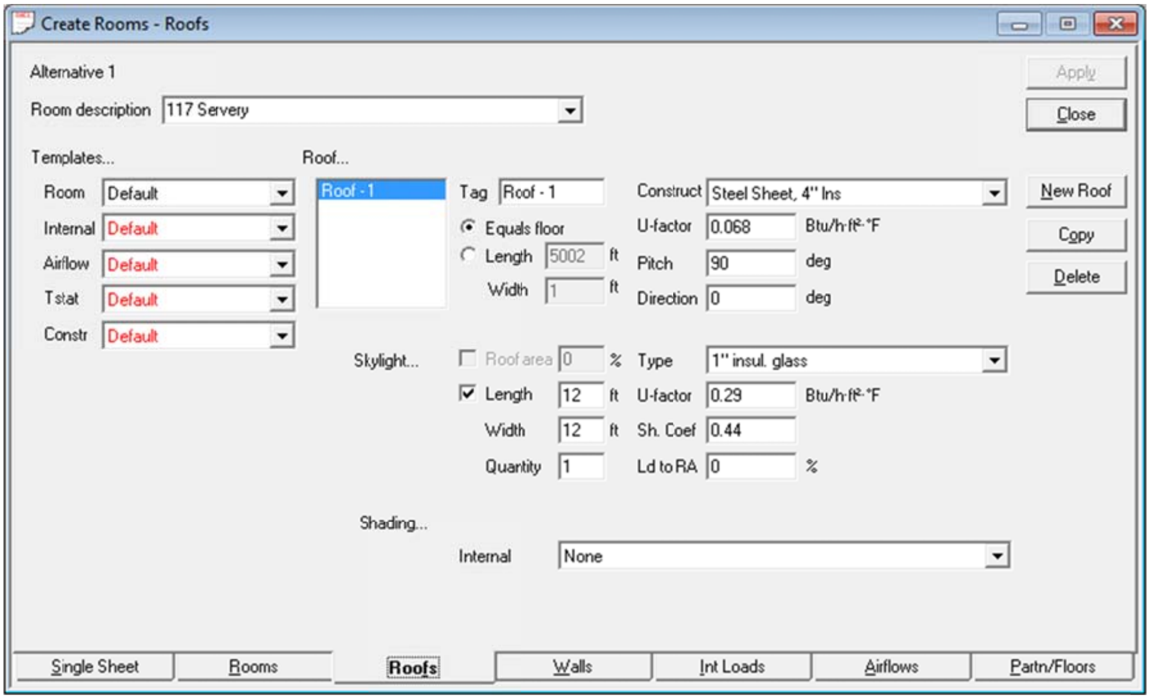
Schedule Template



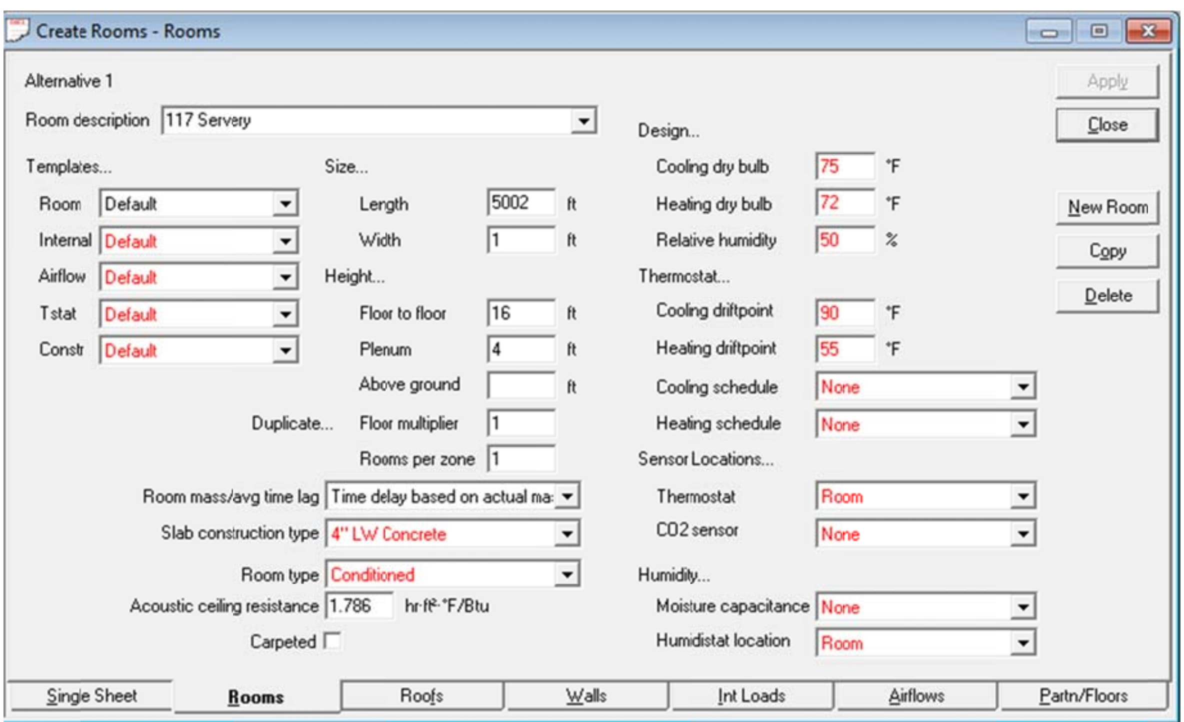
Sample Exterior Wall Template



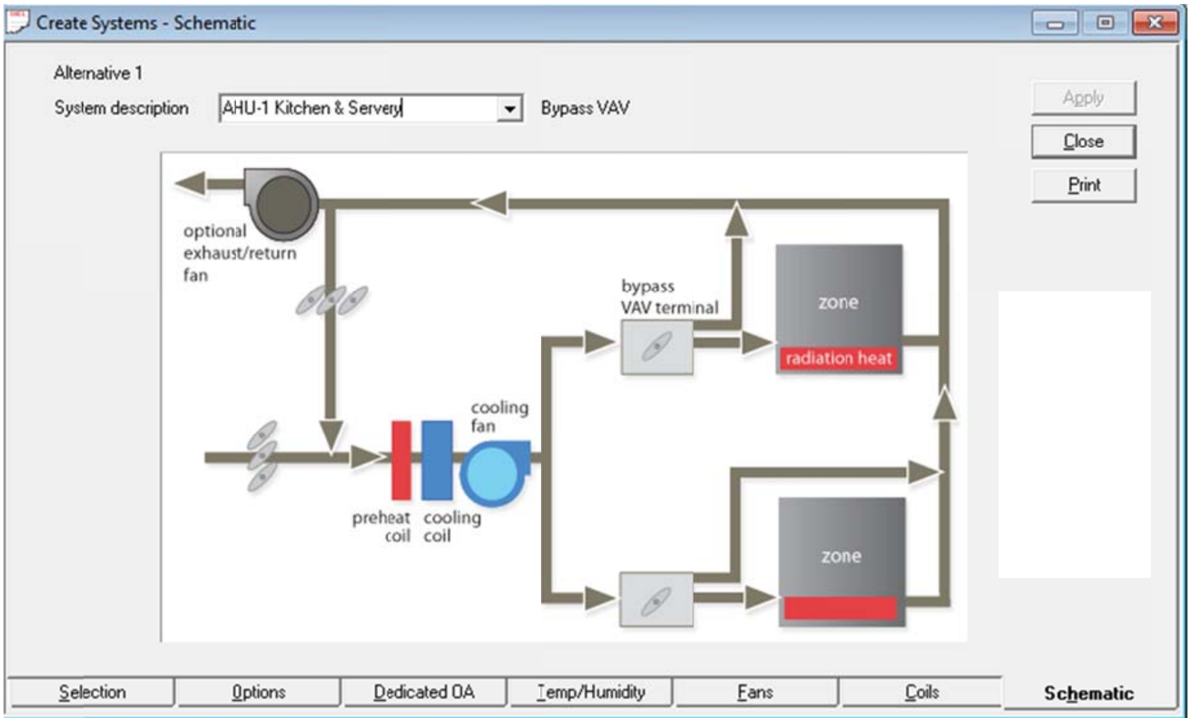
Sample Roof Template



