TECHNICAL REPORT TWO

BUILDING AND PLANT ENERGY ANALYSIS

DALE E. HOUCK | MECHANICAL

CONSULTANT: DR. BAHNFLETH

3 NOVEMBER 2010

PENN STATE UNIVERSITY ARCHITECTURAL ENGINEERING

TABLE OF CONTENTS

EXECUTIVE SUMMARY **3**

MECHANICAL SYSTEMS SUMMARY **4**

DESIGN LOAD ESTIMATION **5**

- Design Conditions **5**
- Building Materials **6**
- Internal Loads **7**
- Schedules **8**
- Design vs. Modeled Loads **9**

ENERGY AND EMISSIONS REPORT **10**

- Assumptions **10**
- Annual Energy Consumption **11**
- Annual Energy Costs **14**
- Annual Energy Emissions **16**

REFERENCES **18**

APPENDIX **19**

EXECUTIVE SUMMARY

This purpose of this report is to provide a summary of modeled loads, energy consumption, operating costs, and emissions for the Unified Science Center in Scranton, PA. This building is a university science center housing laboratories, classrooms, computer rooms, and office spaces.

Analysis was performed using Trane TRACE 700 to simulate loads and energy usage on an annual basis. Room dimensions, occupancy, and glazing areas were entered into the program along with information about the primary heating, cooling, and ventilation systems used in the building. All information was taken directly from the design documents when provided; otherwise, default values provided by ASHRAE were used for analysis.

Results of the TRACE analysis were then compared with design document values. In most cases, the simulation results are within range of the design documents. Difficulty in accurately modeling the complex loads and systems of the Unified Science Center accounts for the discrepancies in heating loads.

According to the simulation, the Unified Science Center will consume approximately 8,666,768 kWh per year and approximately 124,195 MBTU of natural gas. The building will cost nearly \$9.00/ft^2 to operate. Detailed information about modeling methods and results is found in the following report.

MECHANICAL SYSTEMS SUMMARY

The majority of the Unified Science Center is supplied with 100% outside air from five rooftop AHUs with energy recovery wheels and variable frequency drives. AHUs 1 and 2 serve the same supply air ducts with a total of 100,000 CFM. AHUs 3 and 4 operate identically to supply similar spaces including offices, laboratories, and classrooms. AHU 5 provides 5,150 CFM to a ground floor Vivarium. Figure 1 shows the areas served by each unit.

Other systems include a 750 CFM constant air volume unit which serves a room on the first floor and a small variable air volume unit which serves existing variable volume supply terminals. Due to the relatively small size of these units and the areas they serve, they were not considered in the following analysis.

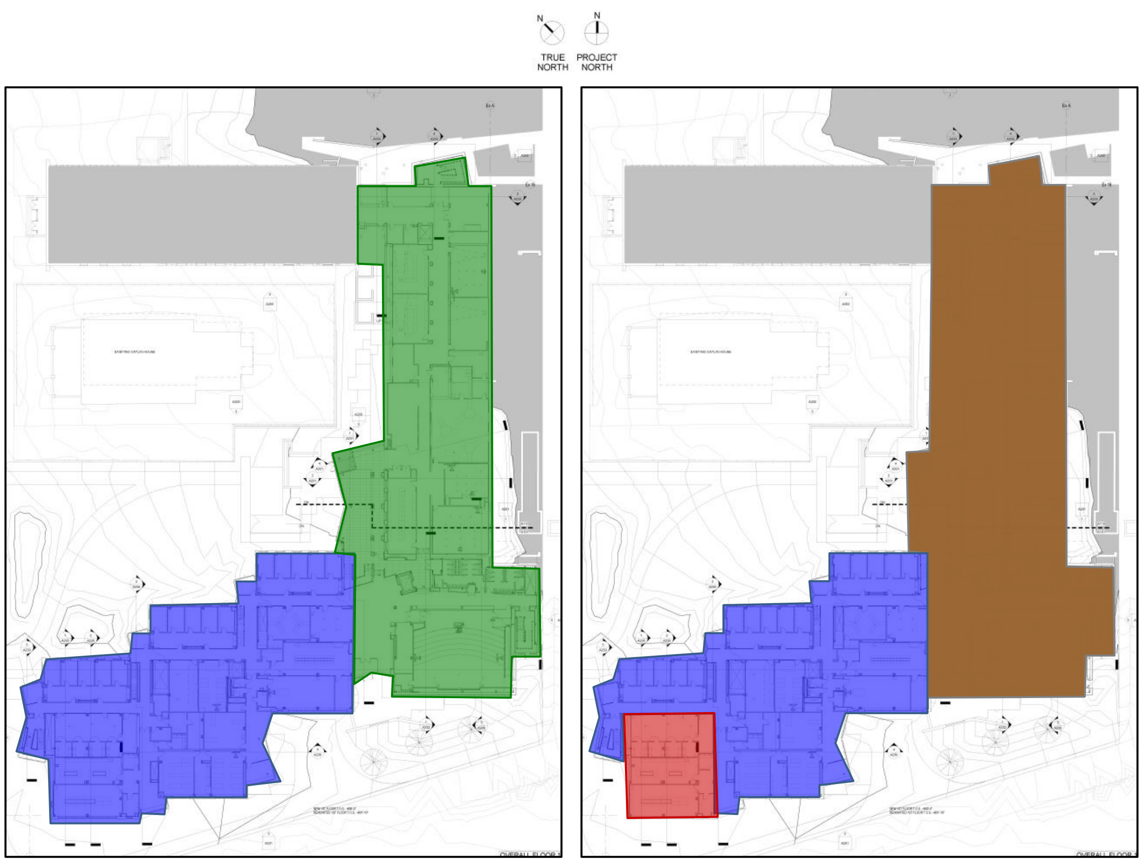


Fig. 1a Floors 1 – 4, typ. **Fig. 1b** Ground Floor

	AHUs 1 and 2	AHUs 3 and 4	AHU 5
Area Served	87,625 ft^2	85,757 ft^2	3,346 ft^2
	Total Floor Area	**176728 ft^2**	

Fig. 1

DESIGN LOAD ESTIMATION

Trane TRACE was chosen for analysis because of my previous experience with the program and its ease of use. A block load simulation was performed to estimate the design heating and cooling loads. The REVIT model used for analysis was constructed using information provided by the architectural engineers.

Design Conditions

The Unified Science Center is located in Scranton, PA, as indicated in Fig. 2. The design outdoor air conditions used for analysis were obtained from ASHRAE Fundamentals 2007, and are listed in Table 1. Design setpoints were taken from the project documentation.

