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Technical Report Two

Building and Plant Energy Analysis

Evaluation

SALK HALL ADDITION

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Fall 2010, Senior Thesis Design Project

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Executive Summary

The Salk Hall laboratory, located in Pittsburgh, PA, is designed with a variable volume air distribution system. The laboratories and their support spaces have high internal loads as well as high ventilation rates. Due to limitations of the simulation software, the fume hood exhaust systems and radiant floor heating system were not modeled in the TRACE 700 building simulation. The northwest laboratory on the third floor was modeled in TRACE 700 as well as the 2009 ASHRAE RSTM load calculation spreadsheet. The results demonstrate the varying outputs that different simulations yield.

TRACE suggests that Salk Hall will demand 4,260,888 [kWh] of electricity at a cost of $357,915. The largest demand on the electrical system, relative to the mechanical systems, is the energy required for fan operation. The major discrepancy between the two simulations of the northwest laboratory was the solar thermal load. TRACE estimated the load to be around 13,000 BTU/hr while the RSTM spreadsheet simulated a solar load of around 9,000 BTU/hr. After considering the TRACE 700 outputs, Salk Hall is estimated to produce 1,535,839 pounds of pollutants per year.

Building Simulation Myths and Modeling Assumptions

Computerized building energy simulations have become the foundation for determining energy efficiency within new and existing buildings. There are a number of simulation programs available to an HVAC designer; this includes software from both the commercial and private sector. Each simulation is dependent on the accuracy of the inputs, the method in which the loads are calculated, and the procedures in which energy use is modeled. Any given building can be modeled using a variety of methods, each of which will yield its own set of results. These results can often be very different. Since there is not an industry standard on how building should be modeled, building simulation should be viewed as a relative science.

The governing variable in which all simulation calculations are dependent is the applicable weather data. It is very important to realize that weather data is not "real weather." It is impossible to predict long term future weather forecasts. This fact alone constitutes a degree of uncertainty between the model outputs and the actual building performance. Trane TRACE 700, for example, uses a typical 24 hour weather profile on a monthly basis. This yields 288 hours of weather data for each location in the TRACE 700 library. Typical meteorological year (TMY) data is compiled to contain average hourly weather profiles throughout the year. Determining which type of weather data is to be used is up to the designer, but once selected, should be held constant throughout the comparison of multiple system designs.

Once the type of weather data is selected, it is appropriate to examine the envelope of the building and determine the method in which the thermal load will be calculated. Again, there are a variety of procedures in which the building can be modeled. In this report, all load calculations were produced using ASHRAE's Radiant Time Series Method (RSTM). This method was derived from the fundamental heat balance method of a control volume. The radiant time series algorithm splits solar thermal gains, thermal conductive gains, and internal thermal loads into their respective radiant and convective portions. Infiltration loads are summed directly with the convective gains. After applying the appropriate radiant time series and conduction time series coefficients, to account for thermal lag, the convective and radiant gains are summed to determine the hourly cooling load in each zone.

A block building simulation constitutes zoning regions of similar load profiles together and performing calculation on these thermal zones. This procedure yields results with an acceptable degree of accuracy for most buildings.

Some buildings, such as laboratories, have a wide range of varying ventilation rates and internal loads that cannot be accurately modeled using this procedure. The building simulation presented in this report is zoned on a space by space basis for zones which require conditioning. This allows for flexibility in modeling the required air change rates and equipment loads between the laboratories and their support spaces.

While each piece of simulation software has its advantages and disadvantages, it is important to understand the limitations of each program. In modeling Salk Hall with TRACE 700, there are two main system design characteristics that were not able to be simulated.

TRACE 700 is not able to model a radiant floor heating system and an overhead air distribution system simultaneously on the same zone. To simplify the model, the zone which is thermally conditioned by the radiant floor could be separated into its own system. Ventilation loads would not be included in this zone calculation. Even with this simplification, the zone's thermal profile still cannot be accurately evaluated since the space receives a heavy amount of foot traffic as well as transfer air from the adjacent spaces. With these simplifications in place, the zone's thermal profile will range between the following two cases:

Case A: With the absence of foot traffic and the assumption that the vestibules located adjacent to the space remain closed, the air within the space above the thermal boundary layer at the floor could be considered stagnant. The means of heat transfer will be dominated by radiation from the floor and the buoyancy of the warm air. This will allow for free convection within the space as well as radiant heat transfer to the surroundings.

Case B: With heavy foot traffic and the constant changing of occupancy in the space, the radiant floor will transfer heat by conduction, convection, and radiation. Conductive heat transfer will take place between the radiant floor and the occupants travelling across it. This form of heat transfer will be negligible compared to the convective transfer from the floor to the air. Free convection conditions will no longer exist and the convective heat transfer coefficient will depend on the velocity of the air. The velocity is dependent on the occupants' movements and cannot be accurately modeled until an average velocity is experimentally evaluated. Radiant heat transfer will be negligible compared to convective heat transfer at these conditions.

Due to the potential wide ranging conditions in an already over-simplified thermal zone, the radiant floor system has not been included in the load calculation or energy model.

Laboratories often have minimum air change rates associated with safety factors. These rates are influenced by the type of research expected to take place. The University of Pittsburgh's laboratory standard is 6 air changes per hour (ACH) when the zone is occupied and 4 ACH when the zone is unoccupied. Salk Hall includes a number of biological safety cabinets and fume hoods. These local exhaust systems can be constant or variable volume and can be active intermittently throughout the day. Again the situation between two extremes arises. The fume hood exhaust systems can be modeled in two ways: always active or always inactive. A schedule cannot accurately be created to simulate the use of fume hoods over a prolonged duration due to the uncertainty of when they will be active since their use depends on the specific researcher and the nature of his or her work. Salk Hall uses tracking pairs of Phoenix Venturi style laboratory valves to provide supply make-up air when the fume hoods are active. TRACE 700 does not have the capability of modeling this design correctly. Therefore, the fume hood exhaust system and the supply make-up air system have not been included in the simulation.