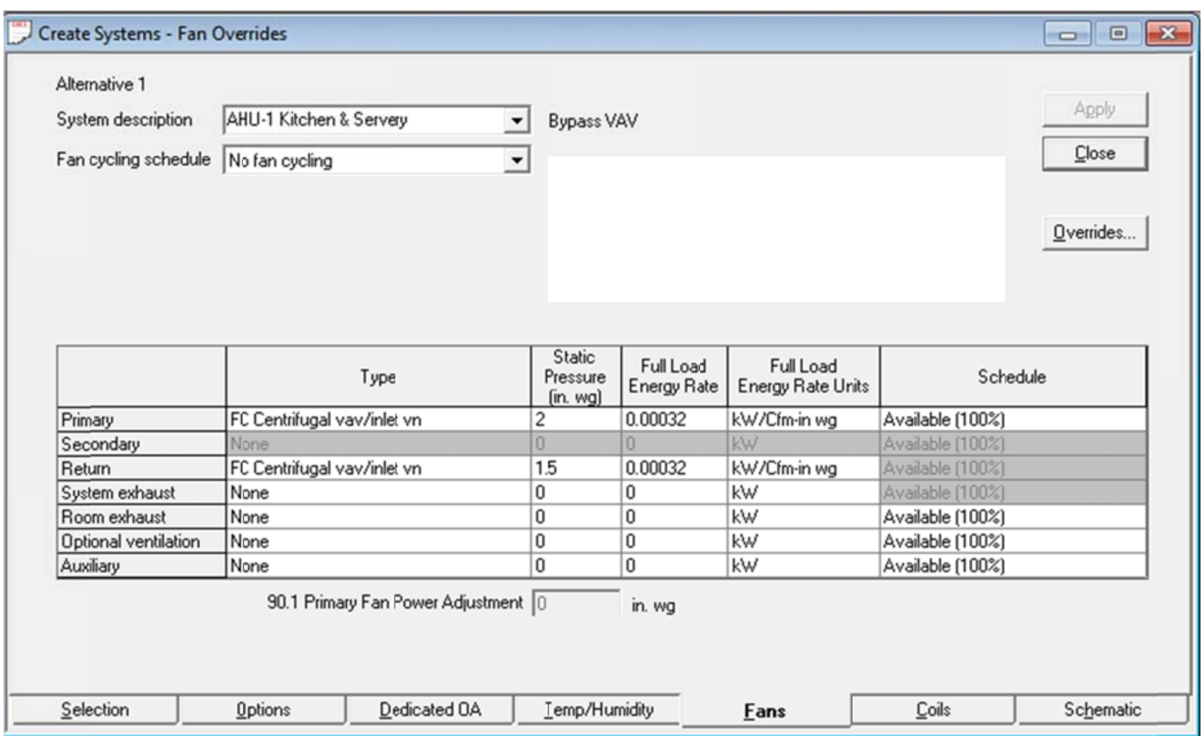
Sample Room Template



Sample System Schematic

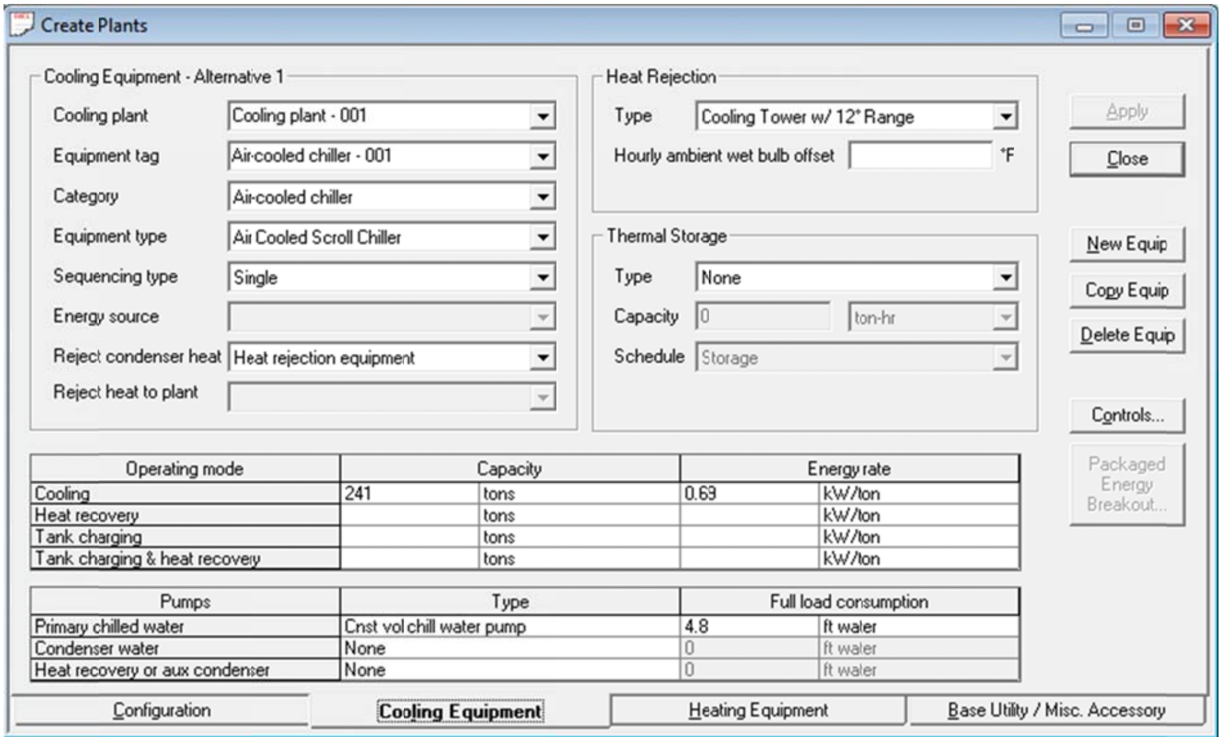


Sample System Fan Override

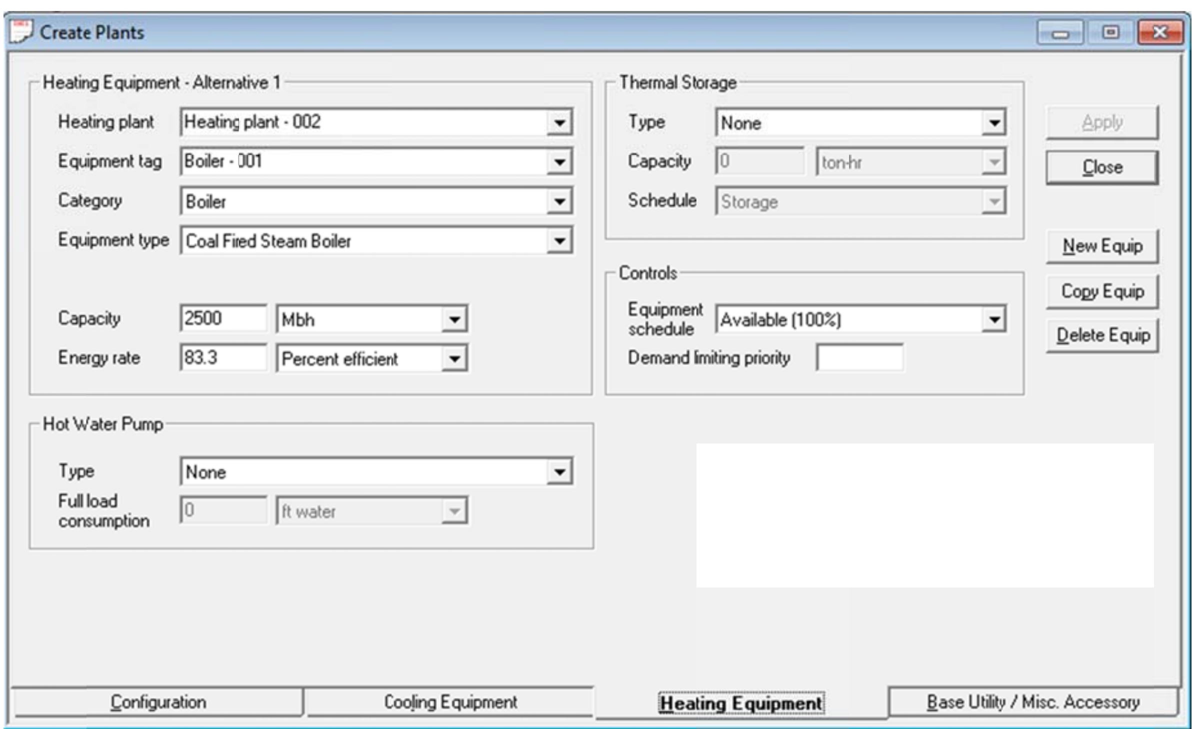


	Type	Static Pressure (in. wg)	Full Load Energy Rate	Full Load Energy Rate Units	Schedule
Primary	FC Centrifugal vav/inlet vn	2	0.00032	kW/Cfm-in wg	Available (100%)
Secondary	None	0	0	kW	Available (100%)
Return	FC Centrifugal vav/inlet vn	1.5	0.00032	kW/Cfm-in wg	Available (100%)
System exhaust	None	0	0	kW	Available (100%)
Room exhaust	None	0	0	kW	Available (100%)
Optional ventilation	None	0	0	kW	Available (100%)
Auxiliary	None	0	0	kW	Available (100%)

