The

Gaige

Technology and Business Innovation Building

Penn State Berks, Reading PA

Technical Report Three

Mechanical Systems Existing Conditions Evaluation

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Matthew Neal, Mechanical Option

Stephan Treado, Advisor

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Technical Report Three

Executive Summary

This report outlines the specifics of the mechanical system within the Gaige Building. As a key, new and influential building on the Penn State Berks Commonwealth Campus, the Gagie Building is expected to be not only a quality construction, but a landmark and display of efficiency. It needs to be an example for other construction projects around the area and set a standard for new construction in years to come. With its advanced building controls, efficient systems, and logical design, the Gaige Building is the symbol it seeks to be.

First, the design requirements, energy sources, annual energy consumption, ventilation requirements, and heating and cooling loads are analyzed. With this data, it is seen that all of the design choices made by the mechanical engineers on the Gaige Building were sound, and have been validated through further study. The ventilation calculations, now validated using the ASHRAE Standard 62.1 method with E_v calculations from Appendix A, have been validated with the values used by the mechanical system designers on the project. Finally, the heating and cooling loads that were modeled for this project have been compared with the values determined from the Carrier HAP model by the engineers. While some major differences have been found, it was also determined that the model should be validated against actual building utility costs as opposed to the design model for the Gaige Building.

With actual cost data for the Gagie Building, the monthly utility costs are compared from the modeled and actual results, and these results were found to match fairly well. First, the natural gas consumption is very consistent, and the over prediction of the electricity consumption is discussed and further analyzed. Also, the mechanical system's overall construction and first-costs are presented to further understand the system. Schematics of the systems are provided for all major mechanical systems, and then, the system controls and operations are discussed in relation to system operation. The building contains a state of the art building automation system to allow for energy efficiency.

Finally, this report concludes with an analysis of this building against the current LEED rating system for major renovations and new construction. Although the Gaige Building achieved LEED Gold rating under a previous version of the LEED rating system, it currently only achieves certification under the new rating system. This new status is discussed, as well as the possibility of achieving a LEED Gold rating under the new standards. By ensuring that a few credits, previously rejected during the LEED analysis of the building, are met, and pursuing a few additional credits that have been added to the rating system since the Gaige Building's design, the Gaige Building could easily achieve a LEED Gold rating under the new system.

Building Overview and Background

The Gaige Technology and Business Innovation Building is a 64,000 SF building located in Reading, PA, on the Berks commonwealth campus of Penn State University. The Gaige Building is a host of many functions, but primarily, it is used as classroom, office, and lab space for the college's engineering, business, and hotel and restaurant management programs.

The Gaige Building is three stories tall, and it was constructed between April 2010 and November 2011. It was operated on a design-bid-build project delivery method, and had a full range of consulting services, from cost-estimating to A-V consulting. Functionally, the first floor contains classroom and lab spaces primarily, with a large area for studying and relaxing called the Learning Loft. Once you move to the second floor, you see the same classroom and lab emphasis, but a corridor on the east-west wing of the building provides a large amount of conference and office space.

Once you move to the third floor, the east-west wing of the building is capped off at two stories, but the north-sound wing continues up to three stories to accommodate one more classroom space and ample office and conference space. The exterior of the building consists of weather-resistant terracotta panel, metal framed exterior glazing and curtain wall systems, and precast concrete panels. Together, all of these building elements provide an aesthetically pleasing, but sealed and energy efficient building façade and enclosure. More information on the architecture of the building can be found in the building statistics report performed on the Gaige Building through this same thesis project.

Mechanical System Overview

The Gaige Building has three main root top units (RTU-1, RTU-2, and RTU-3) that provide ventilation, conditioning, and exhaust for the majority of the spaces within the building's design. The units are sized to 20,500 CFM, 14,000 CFM, and 12,500 CFM respectively. Each of these units serve a variety of spaces within the first, second, and third floors of the building. Air is supplied from the roof top units at a supply temperature of 55 degrees, and it is ducted throughout the building.

At the individual spaces, variable air volume boxes are provided for each zone. The VAV box takes the 55 degree air, and varies the volume of air being supplied to the space to meet the cooling requirement of the space at the current time. The load is monitored by a thermostat located in each of the zones separately. CO2 and occupancy sensors also are coordinated with the VAV boxes to allow for a reduction in outside air required to be supplied to each space. A minimum set point prevents the VAV box from supplying air less than the minimum outside air requirement for the space. A reheat coil prevents from overcooling the space when providing minimum outside air at a time when cooling requirements are reduced.

Two 1300 MBH boilers provide the hot water service for the building and all mechanical heating requirements. Four split system air conditioners are required to provide individual space cooling for the telecom/data rooms in the building, and one computer room air conditioner is required for the IT storage and equipment room, also supplied with an air-cooled chiller. Unit heaters are provided throughout the building as needed in semi-heated spaces, such as the vestibules at the building entrances.