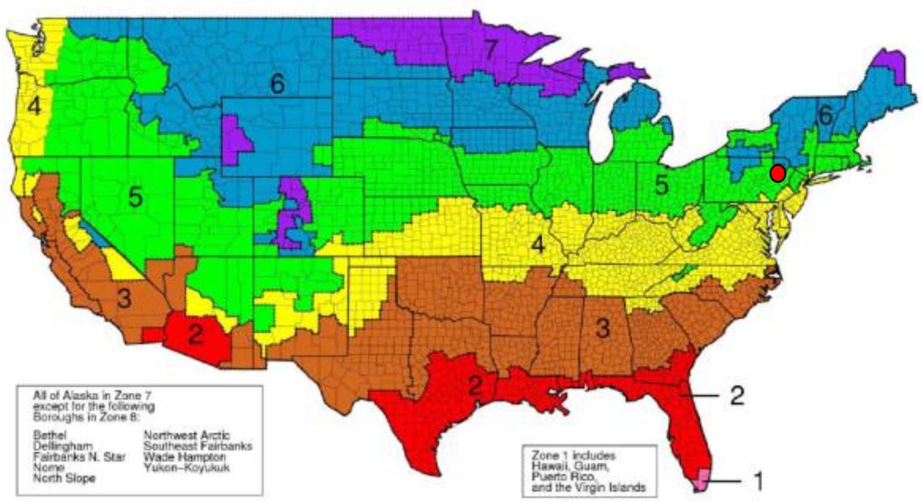


Fig. 2

ASHRAE Design Conditions – Scranton, PA		
	Dry Bulb Temperature (˚F)	**Wet Bulb Temperature (˚F)**
Cooling	**88.9 (0.4%)**	**72.1 (0.4)**
Heating	**3.5 (99.6%)**	**-**
Indoor Design Temperature	**70-75 @ 50% RH**	**-**

Table 1

Building Materials

Materials used for the Unified Science Center are shown in Table 2 along with their corresponding U-values. Though different types of glazing are used throughout the building, all glazing has excellent thermal performance characteristics; for the purposes of this report, all glazing was estimated to have the U-value shown below. The roof was not considered in this analysis, because a penthouse covers most of the rooftop and limits heat conduction; in addition, the white PVC roof material will reflect the majority of incident solar radiation.

Building Materials Characteristics		
Building Component	**Construction**	**U-value (BTU/(h*ft²*°F)**
Façade Wall	**Stone Veneer, Rigid Insulation, Weatherproofing**	**0.0693**
Partition	**¾" Gypsum Wall Board**	**0.388**
Floor Slab	**3-4" NW Concrete**	**0.212615**
Glazing	**Double Pane Low-E Fritted Glass (typ.)**	**0.29 Shading Coefficient = 0.95**

Table 2

Internal Loads

Where not specified in the project documentation, internal loads were estimated using typical data based on space type provided by ASHRAE Fundamentals. Typical occupancy loads and airflows were taken from the project documentation when available; otherwise default TRACE values were used. Table 3 provides a summary of loads according to room type. Samples of TRACE inputs can be found in the Appendix.

Internal Loads					
	Lighting (W/ft^2)	Miscellaneous (W/ft^2)	People (BTU/hr)		People (ft^2/person)
			Sensible	Latent	
Classroom	1.25	0.22	250	200	20
Coffee Shop	1.25	0.1	275	275	15
Computer Classroom	1.25	8	250	200	20
Corridor	1.25	0	250	250	0
Laboratory	1.25	9	250	250	33
Mechanical Room	1	10	250	250	0
Office Suite	1.25	0.5	250	200	143
Student Study Space	1	0.22	250	200	10
Toilet Room	1	3	250	250	50
Vestibule	1	0	250	200	33
Vivarium	1.25	10	250	250	33

Table 3

Schedules

Schedules were generally based on typical values provided by TRACE. Since occupancy and daylight sensors will be utilized to control the lighting levels, the default TRACE schedule "College" was used to designate lighting and people loads. Miscellaneous loads including computers, servers, and laboratory equipment are scheduled for 100% of the time. All loads for the Vivarium space are scheduled for 100% of the time. Table 4 summarizes the schedules used. Samples of TRACE inputs can be found in the Appendix.

Lighting & Occupancy Schedules		
Time	**Lights (%)**	**People (%)**
Midnight-6 AM	0	0
6-7 AM	10	50
7-8 AM	50	50
8AM-Noon	100	100
Noon-1 PM	30	30
1-4 PM	100	100
4-5 PM	50	100
5-6 PM	10	50
6 PM – Midnight	0	0

Table 4

Design vs. Modeled Loads

The building was modeled using Trane TRACE 700. With the exception of the heating load and the Vivarium supply air rate, the modeled load and ventilation indices are comparable with those of the design documents. Results of the TRACE analysis are summarized for the entire building in Table 5. Additional information about modeling methods and examples of inputs can be found in the Appendix.

The model was created by combining spaces with similar uses, including office clusters and adjacent laboratories, to perform a block load analysis for the entire building. The AHUs were each assigned rooms based on the design documents, and were treated as three separate units. Rooms on the 4th and 5th floors of the renovation were not included in the model because these floors are slated for future expansion and have not yet been assigned space types or ventilation rates. They will be served by AHUs 3 and 4; accordingly, the overall cooling load and the supply air for these AHUs differ from the design documents by approximately 25%.

The modeled heating load is considerably lower than the design documents; this is due to difficulties in accurately modeling the heating system of the building. Hot water produced by 8 natural gas fired boilers serves all the air handlers and terminal units. Space heating is achieved in a variety of manners according to space type, including VAV terminal boxes with hot water reheat, fan coil units, cabinet heaters, and finned tube radiation. The model was simplified as a 100% outside air unit with VAV terminal reheat, and underestimated heating loads as a result.

The Vivarium was scheduled for 100% occupancy based on 100 people in the space – this was not a reasonable assumption, and the analysis resulted in an overestimation of supply air. To a lesser extent, this error also affected the overall building cooling load.

	Cooling Load (ft^2/ton)	Heating Load (BTUh/ft^2)	Supply Air (CFM/ft^t)		
			AHUs 1&2	AHUs 3&4	AHU 5
Designed*	180	70	1.14	1.17	1.54
Modeled†	135	24	1.31	1.62	4.5

*Based on design square footage = 200,000 ft^2 (includes future expansion)
†Based on modeled square footage

Table 5

ANNUAL ENERGY CONSUMPTION AND OPERATING COSTS

The annual energy consumption and operating costs were estimated using the same TRACE model that was used for load calculations. The building is not yet occupied, so actual energy bills are not available for comparison with the model. Information pertaining to energy modeling performed by the architectural engineers was not available at the time of this writing.