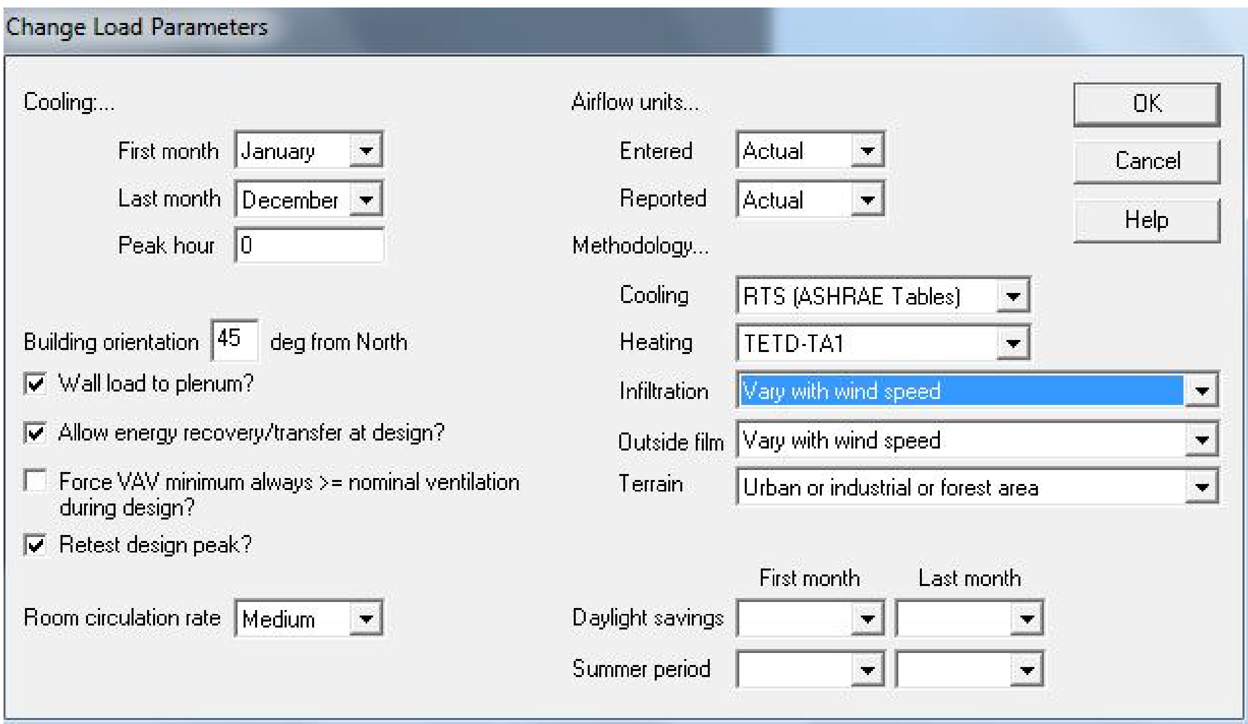
While the entire building was modeled with TRACE 700, the northwest laboratory on the third floor was modeled with the 2009 ASHRAE RSTM spreadsheet. This report will evaluate the building as a whole from the TRACE 700 simulation, but will also compare the differences between the simulations of the northwest laboratory.

Building Simulation using Trane TRACE 700 Inputs

The section that follows outlines the procedure in which the building was modeled.

Load Parameters:

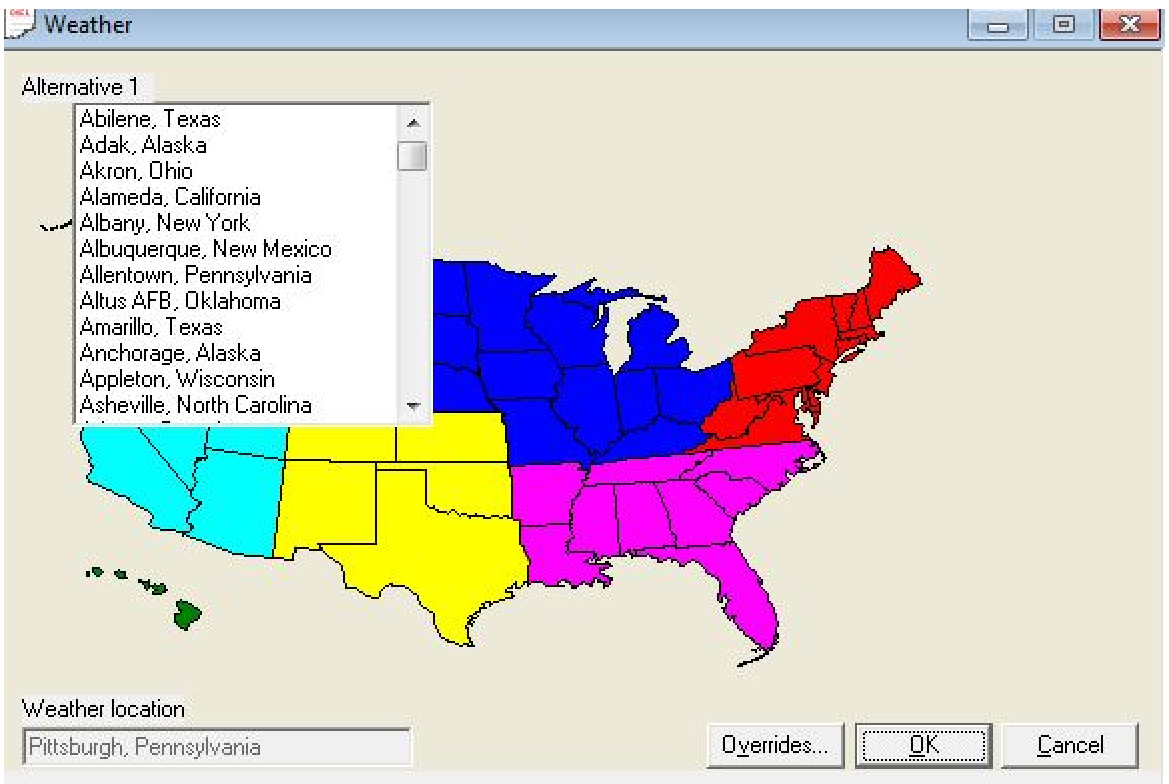
To begin constructing a building simulation in TRACE 700 (TRACE), the load parameters should be constructed first.



As seen in the figure above, the cooling methodology is set to the radiant time series method. The other two key inputs with regard to the load parameters are the building orientation from true North and the terrain in which the building is located. All other inputs are program standards.

Weather Parameters:

Weather information should be selected next. TRACE's weather library includes Pittsburgh, PA as a factory default. Again, this includes 288 hours of averaged weather data.



Library Values: Construction Types

Constructing the building according to the design documents is the next step in the modeling process. These construction types are created in the TRACE library and then applied on a room-by-room basis.

The following are the constructions and calculated U-Values that have been inputted into Trace:

Surface at Salk Hall	U-Value [BTU/hr*ft^2*°F]
Roof	0.05048
Terracotta Wall	0.084
Floor	0.4219
Zinc Wall	0.0713
Solar Ban Windows	0.5

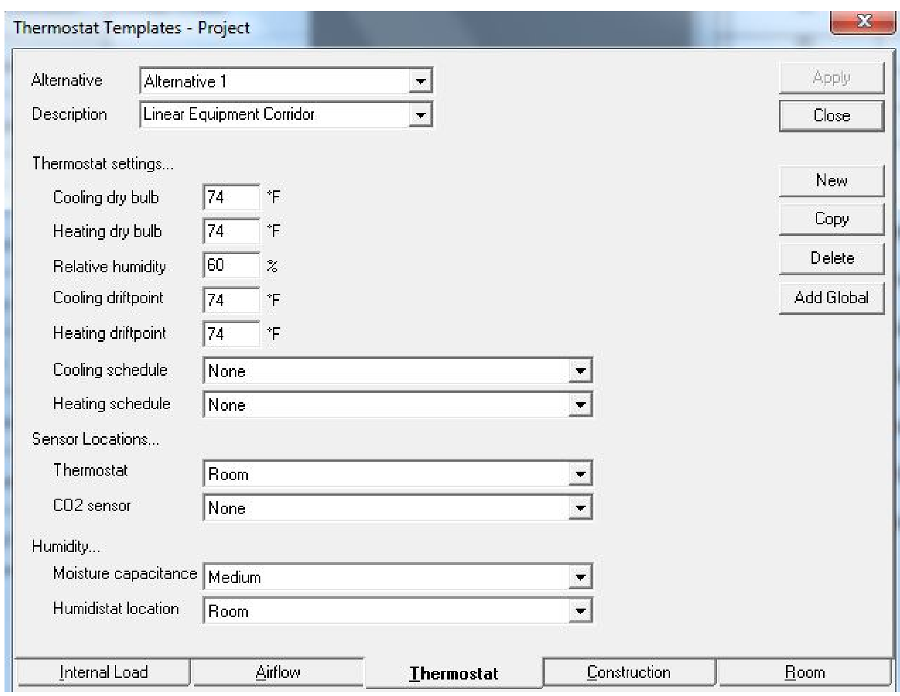
Templates: Thermostat

After the construction types have been created, it is necessary to set up templates to describe zones with similar design characteristics. The thermostat template allows the user to set heating and cooling set points, temperature drift points, and the design relative humidity. The Salk Hall model assumes that all thermostats and humidistats are located within each respective zone.