Finally, the heating loads for the building are met by radiant-heating panels and fin-tube heat exchangers placed at exterior walls of spaces that don't experience a year round cooling load. This allows for simultaneous heating and cooling throughout the building in spaces that contain these heating elements. Although it provides poor energy efficiency, the VAV boxes are equipped with reheat coils, so some heating in spaces without panes or fin-tubes could potentially have some heating capacity, but that is not the primary design intent.

Existing Mechanical System

In this section of technical report three, an extensive analysis of the mechanical system of the Gaige Building, at Penn State's Berks Commonwealth Campus, is conducted. The design focuses and goals will be initially stated, and then, all aspects of the mechanical system within the Gaige Building will be discussed and analyzed. First, the objectives of the Gaige Building's design will be highlighted, as well as the energy sources that were present at the building's site. Then, the ventilation system of the building will be discussed. Finally, the heating and cooling loads for the building and the heating and cooling systems will be presented. Schematics of major water and air flow systems will be given to provide an overall graphic representation of system operation.

Design Objectives

One of the main focuses of the Gaige Building was the need for energy performance. As a Penn State Building, it was expected that The Gaige Building would underperform an ASHRAE Standards baseline building by at least 30%. This could be accomplished through the envelope construction of the building as well as the mechanical system used by the building. This need for energy efficiency led to a decision to incorporate very high performance windows and glazing into the façade of the building, a step towards the 30% reduction expectation. As well, the rooftop units for the Gaige Building are each equipped with energy recovery wheels that help to pre-heat outside air in the winter with exhaust air, or pre-cool in the summer.

As well, since the Gaige Building is simply a standalone classroom building, all of the heating and cooling systems are provided from boiler and air-cooled chillers on-site. As a result of the lower loads associated with this type and size of building, a centralized heating boiler plant is used, but all cooling required is provided by separate systems. Each rooftop unit is equipped with internal equipment that provides the necessary cooling, and the individual air-conditioning units are connected to air-cooled chillers that provide the cooling needed for each unit.

The final key design objective was for water efficiency throughout the design of the Gaige Building. To accomplish this goal, the Gaige Building incorporates a rainwater harvesting and storage system that provides for nearly 100% of the building's non-potable water usage.

Overall, the Gaige Building is designed to be a building that is a landmark for the Penn State Berks campus. It is a building unlike any other on campus. It acts as a showcase for students, a standard for the building community, and an educational tool for the Reading community. With its energy efficiency, water efficiency, and status in the area, it will be a landmark for much of the future to come. The Gaige Building, as it educates students at the Penn State Berks campus, will be long remembered.

Energy Sources and Rates

For the Gaige Building, the two sources of energy used in the mechanical system are natural gas and electricity. Natural gas is used primarily for the two boilers that provide the hot water for the heating coils in the rooftop units, auxiliary coils in the VAV units, and radiant and fin-tube heaters throughout the building. Electricity is the main utility used by the Gaige Building, and it is used for all internal building operations and cooling. All cooling units (the rooftop units and the air-cooled chillers) use electricity as their energy source. Below is a table of the energy rates that were provided by the mechanical engineers on the project for the energy analysis for the building. These rates were determined before the construction of the Gaige Building, so they do not reflect actual costs.

Energy Rates, Estimated		
Energy Source	Rate	Units
Electricity	0.0964	$/kWh
Natural Gas	15	$/MCF

Table 1: Energy rates used for the cost analysis for the Gaige Building, used in both the Trace 700 and HAP models from Technical Report 2

The electricity for the Gaige Building is provided by American Powernet, and PP & L is the company that bills for the distribution of the energy. Since these rates are approximate, energy bills for the Gaige building's natural gas and electricity were sought out and have been provided by the COO at Penn State Berks. From the data given from Penn State Berks, New rates have been calculated below by averaging the rates on a monthly basis. The data used for the averaging ranges from September of 2011 to June of 2013.

Energy Rates, Actual		
Energy Source	Rate	Units
Electricity	0.0940	$/kWh
Natural Gas	10.44	$/MCF

Table 2: Energy rates that have been calculated using data provided from actual energy bills for the Gaige Building from 2011 to 2013

As you can see, the rate for electricity was a very good approximation, which is to be expected. The natural gas price has shown to be a much lower rate than was expected during the design of the Gaige Building. When the building was originally modeled, around prior to 2009, the rates for natural gas were much higher, around the $15/MCF prediction. Since then, the rates have dropped to the new prediction, and even into the $9.00/MCF range. With this new data, updates will be made to the energy model, to further check the cost data for the Gaige Building, and verify results with the actual energy bills from the Gaige Building.

Design Conditions

In the following two sections, the design conditions associated with the Gaige Building will be discussed. These design conditions reflect both the actual design conditions from the Gaige Building and the values used during the prior and current modeling of the building. First, the indoor design conditions will be presented, and then the outdoor extreme design day data will be given.

Indoor Design Conditions

The Gaige Building, being like any modern building, is equipped with individual thermostats to control the space temperatures within the building. Each thermostat logically controls the variable air boxes that adjust the amount of air that is delivered to each space. Below is a table that summarizes the set points for the different types of spaces within the Gaige Building, depending both on space type and season (cooling/heating values).