Analysis shows that energy consumption and costs are dominated by natural gas use. However, delivered electricity accounts for the majority of annual source emissions due to electricity use and distribution losses.

Assumptions

All of the equipment was modeled using information from the design documents, including efficiencies and horsepowers. Representative TRACE inputs can be found in the Appendix.

Utility rates were estimated based on average values for Northeastern Pennsylvania, and can be found in Table 6. Though electricity rates fluctuate yearly, they average at $0.10/kWh, which was the value used for estimation. Current natural gas rates are likely to decrease in the future as a result of developments in local Marcellus shale mining, but a conservative rate was used in analysis nonetheless.

Gas and Electricity Rates	
Electricity Demand	$10.00/kW
Electricity Supply	$0.10/kWh
Gas	$0.72/therm
Water	$11.00/1000 gallons

Table 6

Annual Energy Consumption

Table 7 provides a breakdown of annual energy consumption by load type. The heating load easily dominates modeled annual energy usage with 80% of the total. Though the overall cooling, auxiliary, lighting and receptacle loads are typical, the natural gas usage seems excessively high, and skews the percentage values of each load type. Given the location in northeastern Pennsylvania and the focus on daylighting and energy conservation, the other results are generally reasonable.

Annual Energy Consumption				
Load	**Electricity (kWh)**	**Natural Gas (kBTU)**	**Water (1,000 gal)**	**% of Total**
Heating				**80**
Primary		**124,195,200**		**79.5**
Other	**127,024**			**0.6**
Cooling				**6**
Compressor	**1,615,573**			**3.6**
Cooling Tower/ Condenser Fans	**398,595**		**16,550**	**0.9**
Condenser Pump	**220,635**			**0.5**
Auxiliary				**9**
Supply Fans	**3,489,151**			**7.7**
Pumps	**569,932**			**1.3**
Other				**5**
Lighting	**1,425,080**			**3.2**
Receptacles	**820,778**			**1.8**
Totals	**8,666,768**	**124,195,200**	**16,550**	**100**

Table 7

When the design heating consumption is substituted for the TRACE calculated value in Table 7, the overall results are much more reasonable, and are shown in Figure 3.

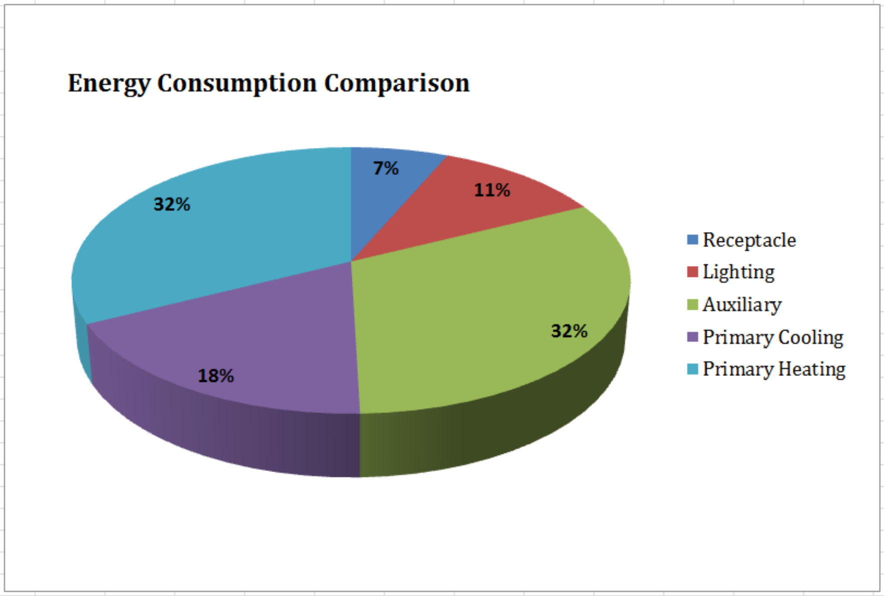


Fig. 3

The chart above provides an estimate of annual energy consumption according to load type. Primary heating loads and auxiliary equipment, including supply fans and pumps, consume most of the annual energy, followed by primary cooling, lighting and receptacle loads. While these results are acceptable, the receptacle load should account for a greater portion of the overall energy use given the amount of laboratory and computer equipment requiring power.

Monthly Energy Consumption

Figures 4 and 5 show the fluctuations in energy usage over the course of the design year. As expected for this climate, electricity use peaks in the summer months (Fig. 4), while gas usage peaks in the winter (Fig. 5). Figure 5 also indicates a summertime surge in natural gas consumption, the reason for the unexpectedly large annual heating load seen in Table 7. This spike is most likely due to the modeled interior and underground spaces requiring VAV reheat during the summer, and is most likely not a realistic estimate of this building's gas consumption. Table 8 shows the numerical values which were given by TRACE and used to produce these graphs.

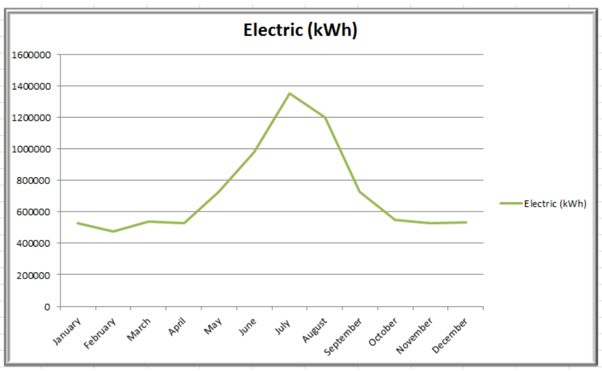


Fig. 4

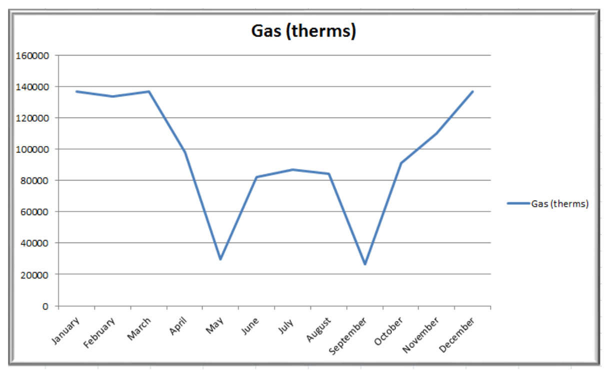


Fig. 5

Monthly Energy Consumption												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Electric - on peak (kWh)	196594	176785	217748	194321	342564	490203	483988	537002	333919	213753	204135	187979
Electric - off peak (kWh)	332773	299699	320868	334547	383614	486969	867202	663076	395704	336323	324621	342380
Electric - total (kWh)	529367	476484	538616	528868	726178	977172	1351190	1200078	729623	550076	528756	530359
Gas (therms)	136759	133524	136759	97817	29510	82032	86759	84266	26468	91261	110038	136759