The following parameters have been set for each general type of space:

Room Type	Summer Dry Bulb (° F)	Max. Summer Relative Humidity (%)	Winter Dry Bulb (° F)
Offices, Meeting Rooms, Conference Rooms	72	50	72
Laboratories	72	60	72
Lab Support Rooms	72	60	72
Lab Personnel Corridors	72	60	72
Tele-data Rooms	74	50	70
Lab Linear Equip. Corridor	74	60	74

In the example template, the settings for the Linear Equipment Corridor, the drift points are set to the set points of the zone. Since the linear equipment corridors have extremely high internal equipment loads, and cooling is abetted by fan coil units placed along the corridors, it is important to keep the zone temperature as close to the design set points as possible in order to ensure that



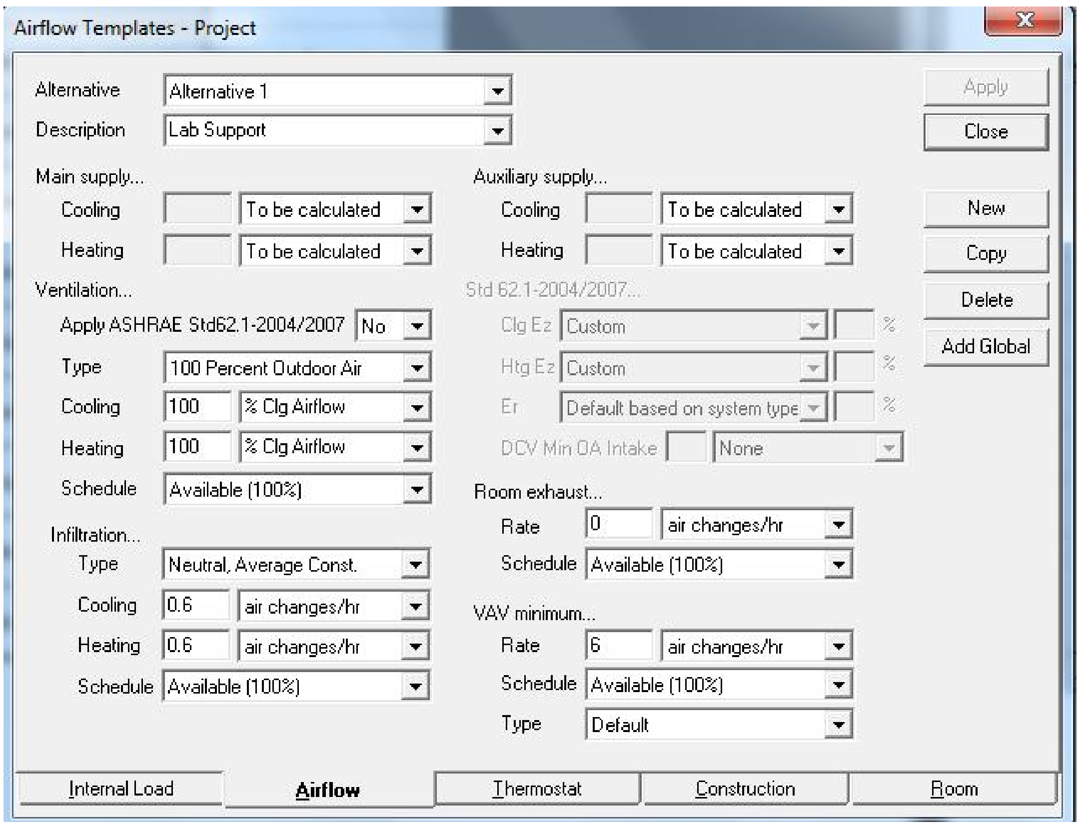
the fan coil units cool the zone within their capacity. Fan coil units have not been modeled per zone but their total energy demand at peak load has been set as a constant in the system parameters.

Template: Airflow

The airflow template allows ventilation rates, infiltration rates, and room exhaust rates to be set. As stated in the previous section, fume hoods in the laboratories have not been modeled. Salk Hall delivers 100% outdoor air to each space. This design characteristic adds a new simulation constraint while using TRACE. The software does not allow for the prescriptive requirements of ASHRAE Standard 62.1 to be followed if 100% outdoor air is used. For the laboratories and their support spaces this is not an issue since they are governed by minimum air change rates per hour and this rate can be set as the VAV minimum. For all non-laboratory spaces, the VAV minimum has been set to 30% of the cooling airflow. This is often a satisfactory measure for ensuring that the appropriate amount of ventilation air is delivered to offices, administrative spaces, and conference rooms. It is good practice to examine the room data outputs and ensure that they are receiving the appropriate amount of ventilation. If rooms are found to receive less than the required amount of ventilation air per Standard 62.1, the appropriate airflow should be set as the VAV minimum of the respective zone.

With regards to infiltration, each zone is assumed to be neutral and have an average construction tightness.

With regards to room exhaust, TRACE is self balancing and therefore will exhaust a quantity of air equal to that of which is supplied for cooling purposes.



Template: Internal Loads

The internal loads template allows the designer to set averaged loads for similar spaces. This includes occupant density, lighting power density, and miscellaneous loads. The occupant density for the laboratories is 10 researchers per module. The occupant density for each office is 1 person, while the density for each conference room is 8 people.

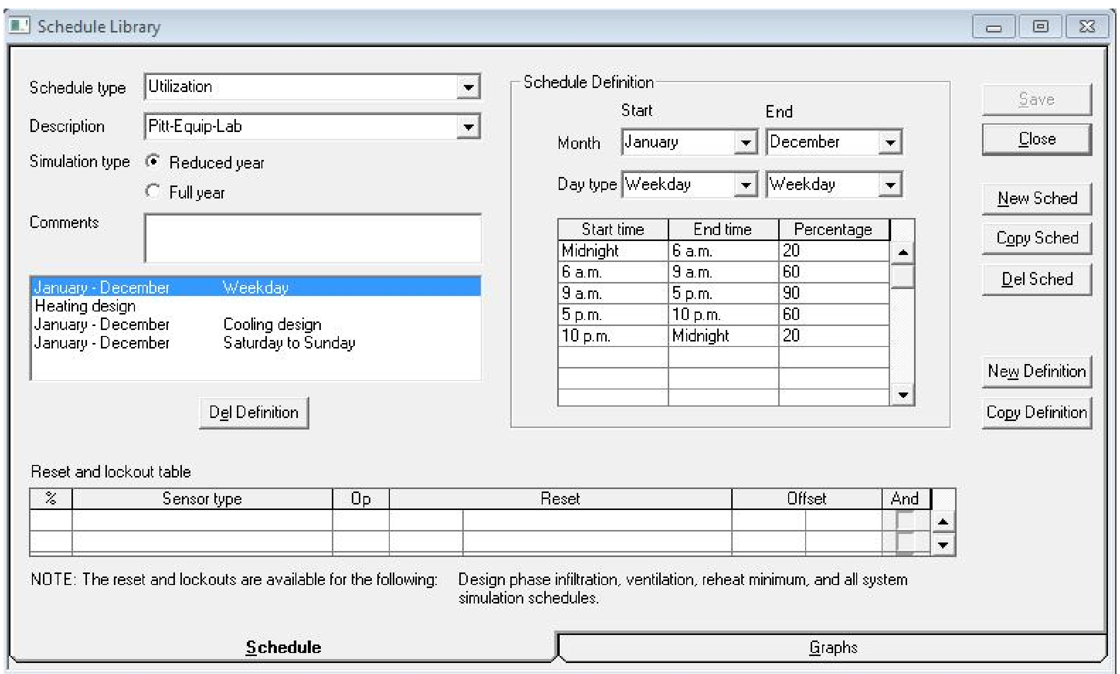
The spreadsheet that follows defines the designed internal load values for each space type:

TEMPLATES	LIGHTS [W/SF]	LIGHT SCHEDULE	EQUIPMENT [W/SF]	EQUIPMENT SCHEDULE	PEOPLE	PEOPLE SCHEDULE
Break Room	1.1	Pitt-Lighting-Public Areas	3	Pitt-Equipment-Public Areas	Per Architectural Dwgs	Pitt-People-Conference Area
Conference Room	1.1	Pitt-Lighting-Office	2.5	Pitt-Equipment-Office	Per Architectural Dwgs	Pitt-People-Conference Room
Laboratories Support	1.6*	Pitt-Lighting-Lab	7	Pitt-Equipment-Workstation	Per Architectural Dwgs	Pitt-People-Lab
Linear Equipment Corridor	1.4	Pitt-Lighting-Lab	15	Pitt-Equipment-Linear Equipment	Per Architectural Dwgs	Pitt-People-Linear Equipment
MEP	1	Pitt-Lighting-MEP	4	Pitt-Equipment-MEP	Per Architectural Dwgs	Pitt-People-MEP
Office	1.3*	Pitt-Lighting-Office	2	Pitt-Equipment-Office	Per Architectural Dwgs	Pitt-People-Office
Open Laboratories	1.6*	Pitt-Lighting-Lab	7	Pitt-Equipment-Lab	Per Architectural Dwgs	Pitt-People-Lab
Public Areas	1.1	Pitt-Lighting-Public Areas	1	Pitt-Equipment-PublicSpace	Per Architectural Dwgs	Pitt-People-Public
Workstation	1.4	Pitt-Lighting-Lab	2.5	Pitt-Equipment-Workstation	Per Architectural Dwgs	Pitt-People-Lab

* Values include a 0.2 [W/SF] addition for task lighting

Library Values: Schedules

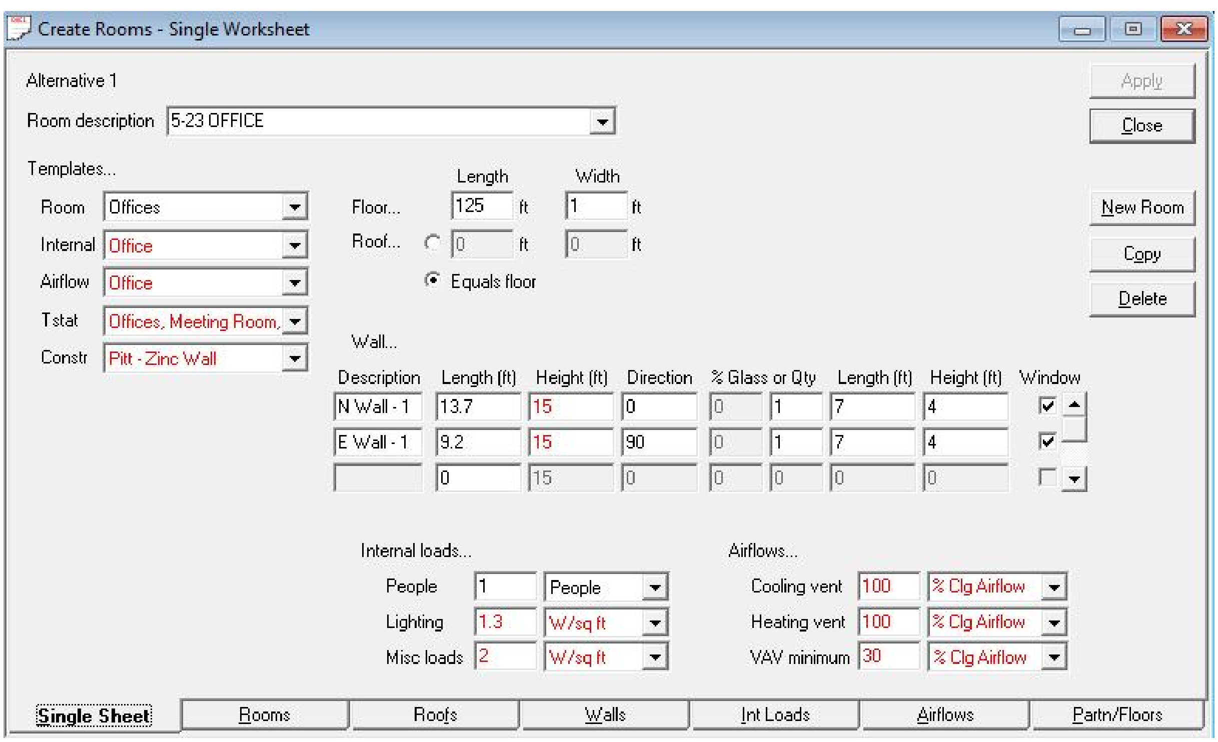
TRACE uses utilization schedules to allow the designer to designate the percentage of full load capacity that the equipment will use during a specified period. These are the last library values that must be created before construction of the thermal zones begins. The following is the equipment schedule for the laboratories. The utilization percentages are ramped accordingly to estimated usage rates.