Design Set Point for the Gaige Building			
Space Type	Temperature (°F)		Humidity
	Cooling	Heating	
Conditioned Spaces			
Set Point (occupied)	75	70	50%
Drift Point (unoccupied)	85	60	50%
Heating/Ventilation Spaces			
Set Point	110	70	50%
Drift Point	110	60	50%

Table 3: Design set points for the Gaige Building for differing spatial types and seasons

Outdoor Design Conditions

The Gaige Builidng is located in Reading, PA, so design values for this site are taken from the ASHRAE 2009 Handbook of Fundamentals. In the model created by the design engineers, which was done only in Carrier HAP, the location of the building was set to Harrisburg, PA. After looking in the ASHRAE Handbook of Fundamentals, it is noted that the Spaatz Field, a local airfield serving Reading PA, has such provided data. Since Spaatz Field is located less than two miles from this project's site, data for it will be used in further analysis of the Gaige Building. When the model is compared with the design engineer's model, it will be compared using the location of Harrisburg, PA, but when the modeled results are compared to actual building usage data, and for further analysis of this data, the data for Spaatz Field will be input to the modeling program.

Weather Inputs-Harrisburg, PA		
Heating	Cooling Data	
DB: 99.6%	DB: 0.4%	WB: 0.4%
8.7 °F	92.4 °F	73.8 °F

Table 4: Data used for the weather design conditions in the Trace 700 model, from the 2009 ASHRAE Handbook of Fundamentals

Weather Inputs-Reading, PA-Spaatz Field		
Heating	Cooling Data	
DB: 99.6%	DB: 0.4%	WB: 0.4%
9.4 °F	92.4 °F	74.1 °F

Table 5: Data used for the weather design conditions that will be used in future models for my thesis evaluation, despite not being used in the design of the building

Ventilation Requirements

For the Gaige Building, ASHRAE Standard 62.1 was followed to meet ventilation requirements for the building. Not only did Penn State require compliance with this ASHRAE standard, the LEED rating system for new construction also required that the Gaige Building meet ASHRAE requirements to achieve a LEED Gold rating. The Gaige Building is a mix of laboratory, office, and classroom spaces, along with the general required support spaces for any educational building. Previously, in Technical Report One, the Gaige Building's design ventilation values were compared with hand calculations performed using values from ASHRAE Standard 62.1. Below is a table that summarized the results from that Analysis. For future information on the design assumptions for that analysis or specifics associated with these calculations, please see appendix A in this report, or refer back to Technical Report One.

Ventilation Calculation Summary: Table 6.3 Method			
Unit	Required V_{ot}	Design V_{ot}	Comply?
RTU-1	11993	9020	No
RTU-2	7133	5040	No
RTU-3	1848	4375	Yes

Table 6: Summary of the ventilation calculations performed for the Gaige Building's three RTUs

On issue identified from the previous analysis was a slight procedure difference between the calculation methods used by H. F. Lenz Company, the mechanical engineers on the project, and my analysis of the ventilation requirements of the building. H. F. Lenz's calculation used appendix A of Standard 62.1 to calculate all E_v values, and those changes resulted in higher E_v values, and therefore, a lower requirement for indoor air intake. This difference created lower required ventilation values, and resulted in what looks like and underperformance from the building's ventilation system. After further reviewing the Appendix A method of calculating ventilation requirements, a re-evaluation of the Gaige Building's compliance with ASHRAE Standard 62.1 was conducted. For this evaluation, E_v was calculated according to methods laid out in appendix A of ASHRAE standard 62.1, and the table below summarizes this new analysis.

Ventilation Calculation Summary: Appendix A Method			
Unit	Required V_{ot}	Design V_{ot}	Comply?
RTU-1	9367	9020	No
RTU-2	5514	5040	No
RTU-3	1699	4375	Yes

Table 7: Summary of the ventilation calculations performed for the Gaige Building's three RTUs

Although the Gaige Building is still not compliant with the newly calculated requirements, the results are much more reasonable and on much more of a comparable scale than before. The value for E_p, the fraction of primary air to discharge air in the ventilation zone, was assumed to be 1.0 in this calculation, which resulted in F_a, F_b, and F_c to have the value of 1.0 as well. Despite the system's underperformance, the required changes would be very minimal to compensate for the differences. The differences, because of their small size, are probably due to different area measurements or some other similar deviation. The results for this new calculation procedure can be seen in Appendix B, and contrasted with the previous results found in Appendix A.

Heating and Cooling Loads

Heating and Cooling loads were calculated for the Gaige Building using a Trace 700 model, and the results were compared in Technical Report Two with a Carrier HAP model that was created during the design of the Gaige Building. This model was created for design purposes, and it was used to demonstrate that the Gaige Building met requirements set forth in the LEED rating system for new construction. Below, tables eight and nine summarize the calculated heating and cooling loads for the Gaige Building, and then make the comparison between the Trace 700 model and the Carrier HAP model from the building's design.