Table 8

Annual Energy Cost Analysis

Monthly Energy Costs					
Month	Electricity ($)	Natural Gas ($)	Water ($)	Total ($)	% of Annual Total
January	28,464	98,467	9,485	136,415	8.5
February	26,422	88,938	8,510	123,869	8
March	30,769	98,467	9,862	139,098	9.6
April	28,516	70,428	10,001	108,945	6.6
May	55,419	21,247	15,190	91,857	6
June	71,003	66,263	22,573	159,839	10
July	71,142	98,467	32,532	202,141	12.5
August	76,423	89,472	28,723	194,618	12
September	55,737	19,057	15,350	90,143	5.5
October	31,561	65,708	10,450	107,719	6.5
November	30,023	30,023	9,805	119,055	7.4
December	27,748	27,748	9,570	135,785	8.4
Totals	533,228	894,205	182,051	1,609,484	100

Table 9

Table 9 provides a monthly summary of overall utility costs based on the rates in Table 6. Figure 6 provides a graphical representation of overall monthly utility costs. Energy costs will be at their peak in the summer months as a result of the cooling demand; an increase in natural gas consumption also contributes to this peak in overall energy costs. Natural gas usage constitutes the greatest economic cost, at 55% of the yearly total.

The building will cost approximately \$8.04/ft^2 to operate for a typical year. Comparisons of the costs according to type can be found in Figure 7 and Table 10.

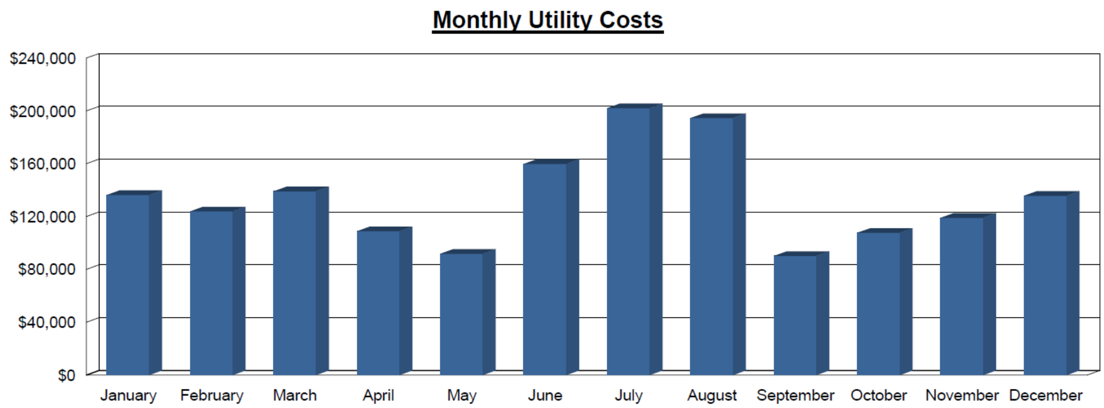


Fig. 6

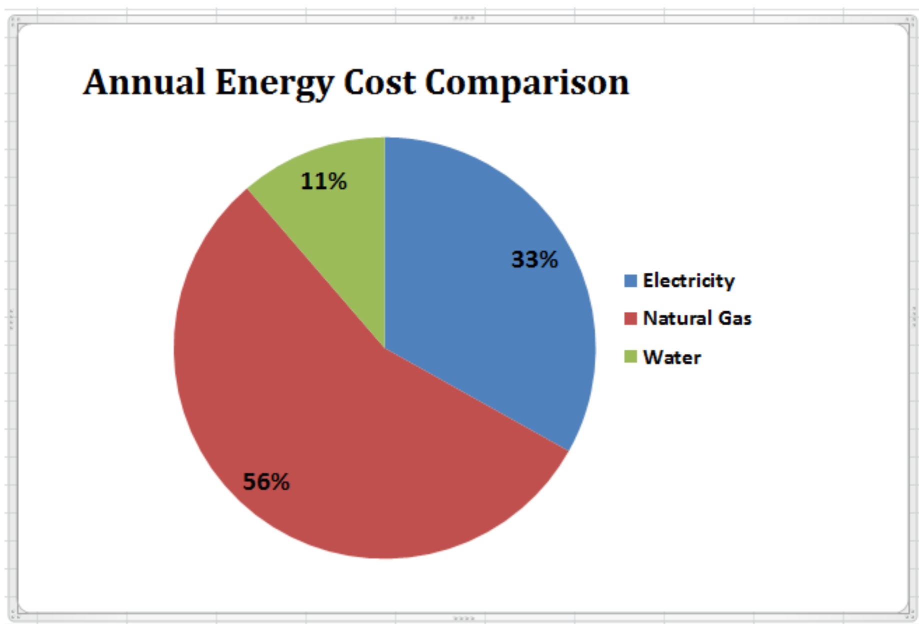


Fig. 7

Overall Cost Comparison			
Electricity	Natural Gas	Water	Overall
$2.66/ft^2	$4.47/ ft^2	$0.91/ ft^2	$8.04/ ft^2

Table 10

Annual Energy Emissions

An emissions calculation was performed using the results of TRACE analysis and the 2007 NREL Regional Grid Emission Factors data. This project is located in the Eastern Interconnection of the North American Electrical Reliability Council electrical grid depicted in Figure 8.

Analysis shows that emissions are primarily the result of delivered electricity. This is the result of the large building electrical loads in combination with the poor efficiency of delivering the electricity itself. High efficiency on-site low-No_x boilers with sealed combustion effectively limit environmental impact from natural gas combustion. The TRACE model produced the summary of overall annual emissions found in Table 11.