Zone Design Parameters

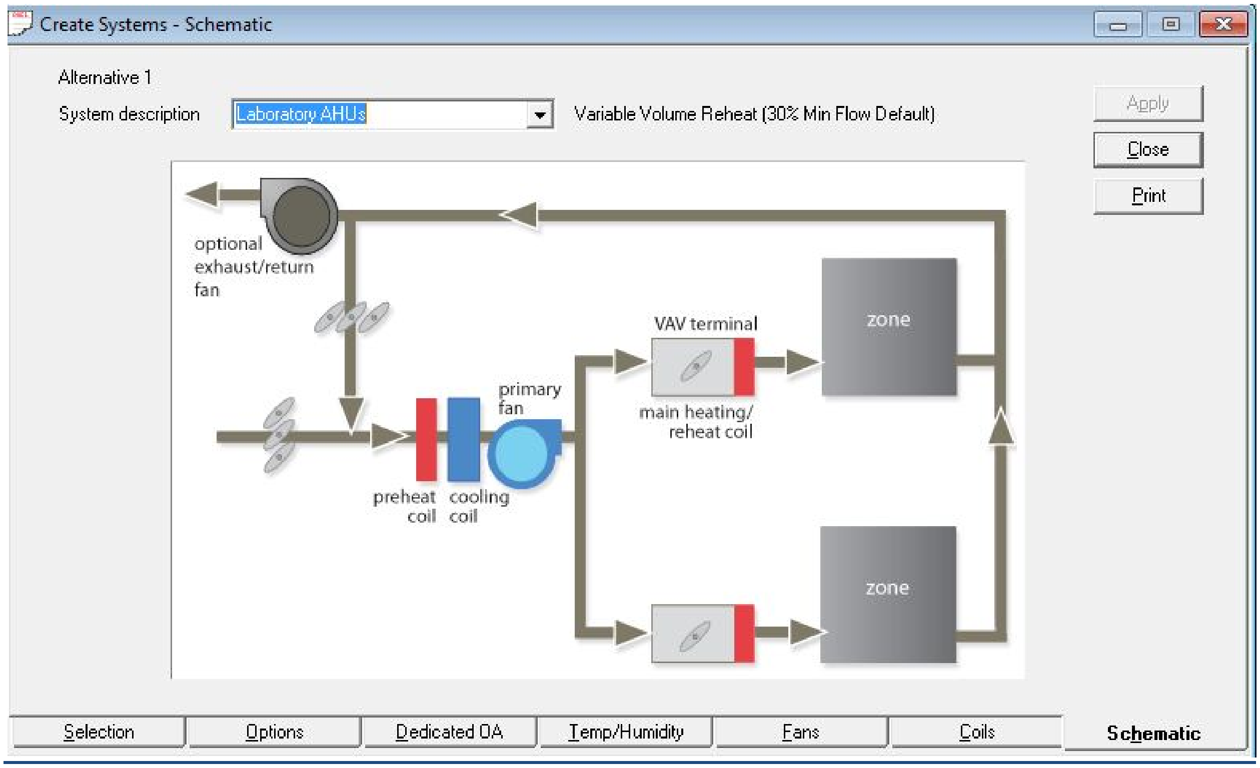
After creating a new room, it is important to select the appropriate templates that will describe its design characteristics. Since not all rooms have square dimensions, their area is inserted into the length dimension and multiplied by a width dimension of 1. Wall, window, and glass dimensions are to be inputted next. The most important variable is the direction in which the exterior wall faces.

North= 0 Degrees	East= 90 Degrees
South= 180 Degrees	West= 270 Degrees

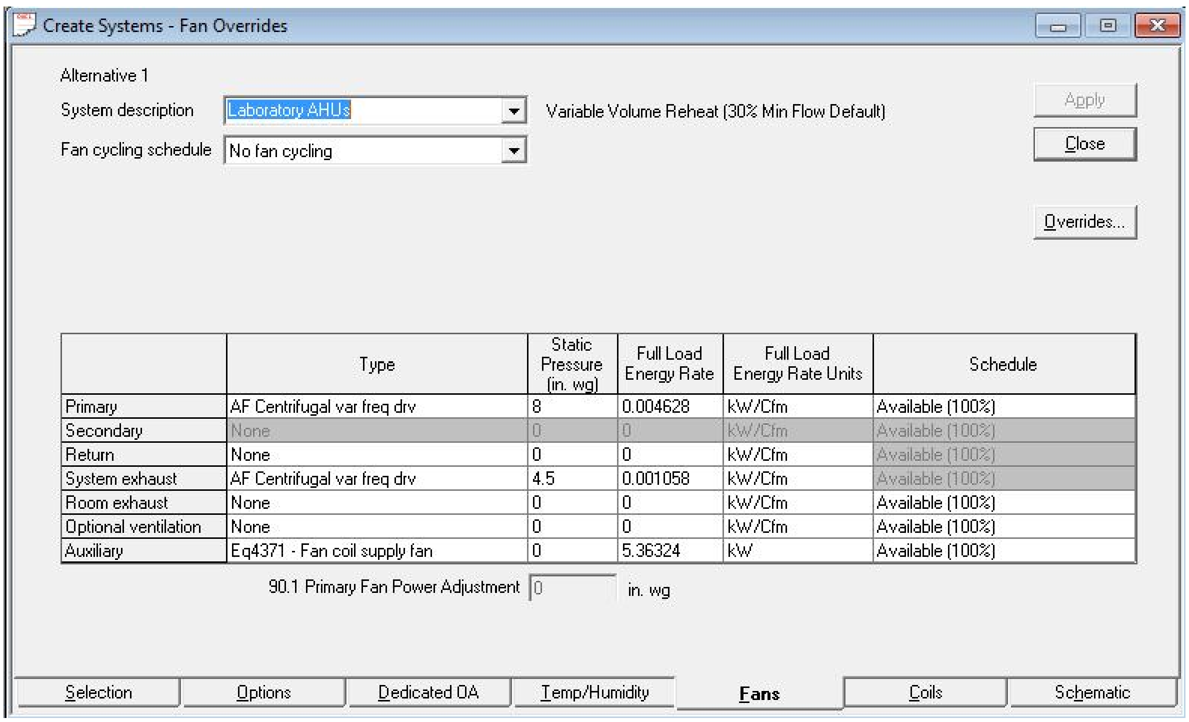


System Parameters

Selecting a system and inputting its performance characteristics is the first step towards building an energy model. While creating systems, it is important to select the appropriate supply air distribution type, set the performance characteristics for energy recovery, and set the power consumption rates for the designed fans and/or auxiliary units. Salk Hall has been modeled with a VAV reheat system with enthalpy wheel energy recovery.



The Salk Hall model does not limit capacity on any of the heating or cooling coils. Full load energy rates for the supply and exhaust fans have been calculated from the total designed capacity and horse powers that have been scheduled in the construction documents. These load rates are inputted as a [kW/CFM] unit. The full energy load for the fan coil units has been calculated and inputted as a constant energy value.



	Type	Static Pressure (in. wg)	Full Load Energy Rate	Full Load Energy Rate Units	Schedule
Primary	AF Centrifugal var freq drv	8	0.004628	kW/Cfm	Available (100%)
Secondary	None	0	0	kW/Cfm	Available (100%)
Return	None	0	0	kW/Cfm	Available (100%)
System exhaust	AF Centrifugal var freq drv	4.5	0.001058	kW/Cfm	Available (100%)
Room exhaust	None	0	0	kW/Cfm	Available (100%)
Optional ventilation	None	0	0	kW/Cfm	Available (100%)
Auxiliary	Eq4371 - Fan coil supply fan	0	5.36324	kW	Available (100%)

Plant & Economic Parameters

Before the energy model can be completed, plant and economic parameters must be set. Salk Hall receives its chilled water and processed steam from campus plants. Pump power and equipment performance characteristics must be set under the cooling and heating equipment tabs. The economic price rates used in the Salk Hall Energy model are those that were delivered to Ballinger in March of 2008. These rates will be held constant throughout the evaluation and redesign process.

Building Simulation using Trane Trace 700 Outputs

In evaluating the results produced by TRACE 700, it is clear that the highest cost associated with Salk Hall is its estimated electricity use. TRACE suggests that Salk Hall will demand 4,260,888 [kWh] at a cost of $357,915. The largest demand on the electrical system, relative to the mechanical systems, is the energy needed for fan operation. The ventilation requirement of Salk Hall's laboratories and their support spaces is the key factor which influences the high fan power demand. In the model, the supply fan delivers 86,000 [CFM] while the exhaust fans pull 91,754 CFM. This offset is due to the purge of the enthalpy wheels in each air handler. It is important to keep in mind that these are relative values and that the fume hood loads and radiant floor system have not been modeled. This fact alone would increase the supply and exhaust fan airflow rates as well as the power consumption and associated costs. The second highest factor to the electrical load is the demand of the receptacles. This demand is based on the internal loads of the building. The receptacle loads will be held constant in the redesign process.