Calculated Design Results					
Unit	Service Area (SF)	Cooling (CFM/ton)	Heating (BTU/hr-SF)	Total Supply (CFM/SF)	Ventilation Supply (CFM/SF)
Calculated					
RTU-1	20033	360	46.0	1.4	0.43
RTU-2	13670	361.34	33.7	1.0	0.37
RTU-3	12500	305	31.9	0.8	0.15
AHU-1	102	585.8	23.4	1.1	n/a
AHU-2	75	586	23.4	1.1	n/a
AHU-3	95	508	35.5	1.5	n/a
AHU-4	51	500	24.0	1.1	n/a
CRAC-1	325	523.6	31.6	1.4	n/a
Heat/Vent	4608	n/a	n/a	n/a	n/a
Total	**51459**				**0.30**

Table 8: A summary of the loads calculated for this report from Trace 700

Comparison of Calculated and Design Results					
Unit	Service Area (SF)	Total Supply (CFM/SF)		Ventilation Supply (CFM/SF)	
		Design	Difference (CFM/SF)	Design	Difference (CFM/SF)
RTU-1	20033	1.1	0.3	0.46	-0.03
RTU-2	13670	0.9	0.1	0.38	-0.01
RTU-3	12500	0.8	0.0	0.28	-0.12
AHU-1	102	1.0	0.1	n/a	n/a
AHU-2	75	1.5	-0.4	n/a	n/a
AHU-3	95	1.5	0.0	n/a	n/a
AHU-4	51	1.9	-0.8	n/a	n/a

Total	**51459**	**0.35**

Table 9: A comparison of the loads calculated from the Trace 700 model and the Carrier HAP model

The heating for the Gaige Building is provided by two gas-fired 1300 MBH boilers. Both boilers are piped in parallel, and two variable speed pumps control the overall supply to the building system. For the cooling of the Gaige Building, each unit provides its own cooling demand with internal cooling equipment or with a separate air-cooled chiller. For the three rooftop units, all were in good agreement with the calculations from the engineers. Only RTU-3 significantly underestimates the ventilation supply of a CFM/SF basis.

Annual Energy Use

To estimate the annual energy use of the Gaige Building, a model was created in Trace 700, an hourly analysis program that simulates building loads and conditions throughout the year. Below, table ten summarizes the results from this analysis. As well, these results are compared to a Carrier HAP model that was created by the mechanical engineers on the project, from H. F. Lenz Company. The Carrier HAP model was used to design the mechanical system and to demonstrate compliance in the LEED certification process. As well, below, figure one shows the overall breakdown of energy usage in the Gaige Building.

Building Energy Usage Breakdown			
Type	Load (kBTU/yr)		% Difference
	Designed	Modeled	
Heating	1867073	1017367	-46%
Cooling	236739	465831	97%
Air System Fans	156909	229301	46%
Pumps	44954	28037	-38%
Lights	480901	519662	8%
Electrical Equipment/ Receptacles	1839097	1727367	-6%
Misc. Fuel	113292	272740	141%
Total:	**4738965**	**4260306**	**-10%**

Table 10: A comparison of the annual energy usage calculated from the Trace 700 model and the Carrier HAP model

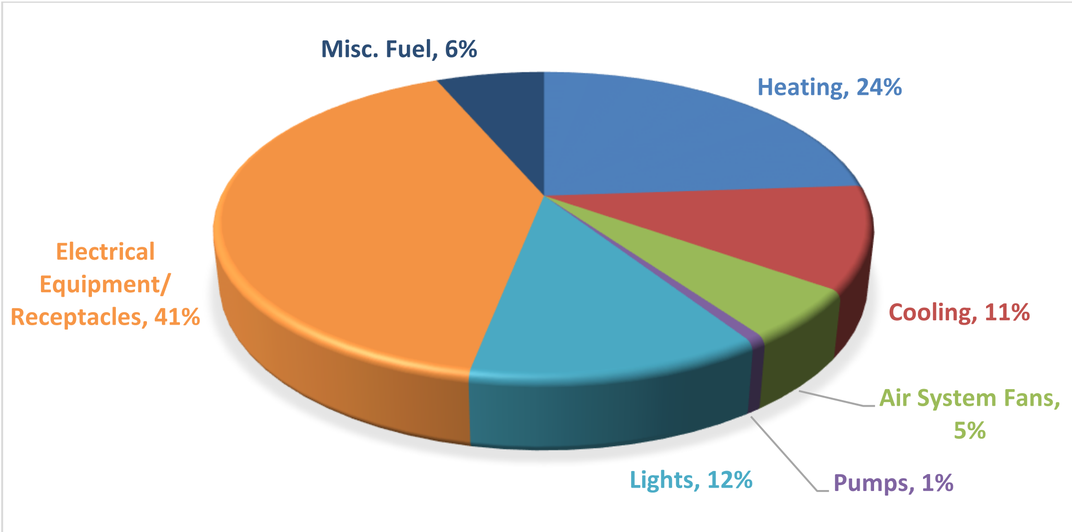

Figure 1: Annual energy distribution as calculated by the Trace 700 model used for the energy estimation for this report

After this analysis, the overall analysis performed very well, coming in with only a 10% difference between the models. Despite the fact that this difference is a seemingly good result, with further study of the individual differences in the various categories of loads, more difference is found. By analyzing the results, you can see that while the heating of the Gaige Building is under predicted when comparing Trace 700 to Carrier HAP, the cooling is drastically over predicted. These two errors will tend to cancel each other out, and hide some amount of difference between the models. Further work is being done to refine this model.