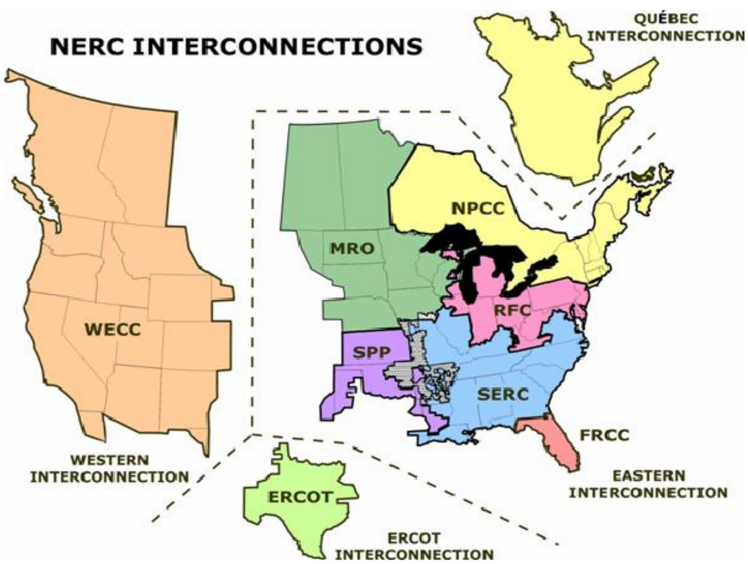


Fig. 8

Computed Emissions Summary		
CO_2	SO_2	NO_x
54,797,620 lb/yr	423,662 gm/yr	85,156 gm/yr

Table 11

Tables 12 and 13 summarize emissions from delivered electricity and on-site combustion, respectively.

Annual Emissions from Delivered Electricity		
Pollutant	lb of Pollutant per kWh of Electricity	Annual lb of Pollutant Annual Electricity Consumption = 8,666,768 kWh
CO2e	1.74E+00	15080174.58
CO2	1.64E+00	14213497.88
CH4	3.59E-03	31113.69
N2O	3.87E-05	335.40
NOX	3.00E-03	26000.30
SOX	8.57E-03	74274.19
CO	8.54E-04	7401.42
TNMOC	7.26E-05	629.21
Lead	1.39E-07	1.20
Mercury	3.36E-08	0.29
PM10	9.26E-05	802.54
Solid Waste	2.05E-01	1776687.24
Total Annual Emissions (lb)		31,210,917.95

Table 12

Annual Emissions from Natural Gas Boilers		
Pollutant	lb of Pollutant per 1000 ft3 Natural Gas	Annual lb of Pollutant
CO2e	1.23E+02	141690.096
CO2	1.22E+02	140538.144
CH4	2.50E-03	2.87988
N2O	2.50E-03	2.87988
NOX	1.11E-01	127.866672
SOX	6.32E-04	0.728033664
CO	9.33E-02	107.4771216
VOC	6.13E-03	7.06146576
Lead	5.00E-07	0.000575976
Mercury	2.60E-07	0.000299508
PM10	8.40E-03	9.6763968
Total Annual Emissions (lb)		282,486.8103

Table 13

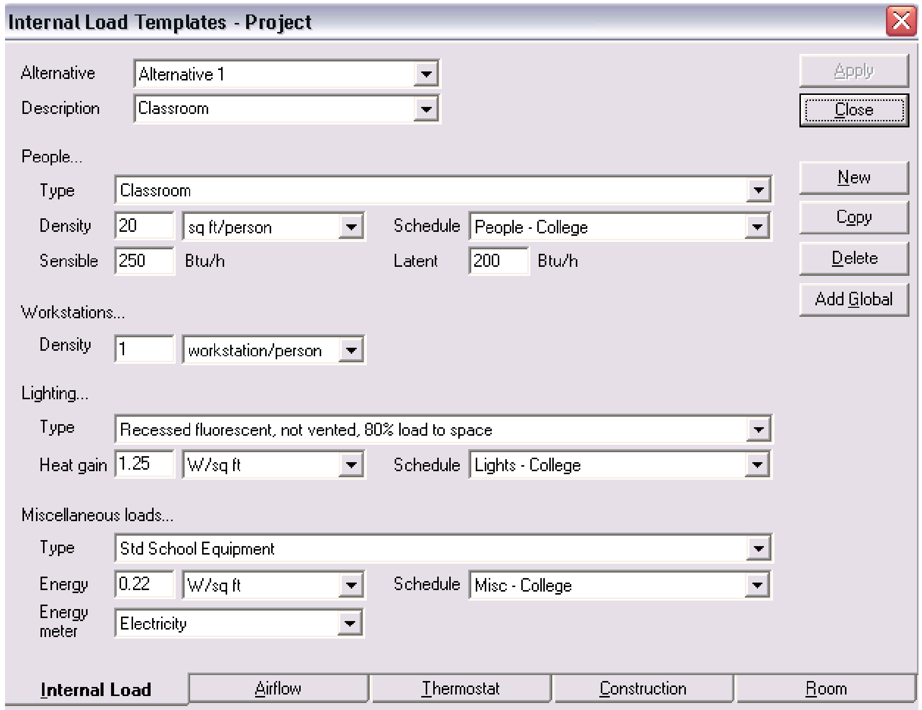
REFERENCES

Deru, M., and P. Torcellini. *Source Energy and Emission Factors for Energy Use in Buildings*. Oak Ridge, TN: U.S. Department of Energy, 2007.