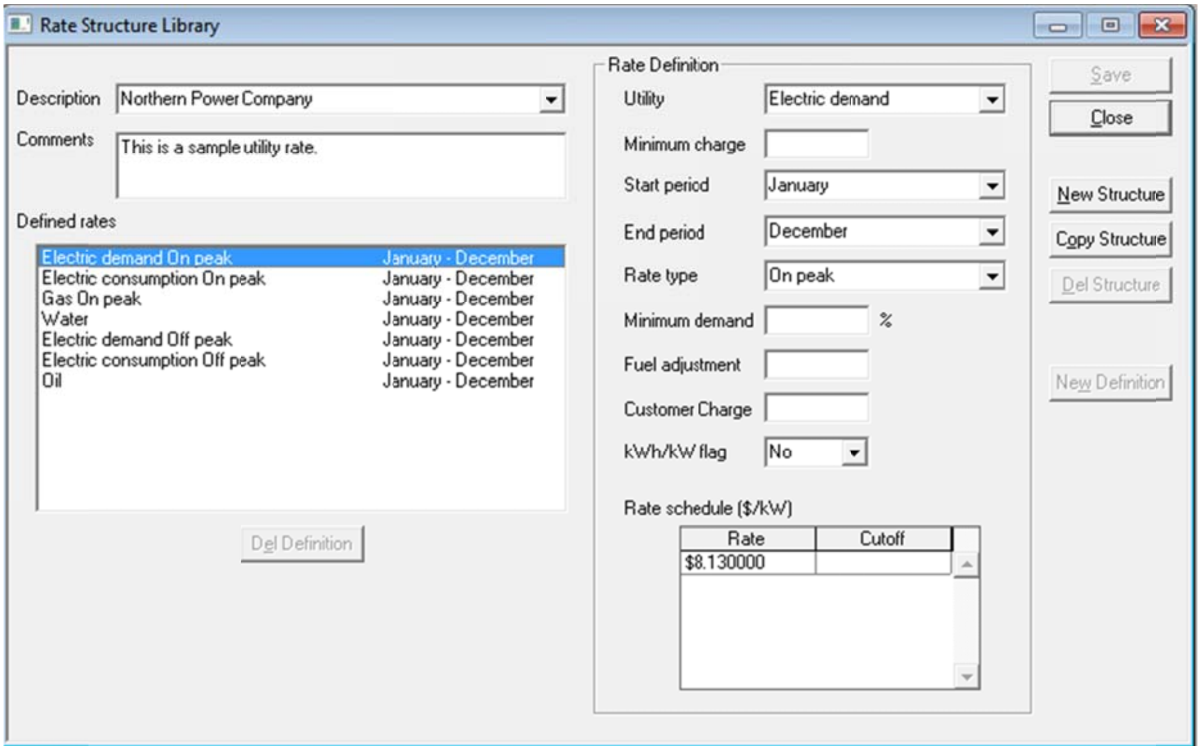
Cooling Plant Equipment Model



Heating Plant Equipment Model



Sample Economic Data Template



A.2 Computed vs. Design Document Load and Ventilation Indices

System	Cooling [ft²/ton]		Difference	Heating [Btu/h-ft²]		Difference	Total Supply Air [cfm/ft²]		Difference	Ventilation Supply [cfm]		Difference
	Analysis	Design		Analysis	Design		Analysis	Design		Analysis	Design	
AHU-1 Kitchen/Servery	191.6	265.5	-27.83%	40.63	29.29	38.72%	1.74	1.37	27.01%	3530	2095	68.50%
AHU-2 Pub/Great Hall	113.3	135.3	-16.26%	102.74	103.2	-0.45%	3.14	2.78	12.95%	10840	9200	17.83%
AHU-3 Tower	276.9	314.7	-12.01%	49.4	42.82	15.37%	1.26	1.23	2.44%	2952	1797	64.27%
AHU-4 Dining Hall	151	130.2	15.98%	63.53	69.82	-9.01%	2.14	2.36	-9.32%	14306	14965	-4.40%
AHU-5 Catering Make-Up	0	0	0.00%	636.7	636	0.11%	8.34	8.33	0.12%	7500	7500	0.00%
AHU-6 Servery Make-Up	0	0	0.00%	158.68	152.87	3.80%	2.08	2	4.00%	10400	10400	0.00%
AHU-7 Loading Dock B04	0	0	0.00%	3.39	17.6	-80.74%	0.02	0.26	-92.31%	38	55	-30.91%
FCU-1 Bemis Music Room	132.3	140.3	-5.70%	102.47	111.06	-7.73%	3.5	3.18	10.06%	1079	1079	0.00%
CUH Mechanical Room	0	0	0.00%	3.02	11.82	-74.45%	0.05	0.21	-76.19%	0	0	0.00%
CUH Non-Cooled Spaces	0	0	0.00%	7.95	16.87	-52.87%	0.09	0.16	-43.75%	801	304	163.49%
CUH Stairs	0	0	0.00%	39.51	68.73	-42.51%	0.62	1.14	-45.61%	106	93	13.98%
CUH Storage	0	0	0.00%	20.55	58.05	-64.60%	0.24	0.84	-71.43%	148	56	164.29%