Also, despite the fact that the Carrier HAP model developed by the mechanical engineers on the project is reliable, the Trace 700 model really should be validated against actual building consumption data, and not simply initial design assumptions of this data. More analysis on this will be done in the building operation section of this report. By validating the Trace 700 model against actual building data, the model can gain some reliability, and potentially accurately predict the actual performance of the building. These are key factors that will drastically influence potential design changes that will be analyzed in the upcoming semester.

Mechanical Equipment Summary

The main mechanical systems in the Gaige Building are the air distribution system consisting of three roof top units, the air conditioning units serving the telecommunication rooms, the boilers serving all of the buildings hot water coils, and the chillers serving the air conditioning units. Working together, all of these separate systems interact to provide space conditioning, ventilation, and adequate indoor environmental quality within the Gaige Building. Below, the airside mechanical system is initially explained. Once the major pieces of equipment are provided and explained, then the waterside system is described. Schedules and descriptions of both the hot water and chilling equipment are given in the second of the following two sections.

Airside Equipment Summary

First, the main heating, cooling, ventilation, dehumidification, and return air are provided by the three rooftop units. Each of these three units are listed below in the rooftop unit schedule, in table eleven.

Major Equipment: Rooftop Units									
Unit	Services	Supply CFM	OA CFM	Supply Fan			Exhaust Fan		
				Type	HP	RPM	Type	HP	RPM
RTU-1	1st and 2nd, West	20500	9020	BI	20	1498	BI	10	1412
RTU-2	1st and 2nd East	14000	5040	BI	20	1485	BI	5	1135
RTU-3	2nd, West and 3rd East	12500	4375	BI	20	1415	BI	5	1085

Table 11: A schedule of the packaged rooftop units used in the Gaige Building

Also, a schematic is provided to overview the packaged rooftop unit. Below, this schematic shows all of the important components of the rooftop unit.

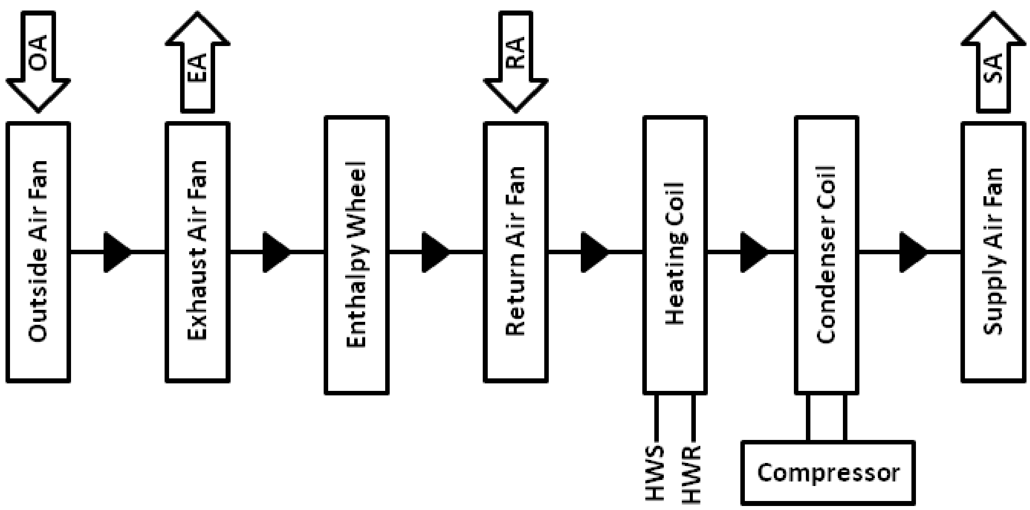

Figure 2: A schematic showing the major components of the packaged roof top units

First, outside air is brought into the unit through the outside air fan. Then it, as well as exhaust air controlled with the exhaust air fan, are sent in opposite directions through the enthalpy wheel. After recovering energy from the exhaust air, the outside air is mixed with return air. After mixing, the air is conditioned using the heating coil with external energy source, and the condenser coil supplied by the internal scroll compressor. All of the roof top units are set to supply air, after conditioning, at 50 degrees F and 50% RH to the variable air volume boxes. Then, the variable air volume boxes will control space conditioning by changing the amount of air delivered to the space.

Apart from the rooftop units, there are also five air conditioning units that serve special spaces within the Gaige Building. Four of the units serve telecommunication rooms, and one of the units is a computer room air conditioner that serves the server room. Below, table twelve details the different specifications for each of these units.