Purchased chilled water for Salk Hall is estimated to cost the University under $1000 dollars per year. The amount of purchased steam required is under $1200 per year. These two values are relatively low due to the fact that both utilities are delivered from a central plant on campus.

In the chart below, a breakdown of the load sources within the building are listed. As expected, the two largest loads are from the ventilation airflow rates and the internal equipment loads. The lighting, people, and solar loads are all comparable.

Calculated Cooling Load Type	Total Load [Btu/hr]	% of Total
Skylite Solar	24,767	1
Skylite Cond	969	0
Roof Cond	9,837	0
Glass Solar	226,056	6
Glass/Door Cond	57,506	2
Wall Cond	44,343	1
Partition/Door	36,838	1
Floor	-175	0
Adjacent Floor	0	0
Infiltration	195,538	6
Lights	267,794	8
People	251,201	7
Misc	781,820	22
Exh. Fan Heat	-287	0
Ventilation Load	1,044,449	30
Ov/Undr Sizing	18,300	1
Sup. Fan Heat	447,067	13
Duct Heat Pkup	91,506	3
Totals	**3,497,528**	**100**

These results are comparable to the energy model that Ballinger created within an acceptable range.

The following table is a breakdown of energy consumption by each respective piece of heating or cooling equipment. The heating energy requirement is much less than the cooling requirement. This is due to the high internal loads.

System	Elect Cons. (kWh)	PCldW Cons. (kBtu)	P.Stm Cons. (kBtu)	Total Building Energy (kBtu/yr)
Primary heating				
Primary heating			70,055	70,055
Other Htg Accessories	691			2,360
Primary cooling				
Cooling Compressor		128,897		128,897
Auxiliary				
Supply Fans	2,126,627			7,258,176
Pumps	14,400			49,147
Lighting				
Lighting	514,005			1,754,300
Receptacle				
Receptacles	1,604,740			5,476,976
Totals	**4,260,463**	**128,897**	**70,055**	**14,739,912**

The following table is a breakdown of the Laboratory Air Handling Unit system and its design characteristics. The square footage associated with the model refers to conditioned spaces only. When taking the full square footage of the building into account, the associated cost is roughly $4.30 per square foot. This is within an acceptable range, based on the usage rates of other buildings on campus, of the averaged operation cost of $4.40 per square foot.

<table>
<tr><td>System</td><td colspan="3">Type</td><td colspan="2">Floor Area</td><td></td></tr>
<tr><td rowspan="2">Laboratory AHUs</td><td colspan="3" rowspan="2">System - Variable Volume Reheat
(30% Min Flow Default)</td><td colspan="2">[ft²]</td><td></td></tr>
<tr><td colspan="2">59,530</td><td></td></tr>
<tr><td colspan="4">Cooling</td><td colspan="3">Heating</td></tr>
<tr><td>OA %</td><td>CFM/SF</td><td>CFM/Ton</td><td>Btu/hr·ft²</td><td>% OA</td><td>CFM/SF</td><td>Btu/hr·ft²</td></tr>
<tr><td>100</td><td>1.45</td><td>295.3</td><td>58.75</td><td>100</td><td>0.72</td><td>-30.12</td></tr>
</table>

Comparison of North West Laboratory Simulations

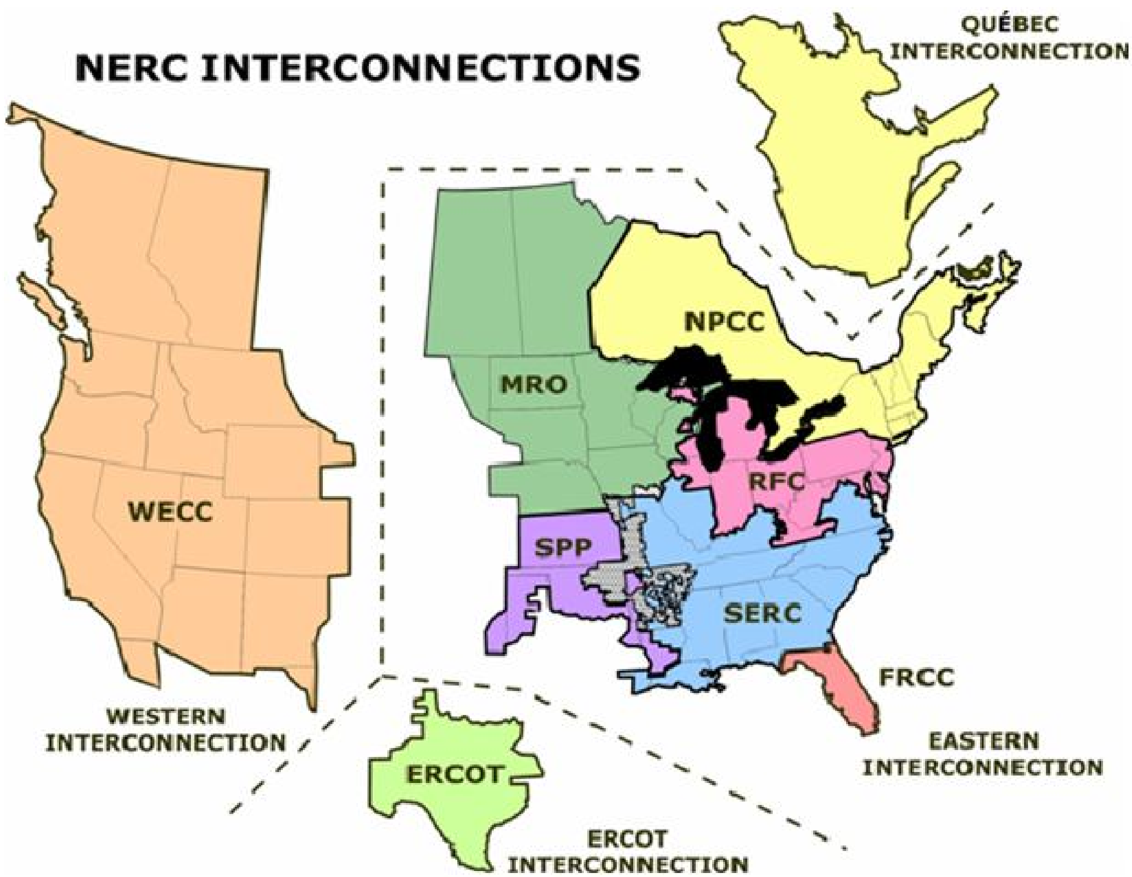
In order to establish an argument for the variation in energy simulations and their associated costs, the Northwest Laboratory on the third floor has been simulated using the 2009 ASHRAE RSTM Spreadsheet. The laboratory was selected due to its high internal loads, two exterior facing walls with windows, and its 20 person occupant density. The same load inputs and construction values used in the TRACE simulation were used in the RSTM spreadsheet simulation. One limitation of the spreadsheet is that it does not calculate ventilation loads. The load calculated in the spreadsheet is based on solar thermal loads, internal heat gains, and the zone's occupant density. The spreadsheet inputs are comparable to the TRACE inputs and have therefore will be evaluated as equals. Keep in mind that the TRACE simulation was also based on the RSTM method.