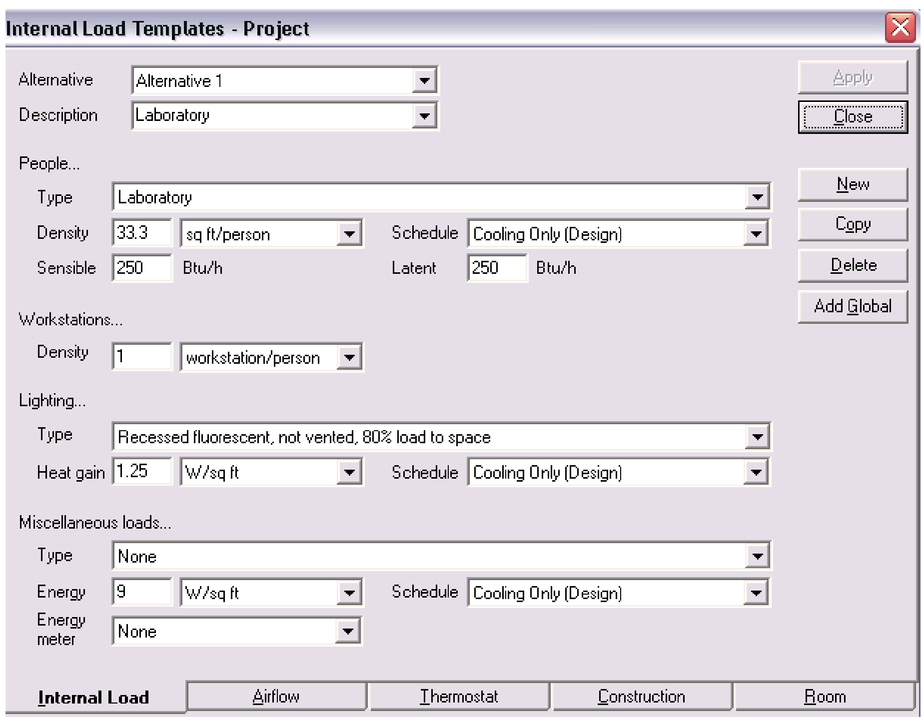
ASHRAE, *2009 Fundamentals.*

Project documentation provided by Einhorn Yaffee Prescott Architecture and Engineering.