Major Equipment: Air Conditioning Units					
Unit	Capacity (BTU/hr)	SEER	CFM		Manufacturer
			Min	Max	
ACU-1	12000	13.8	320	425	Mr. Slim-Mitisubishi
ACU-2	18000	13.8	320	425	Mr. Slim-Mitisubishi
ACU-3	18000	13.8	320	425	Mr. Slim-Mitisubishi
ACU-4	18000	13.8	320	425	Mr. Slim-Mitisubishi
CRAC-1	23800	n/a	800	885	Liebert Minimate2

Table 12: A schedule of the air conditioning units in the Gaige Building

The last main components of the airside equipment are the exhaust fans. These various fans serve to exhaust and ventilate mechanical spaces within the building, and provide localized exhaust to special room spaces. These spaces include restrooms, certain labs, etc. Below, table thirteen summarizes all of the exhaust fans in the Gaige Building.

Major Equipment: Exhaust Fans					
Unit	Services	Type	Fan CFM	HP/Watts	Control Type
EFN-1	Toilet Rooms	Powered Roof Ventilator	2700	0.75	Time Clock
EFN-2	Elevator Machine Room	Powered Roof Ventilator	300	0.17	Direct Digital Control
EFN-3	Toilet 307E	Ceiling	75	50 W	Time Clock
EFN-4	Mechanical Room M118	Propeller	1500	0.5	T-Stat
EFN-5	Vending Area	Inline	300	0.25	T-Stat
EFN-6	Electrical Room P110	Inline	1500	0.33	T-Stat
EFN-7	Welding	Inline	600	0.75	Local Switch
EFN-8	Research Lab 104	Inline	80	0.33	Local Switch
EFN-9	Office 115	Inline	80	0.33	Local Switch

Table 13: A schedule of the exhaust fans in the Gaige Building

Waterside Equipment Summary

The waterside equipment consists of both the heating and cooling systems for the building. First, the heating system consists of two boilers and various hot water pumps. The hot water system's major equipment is summarized below in table fourteen and table fifteen.

Major Equipment: Boilers						
Unit	Type	Size (MBH)	EWT (°F)	LWT (°F)	Head (Ft H_2O)	Efficiency
BLR-1	Gas Fired	1300	160	180	30	94%
BLR-2	Gas Fired	1300	160	180	30	94%

Table 14: A schedule of the boilers in the Gaige Building's hot water system

Major Equipment: Pumps								
Unit	System	Type	Head	VFD?	GPM	Efficiency	Motor HP	Motor RPM
HWP-1A	Boiler 1	In-Line	35	No	65	n/a	n/a	n/a
HWP-1B	Boiler 1	In-Line	35	No	65	n/a	n/a	n/a
HWP-2A	Boiler 2	In-Line	35	No	65	n/a	n/a	n/a
HWP-2B	Boiler 2	In-Line	35	No	65	n/a	n/a	n/a
HWP-3	VAV Boxes	Floor-Mounted	60	Yes	60	74.1%	7.5	1750
HWP-4	VAV Boxes	Floor-Mounted	60	Yes	60	74.1%	7.5	1750

Table 15: A schedule of the pumps used in the Gaige Building's hot water system

Each of the boilers are piped in parallel, and the hot water pumps control the supply of water to all of the heating coils in the rooftop units, the variable air volume boxes, and the fin-tube heaters. Also, major waterside equipment helps to provide cooling to all of the mechanical equipment to meet the building's cooling demand. Although each rooftop unit has its own internal scroll compressor, all of the five air conditioning units require a separate air-cooled chiller to supply cooling potential. All of these chillers are located on the roof, and each air conditioning unit is served by one chiller. Below, table sixteen summarizes each chiller, its design specification, and what air conditioning unit it serves.

Major Equipment: Chillers					
Unit	Services	Type	Capacity (Btu/hr)	dBA	Manufacturer
CU-1	ACU-1	Air-Cooled	12000	46	Mr. Slim-Mitisubishi
CU-2	ACU-2	Air-Cooled	18000	46	Mr. Slim-Mitisubishi
CU-3	ACU-3	Air-Cooled	18000	46	Mr. Slim-Mitisubishi
CU-4	ACU-4	Air-Cooled	18000	46	Mr. Slim-Mitisubishi
CU-5	CRAC-1	Air-Cooled	23800	n/a	Liebert Minimate2

Table 16: A schedule of the chillers in the Gaige Building's cooling systems

For design simplicity, all of the cooling is done separately for each unit. Centralized cooling could potentially provide for more energy efficiency, but more complexity would be required in piping, distribution, and more mechanical space would be required in the building. This could be a potential further systems analysis.

Mechanical System Cost

The total cost of the Gaige Building was $25,700,000.00, of which, about $2,150,000.00 accounted for the heating, ventilation, and air conditioning system costs. Below, table seventeen summarizes the cost breakdown of the mechanical system for the Gaige Building. Each component of the HVAC system is given, and where needed, additional data is provided.