Loads	**TRACE OUTPUT**	**RSTM OUTPUT**	*% Difference (Trace to RSTM)*
Glass Solar	13,505 Btu/h	9,358 Btu/h	44 % Larger
Wall/Window Conduction	5,374 Btu/h	3,555.6 Btu/h	51 % Larger
Infiltration	8,771 Btu/h	7,689.4 Btu/h	14 % Larger
Lights	14,786 Btu/h	15,192.9 Btu/h	3 % Smaller
People	9,468 Btu/h	4853.7 Btu/h	95% Larger
Misc	63,509 Btu/h	61,670 Btu/h	2.9 % Larger

The results illustrate the fact that systems cannot be sized to a specific simulated value, but should be sized to fit a range of values. It is unlikely that the north and west walls of the northwest laboratory receive 13,505 [Btu/h] with regards to the solar load, as per the TRACE simulation. This result was also noticed by Ballinger in the design process. The construction documents specify that the system was designed to handle 87,000 [CFM] of supply air. The TRACE output's required airflow is approximately 86,000 [CFM]; this would leave the system with 1000 [CFM] as added capacity. Assuming the TRACE simulation errors on the high-side, the system is sufficiently sized.

Annual Energy Emissions

Salk Hall's annual energy emissions associated with the laboratory's electrical energy consumption has been calculated. The laboratory, located in Pittsburgh, PA, is within the Eastern Interconnection of the North American Electrical Reliability Council.



The following chart consists of the types of energy used in generating the electricity within the Eastern Interconnection. The largest energy source consumed in creating electricity is Bituminous Coal.

Energy Type	Eastern %	kWh Produced
Bituminous Coal	34.33	1,462,762
Subbitumious Coal	19.6	835,134
Lignite Coal	1.4	59,652
Natural Gas	12.7	541,132
Petroleum Fuels	3.6	153,391
Other Fossil Fuel	0.2	8,521
Nuclear	23.0	980,004
Hyrdo	3.4	144,870
Renewable Fuels	1.7	72,435
Geothermal	0.0	0
Wind	0.1	4,260
Solar (PV)	0.0	0
TOTALS:	**100 %**	**4,260,888**

The laboratory utilizes electricity to provide the air handling equipment with power to meet the hourly cooling loads.

The production of electricity yields emissions that are often harmful to the environment. In determining the total annual emissions due to the electricity consumption of the Laboratory, the total electrical energy demanded by the laboratory was multiplied by the lbm of pollutants per kWh. The largest pollutant created will be CO_2 and its equivalent.

Pollutant	Eastern Emission Factors [lbm/kWh]	Per Salk Hall [lbm]
CO_{2e}	1.74	7.41E6
CO_2	1.64	6.99E6
CH_4	3.59E-3	1.53E4
N_2O	3.87E-3	1.65E4
NO_X	3.00E-3	1.28E4
SO_X	8.57E-3	3.65E4
CO	8.54E-4	3.64E3
TNMOC	7.26E-5	3.09E2
Lead	1.39E-7	5.92E-1
Mercury	3.66E-8	1.56E-1
PM10	9.26E-5	3.94E2
Solid Waste	2.05E-1	8.73E5

Salk Hall is delivered chilled water and processed steam from campus plants. The total load on these systems is unknown and therefore their emissions cannot be calculated. However, regarding electricity use alone, Salk Hall is estimated to produce 1,535,839 pounds of pollutants per year.

Salk Hall has not yet been constructed and therefore no field data is available for comparison to the estimate.

References

- Trane Trace 700 Software, Building Energy and Economic Analysis

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

- Waltz, James P. *Computerized Building Energy Simulation Handbook.* Lilburn, GA: Fairmont, 2000. Print.

- Spitler, Jeffrey D. *Load Calculation Applications Manual*. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2009. Print.

Energy Cost Budget / PRM Summary

By Trial

Project Name: University of Pittsburgh - Salk Hall	Date: October 19, 2010
City:	Weather Data: Pittsburgh, Pennsylvania

Note: The percentage displayed for the "Proposed/ Base %" column of the base case is actually the percentage of the total energy consumption.

* Denotes the base alternative for the ECB study.

		* Alt-1 Enthalpy Wheels		
		Energy 10^6 Btu/yr	Proposed / Base %	Peak kBtuh
Lighting - Conditioned	Electricity	1,754.3	12	283
Space Heating	Electricity	2.4	0	0
	Purchased Steam	70.0	0	44
Space Cooling	Purchased Chilled Water	128.9	1	76
Pumps	Electricity	49.1	0	53
Fans - Conditioned	Electricity	7,258.3	49	2,102
Receptacles - Conditioned	Electricity	5,478.3	37	1,072
Total Building Consumption		**14,741.3**		

		* Alt-1 Enthalpy Wheels
Total	**Number of hours heating load not met**	2,055
	Number of hours cooling load not met	0

	* Alt-1 Enthalpy Wheels	
	Energy 10^6 Btu/yr	Cost/yr $/yr
Electricity	14,542.4	357,915
Purchased Chilled Water	128.9	911
Purchased Steam	70.0	1,190
Total	**14,741**	**360,016**

EQUIPMENT ENERGY CONSUMPTION
By Trial

Alternative: 1 Enthalpy Wheels

Equipment - Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
					------- Monthly Consumption -------								
Lights													
Electric (kWh)	43,649.0	39,425.3	43,674.7	42,236.8	43,661.9	42,262.5	43,636.1	43,674.7	42,236.8	43,661.8	42,249.7	43,636.1	514,005.2
Peak (kW)	83.1	83.1	83.1	83.1	83.1	83.1	83.1	83.1	83.1	83.1	83.1	83.1	83.1
MISC LD													
Electric (kWh)	136,009.4	122,848.6	136,088.3	131,609.4	136,048.9	131,688.2	135,970.0	136,088.3	131,609.4	136,048.9	131,648.8	135,970.1	1,601,628.5
Peak (kW)	313.7	313.7	313.7	313.7	313.7	313.7	313.7	313.7	313.7	313.7	313.7	313.7	313.7
Energy Recovery Parasitics													
Electric (kWh)	297.6	268.8	297.6	288.0	297.6	288.0	297.6	297.6	288.0	297.6	288.0	297.6	3,504.0
Peak (kW)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Cooling Coil Condensate													
Recoverable Water (1000gal)	0.0	0.0	0.0	0.3	6.3	35.0	47.0	30.2	8.5	0.2	0.1	0.0	127.7
Peak (1000gal/Hr)	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.2
Cpl 1: Campus Chilled Water [Sum of dsn coil capacities=291.5 tons]													
Campus chiller [Clg Nominal Capacity/F.L.Rate=291.5 tons / 0.76 Therms] (Cooling Equipment)													
Purc. Chill Water (therms)	0.0	0.0	2.0	51.6	166.0	263.8	322.9	249.6	164.9	49.0	19.2	0.0	1,289.0
Peak (therms/Hr)	0.0	0.0	0.1	0.4	0.6	0.8	0.8	0.8	0.6	0.3	0.2	0.0	0.8
Var vol chill water pump (Misc Accessory Equipment)													
Electric (kWh)	0.0	0.0	16.6	333.1	1,177.8	2,234.8	2,886.9	1,988.3	1,155.4	316.1	136.9	0.0	10,246.0
Peak (kW)	0.0	0.0	0.6	2.4	7.4	11.5	11.5	11.5	6.7	2.0	1.1	0.0	11.5
Hpl 1: Campus Steam [Sum of dsn coil capacities=1,792 mbh]													
Boiler - 001 [Nominal Capacity/F.L.Rate=1,792 mbh / 0.51 Therms] (Heating Equipment)													
Purchased Steam (therms)	121.0	117.5	81.7	44.6	28.6	18.7	15.5	22.8	29.1	54.0	66.5	100.4	700.2
Peak (therms/Hr)	0.4	0.4	0.4	0.4	0.4	0.3	0.2	0.3	0.4	0.4	0.4	0.4	0.4
Eq5007 - Var vol chill water pump (Misc Accessory Equipment)													
Electric (kWh)	725.9	742.9	468.2	261.3	172.5	107.3	88.8	134.5	175.0	319.7	385.8	570.6	4,152.5
Peak (kW)	4.2	4.2	3.8	3.3	2.7	1.7	1.3	2.1	2.9	3.6	3.8	4.0	4.2
Eq5061 - Condensate return pump (Misc Accessory Equipment)													
Recoverable Water (1000gal)	62.7	56.6	62.7	57.3	55.3	51.4	54.3	53.0	53.9	60.8	60.7	62.7	691.4
Peak (1000gal/Hr)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Sys 1: Laboratory AHUs