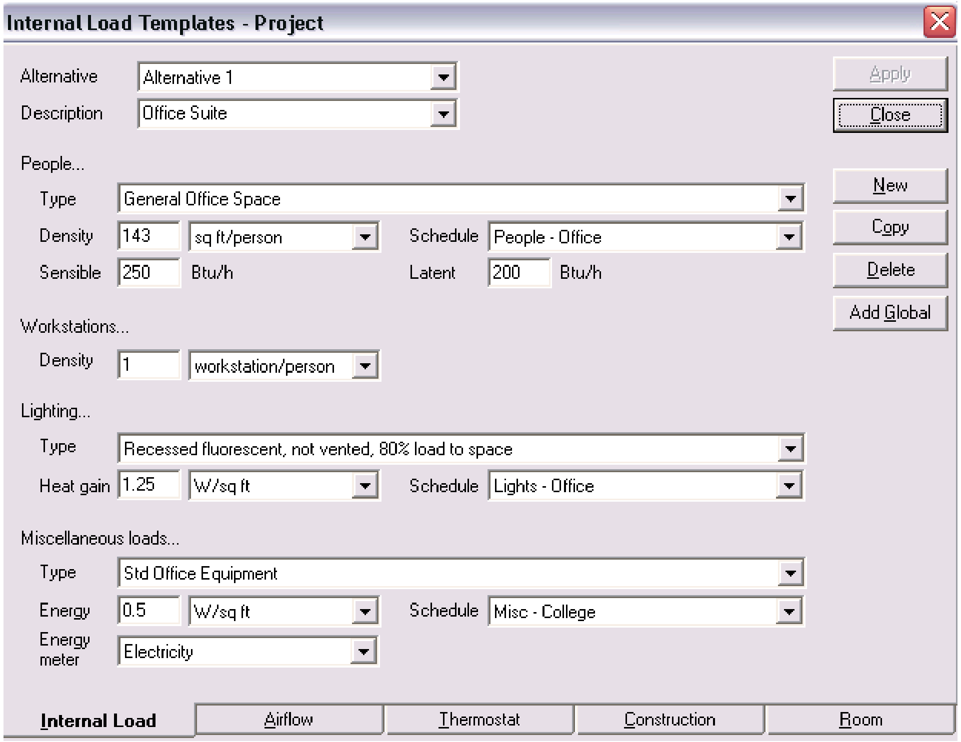
APPENDIX



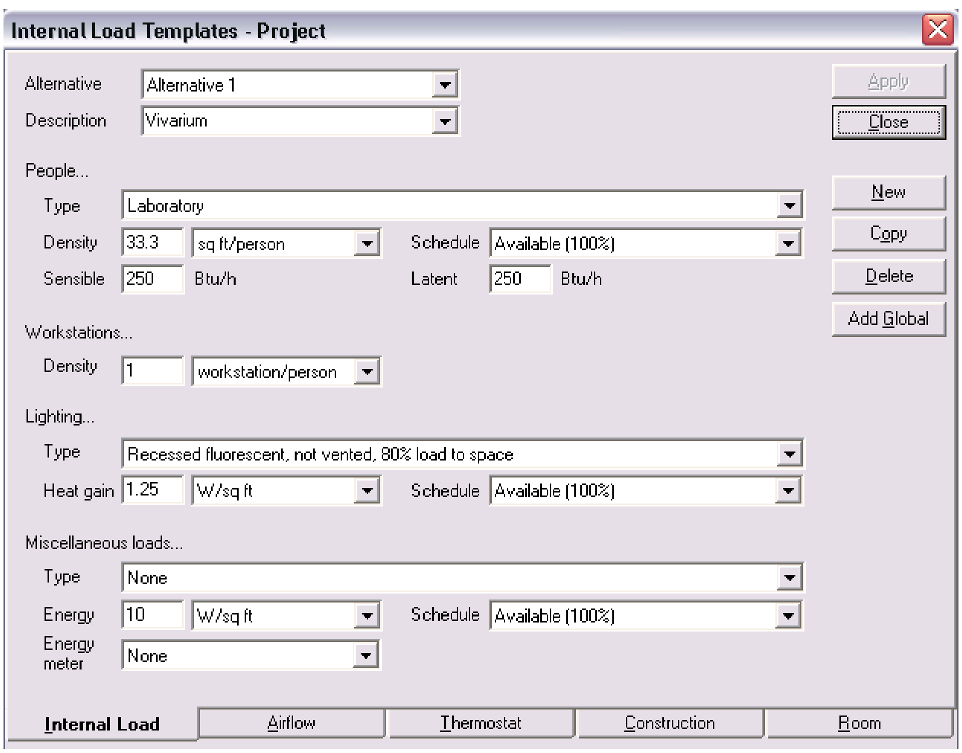
Internal Load Template – Classroom



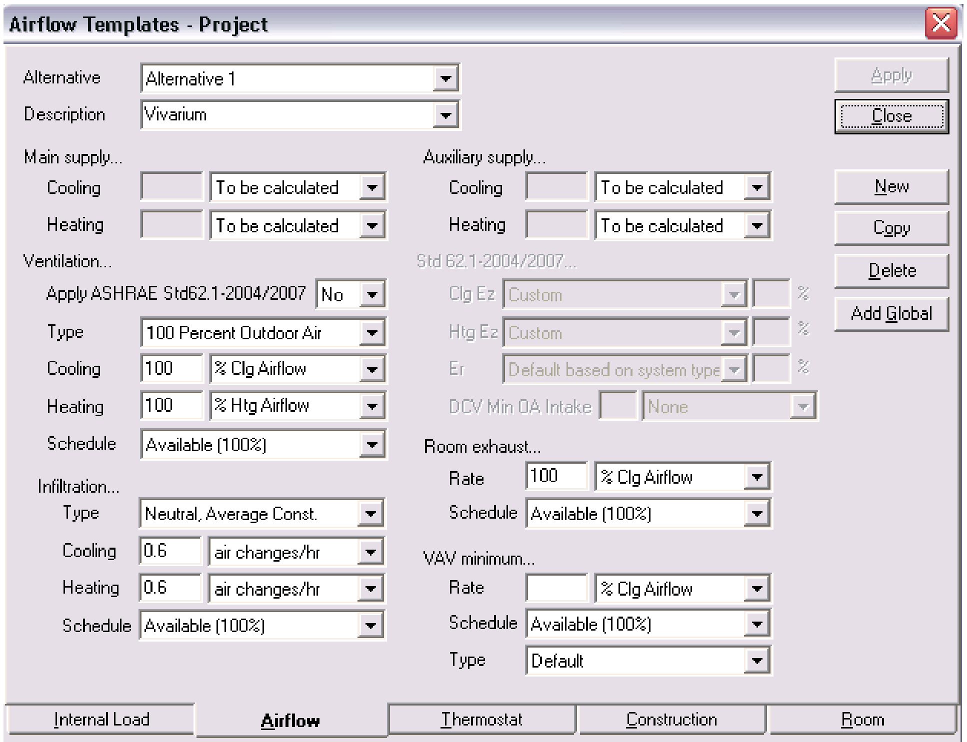
Internal Load Template - Laboratory



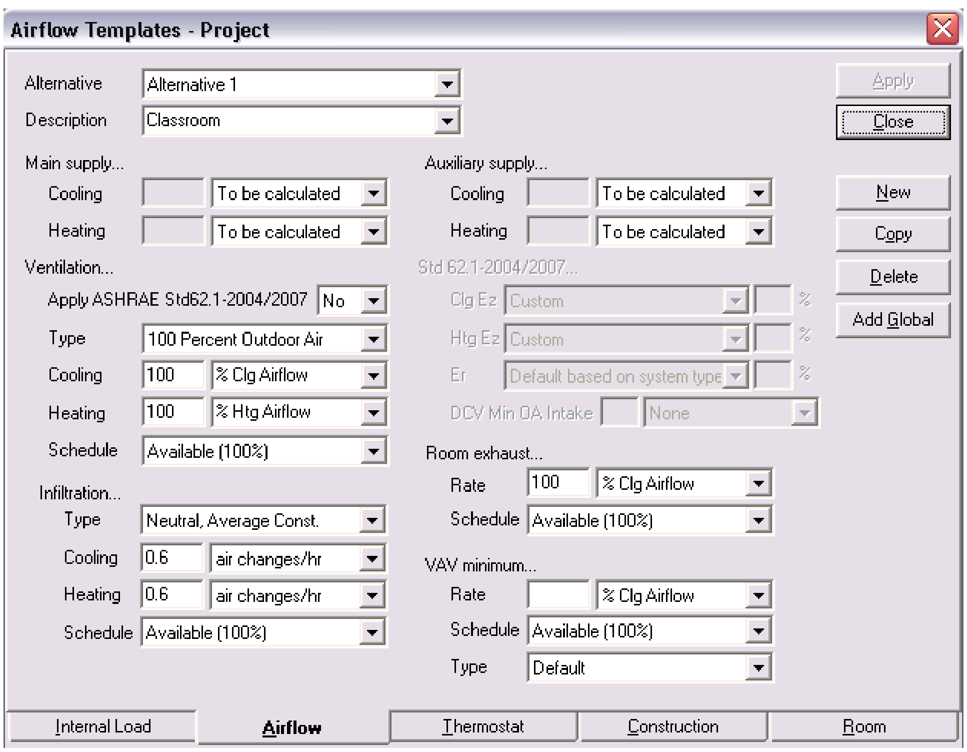
Internal Load Template - Offices



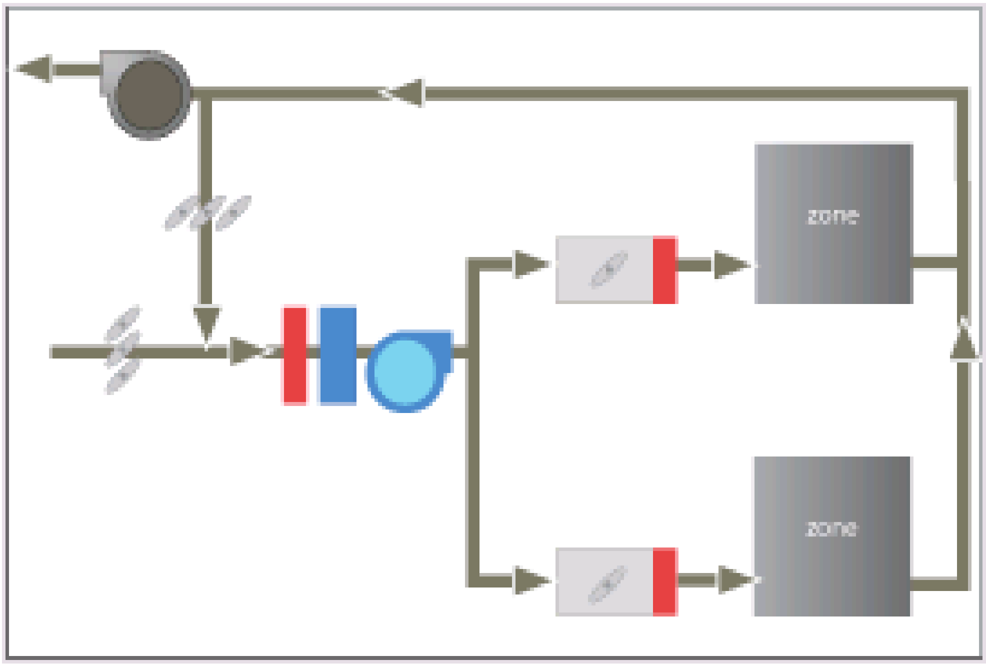