Mechanical System Cost Summary				
Item or service	Amount	Unit	Price per Quantity	Total
Mechanical System				**2,149,400**
Three Rooftop Units (combined)	1	Lump Sum	300,000.00	300,000
Roof Top Units Installation	45,230	CFM	2.00	90,460
Exhaust Fans	7,590	CFM	1.50	11,390
Makeup Air Units-4,000 CFM	1	Each	12,000.00	12,000
3,300 CFM	1	Each	9,900.00	9,900
Kitchen Hood Exhaust	2	Each	5,000.00	10,000
Split System- Mr. Slim 1.5 Ton/Ductless	4	Each	5,000.00	20,000
Computer Room AC	1	Each	7,200.00	7,200
Boilers - 850 MBH	2	Each	24,000.00	48,000
Pumps - 85 GPM	3	Each	2,000.00	6,000
170 GPM	2	Each	4,000.00	8,000
Piping- HW Heating - 4"	30	Linear Foot	100.00	3,000
3 inch	680	Linear Foot	74.00	50,320
2 inch	370	Linear Foot	48.00	17,760
1.5 inch	340	Linear Foot	32.00	10,880
1.25 inch	1,380	Linear Foot	29.00	40,020
1 inch	2,120	Linear Foot	25.00	53,000
0.75 inch	640	Linear Foot	20.00	12,800
Refreigerant Piping	390	Linear Foot	50.00	19,500
Hydronic Specialties - Misc./Etc	1	Each	5,000.00	5,000
Chemical Feeder Tank	1	Each	7,500.00	7,500
Expansion Tank	1	Each	2,000.00	2,000
Fin Tube	1,150	Linear Foot	75.00	86,250
Cabinet Unit Heater	5	Each	1,250.00	6,250
Unit Heater	3	Each	900.00	2,700
Radiant Heat Panels	80	Linear Foot	100.00	8,000
VAVs w/ Reheat	85	EA	1,250.00	106,250
Ductwork - Sheetmetal	52,200	LB	7.00	365,400
16 Gauge Sheetmetal	11,000	LB	7.00	77,000
Insulation	42,270	Square Foot	3.00	126,810
Telescoping Source Capture Arm	1	Each	7,500.00	7,500
Dampers- Volume	232	Each	200.00	46,400
Fire	3	Each	1,000.00	3,000
GRD	60	Each	300.00	18,000
Linear Diffuser	1,230	Linear Foot	100.00	123,000
Jet Flow Diffuser	11	Each	500.00	5,500
Sound Dampers	3	Each	1,000.00	3,000
Controls Allowance	59,750	Square Foot	6.00	358,500

CO2 Sensors	29	Each	500.00	14,500
Testing and Balancing	59,750	Square Foot	0.75	44,810
Commissioning	1	Lump Sum	-	NIC
Louvers	30	Square Foot	60.00	1,800

Table 17: A detailed breakdown of the mechanical systems cost for the Gaige Building

When looking at the overall picture of construction costs below in figure three, you can see that the major portion of the cost of the Gaige Building is associated with its construction. To further look at how the mechanical system in particular plays role in this, in figure five, the constructions costs alone are shown, and the major components of these costs are provided. As you can see, the mechanical system is a major contributor to the overall construction costs associated with the Gaige Building. Apart from the costs associated with the electrical system in the building and the metals in the building, the mechanical system in the next most expensive construction component. With this in mind, the first costs associated with the mechanical system will be a major consideration when evaluating design changes to the Gaige Building. Further work and analysis of the impact of mechanical system first cost will be conducted in future work when considering the balance between increased first costs and design changes for the Gaige Building.