EQUIPMENT ENERGY CONSUMPTION
By Trial

Alternative: 1 Enthalpy Wheels

Equipment - Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
	------- Monthly Consumption -------												
Sys 1: Laboratory AHUs													
AF Centrifugal var freq drv [DsnAirflow/F.L.Rate=86,055 cfm / 486.8 kW] (Main Clg Fan)													
Electric (kWh)	124,751.8	112,053.3	128,698.7	132,815.9	155,007.1	164,078.3	172,615.8	164,083.4	145,972.2	136,237.0	127,909.2	126,823.3	1,691,046.0
Peak (kW)	251.4	252.5	297.6	398.3	488.3	488.3	488.3	488.3	488.3	356.1	304.2	260.3	488.3
AF Centrifugal var freq drv [DsnAirflow/F.L.Rate=91,754 cfm / 127.0 kW] (System Exhaust Fan)													
Electric (kWh)	32,869.9	28,970.4	34,123.7	34,425.2	40,855.2	41,998.4	43,288.0	41,858.2	37,513.1	34,529.9	32,689.7	32,493.0	435,614.6
Peak (kW)	68.3	68.5	80.0	105.3	127.4	127.4	127.4	127.4	127.4	94.8	81.7	70.5	127.4

System Checksums

By Trial

Laboratory AHUs — **Variable Volume Reheat (30% Min Flow Default)**

COOLING COIL PEAK

Peaked at Time: Mo/Hr: 7 / 15
Outside Air: OADB/WB/HR: 86 / 71 / 95

CLG SPACE PEAK

Mo/Hr: 7 / 16
OADB: 85

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	24,767	0	24,767	1	22,689	1
Skylite Cond	0	969	969	0	0	0
Roof Cond	0	9,837	9,837	0	0	0
Glass Solar	226,056	0	226,056	6	222,808	13
Glass/Door Cond	57,506	0	57,506	2	54,583	3
Wall Cond	21,284	23,059	44,343	1	24,323	1
Partition/Door	36,838		36,838	1	36,838	2
Floor	-175		-175	0	-136	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	195,538		195,538	6	80,057	5
Sub Total ==>	561,813	33,865	595,678	17	441,163	26
Internal Loads						
Lights	267,794	0	267,794	8	269,151	16
People	251,201	0	251,201	7	131,776	8
Misc	781,820	0	781,820	22	790,086	47
Sub Total ==>	1,300,815	0	1,300,815	37	1,191,013	70
Ceiling Load	36,145	-36,145	0	0	39,940	2
Ventilation Load	0	0	1,044,449	30	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	18,300		18,300	1	18,183	1
Exhaust Heat		-287	-287	0		
Sup. Fan Heat			447,067	13		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	91,506	3		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	1,917,073	-2,567	3,497,528	100.00	1,690,298	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design
OADB: 5

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	-9,581	0.48
Roof Cond	0	-30,811	1.55
Glass Solar	0	0	0.00
Glass/Door Cond	-333,750	-333,750	16.84
Wall Cond	-78,770	-156,204	7.88
Partition/Door	-35,106	-35,106	1.77
Floor	-44,428	-44,428	2.24
Adjacent Floor	0	0	0
Infiltration	-408,077	-408,077	20.59
Sub Total ==>	-900,132	-1,017,958	51.36
Internal Loads			
Lights	27,251	73,394	-3.70
People	0	1,500	-0.08
Misc	217,317	298,691	-15.07
Sub Total ==>	244,568	373,585	-18.85
Ceiling Load	-117,827	0	0.00
Ventilation Load	0	-1,113,779	56.20
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		0	0.00
OA Preheat Diff.		-223,728	11.29
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-773,391	-1,981,880	100.00

TEMPERATURES

	Cooling	Heating
SADB	54.0	89.3
Ra Plenum	74.3	65.9
Return	72.4	72.2
Ret/OA	76.2	48.1
Fn MtrTD	0.5	0.0
Fn BldTD	1.1	0.0
Fn Frict	3.3	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	86,055	43,153
Terminal	86,055	43,153
Main Fan	86,055	43,153
Sec Fan	0	0
Nom Vent	86,055	43,153
AHU Vent	86,055	43,153
Infil	5,699	5,699
MinStop/Rh	43,153	43,153
Return	91,754	48,852
Exhaust	91,754	48,852
Rm Exh	0	0
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	100.0	100.0
cfm/ft²	1.45	0.72
cfm/ton	295.25	
ft²/ton	204.25	
Btu/hr·ft²	58.75	-30.12
No. People	573	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	291.5	3,497.5	2,568.1	85,730	81.1	66.5	78.4	53.0	53.0	62.5
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	291.5	3,497.5								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	59,530		
Part	5,323		
Int Door	0		
ExFlr	7,262		
Roof	10,326	310	3
Wall	40,468	9,734	24
Ext Door	184	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-1,792.9	43,153	48.1	87.0
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-1,792.9			

ENERGY CONSUMPTION SUMMARY

By Trial

	Elect Cons. (kWh)	PCldW Cons. (kBtu)	P.Stm Cons. (kBtu)	% of Total Building Energy	Total Building Energy (kBtu/yr)	Total Source Energy* (kBtu/yr)
Alternative 1						
Primary heating						
Primary heating			70,020	0.5 %	70,020	93,360
Other Htg Accessories	691			0.0 %	2,360	7,080
Heating Subtotal	**691**		**70,020**	**0.5** %	**72,380**	**100,440**
Primary cooling						
Cooling Compressor		128,899		0.9 %	128,899	99,153
Tower/Cond Fans				0.0 %	0	0
Condenser Pump				0.0 %	0	0
Other Clg Accessories				0.0 %	0	0
Cooling Subtotal....		**128,899**		**0.9** %	**128,899**	**99,153**
Auxiliary						
Supply Fans	2,126,661			49.2 %	7,258,292	21,777,054
Pumps	14,398			0.3 %	49,142	147,440
Stand-alone Base Utilities				0.0 %	0	0
Aux Subtotal....	2,141,059			49.6 %	7,307,434	21,924,494
Lighting						
Lighting	514,005			11.9 %	1,754,300	5,263,425
Receptacle						
Receptacles	1,605,133			37.2 %	5,478,317	16,436,595
Cogeneration						
Cogeneration				0.0 %	0	0
Totals						
Totals**	**4,260,888**	**128,899**	**70,020**	**100.0** %	**14,741,330**	**43,824,104**

* Note: Resource Utilization factors are included in the Total Source Energy value .
** Note: This report can display a maximum of 7 utilities. If additional utilities are used, they will be included in the total.