Internal Load Template - Vivarium



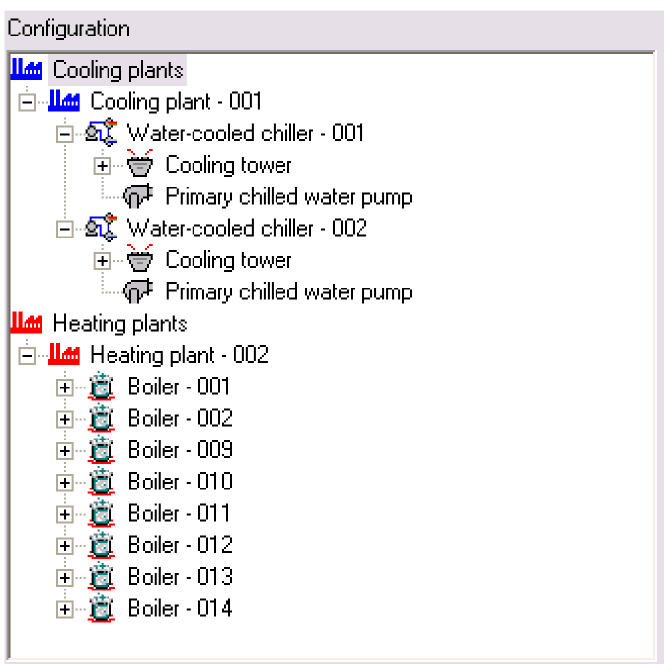
Airflow Template - Vivarium



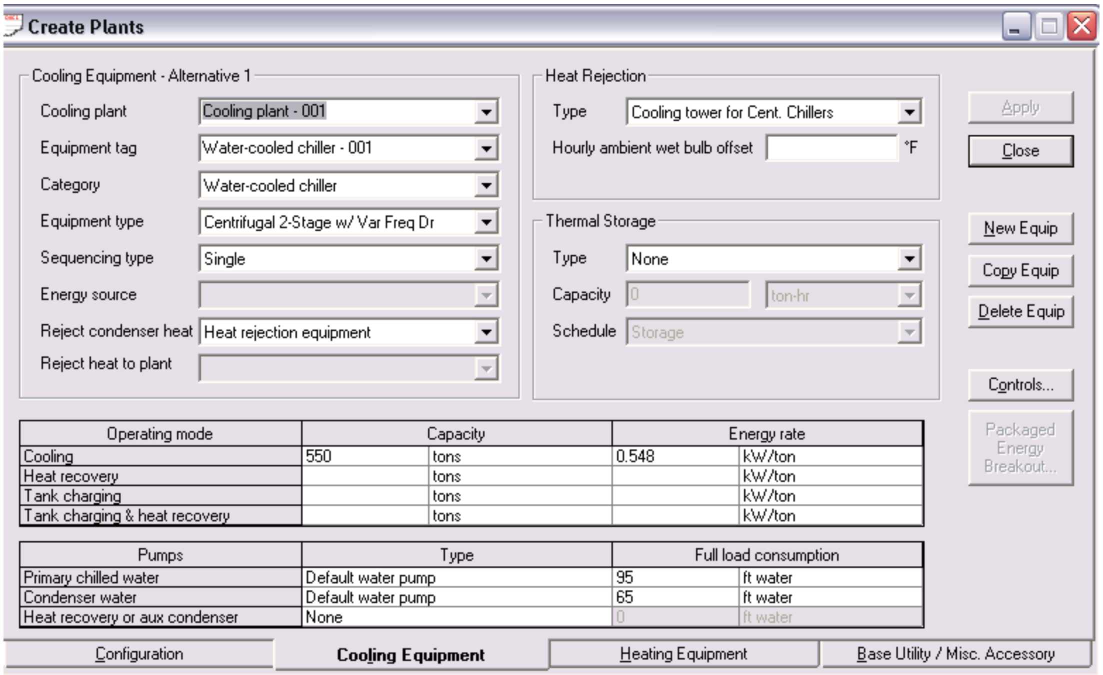
Airflow Template – typ.



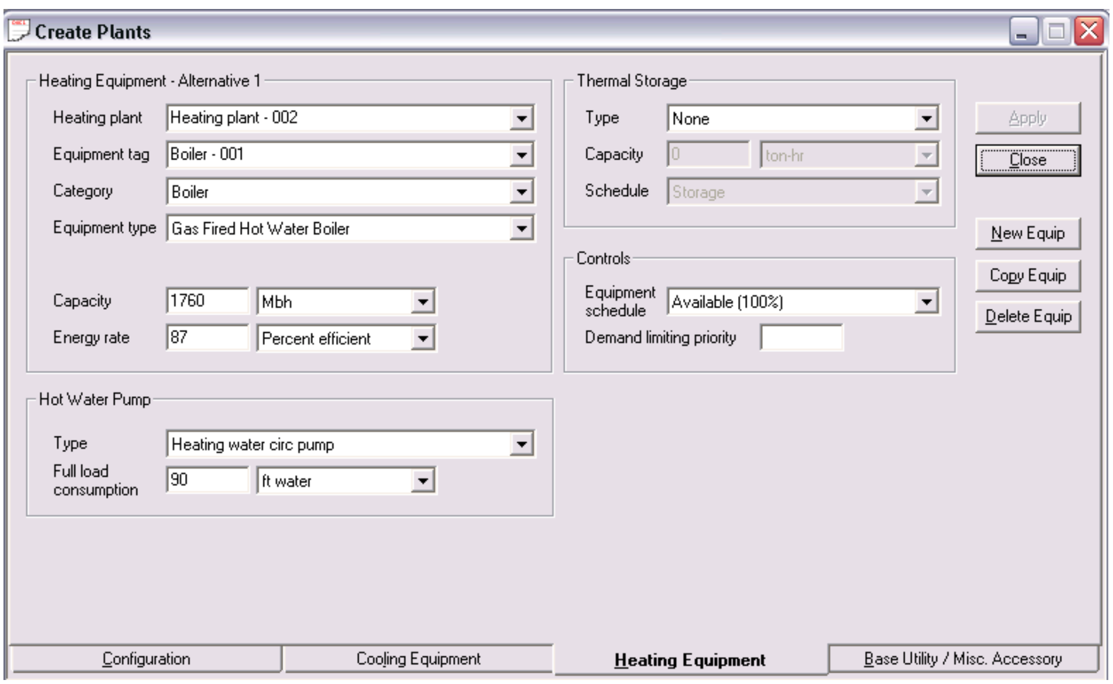
Modeled System Diagram, all AHUs



Modeled Cooling and Heating Plants



Modeled Chillers



Modeled Boilers