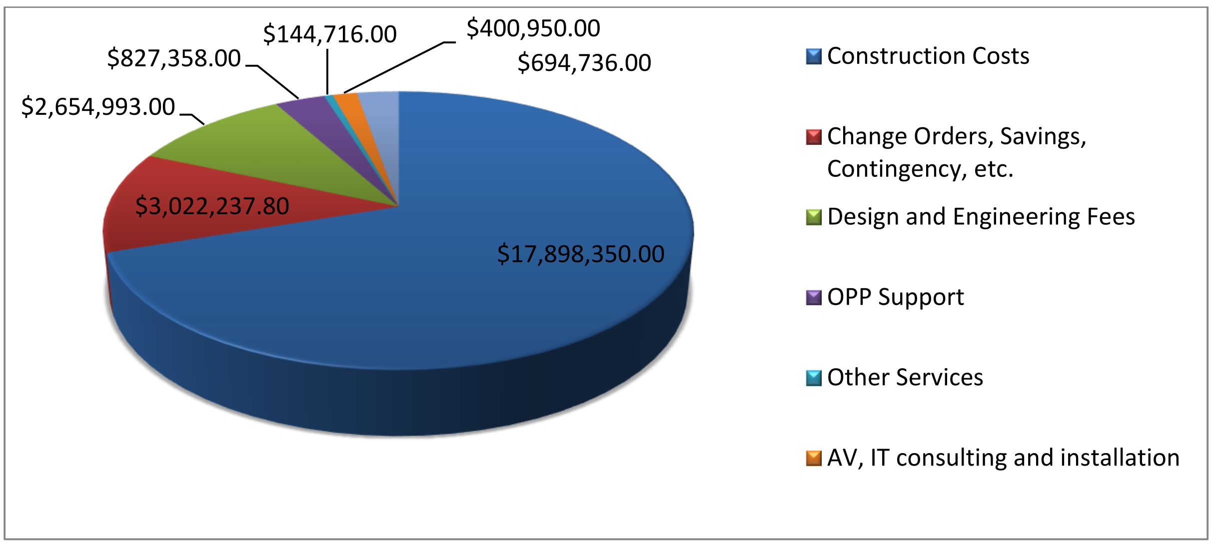

Figure 3: A chart showing a comparison of the major overall building costs

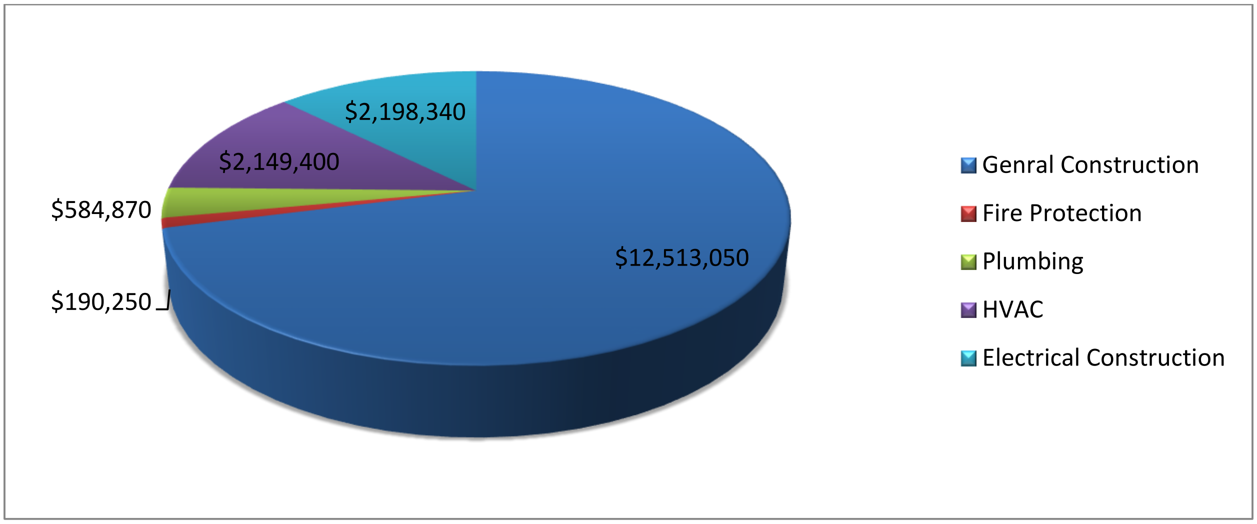

Figure 4: A chart a breakdown of the majors costs associated with construction of the Gaige Building

Mechanical System Space Considerations

Below, table eighteen provides the space in the Gaige Building that is lost due to mechanical system space requirements and other building services:

Overall Lost Space			
Floor	Mechanical Area	Total Area	% Lost Space
First	1214	22366	5.4%
Second	481	20500	2.3%
Third	183	8944	2.0%
Total	**1878**	**51810**	**3.6%**

Table 18: The total area taken up by mechanical spaces compared to the overall usable area of the building

In the Gaige Building, the mechanical requirements are for telecommunications, electrical, mechanical, elevator, and IT rooms. All of the building's service equipment is kept within the 'mechanical area' category. The most of the mechanical space is needed on the First floor, for the main mechanical room which contains the boilers is on the first floor, in the north-west building corner. Overall, 3.6% of the usable floor area is lost to mechanical space requirements. This is a very low number, but it is due to the amount of mechanical equipment placed on the roof. All three rooftop units and the five air-cooled chillers in the Gaige Building are located on the rooftop. This drastically reduces the space requirements for the mechanical system within the building, although it can sacrifice the aesthetics of the building's exterior. More detain in these space calculations can be found in Appendix C.

System Operation and Schematics

This section of the reports provides a detailed explanation of how all of the pieces in the Gaige Building's mechanical system work together and communicate to achieve space conditioning, ventilation, and energy efficiency. The systems are first described graphically by different schematic diagrams. Then, using these schematics as a reference, the specifics of each system is given for a complete understanding of how the Gaige Building's mechanical system operates together as one unit.

Mechanical Schematics

Below are schematic diagrams for both air-side and waterside operations. First, a schematic airflow diagram of the rooftop units is provided, showing what floors each unit serves. Then, waterside schematics are given for both the hot water system and the chilled water system. The hot water schematic shows the piping equipment, and how the boilers serve the heating coils in the system. Finally, a cooling system schematic is provided showing how each air conditioning unit is served by an individual air-cooled chiller.

Airside Schematic

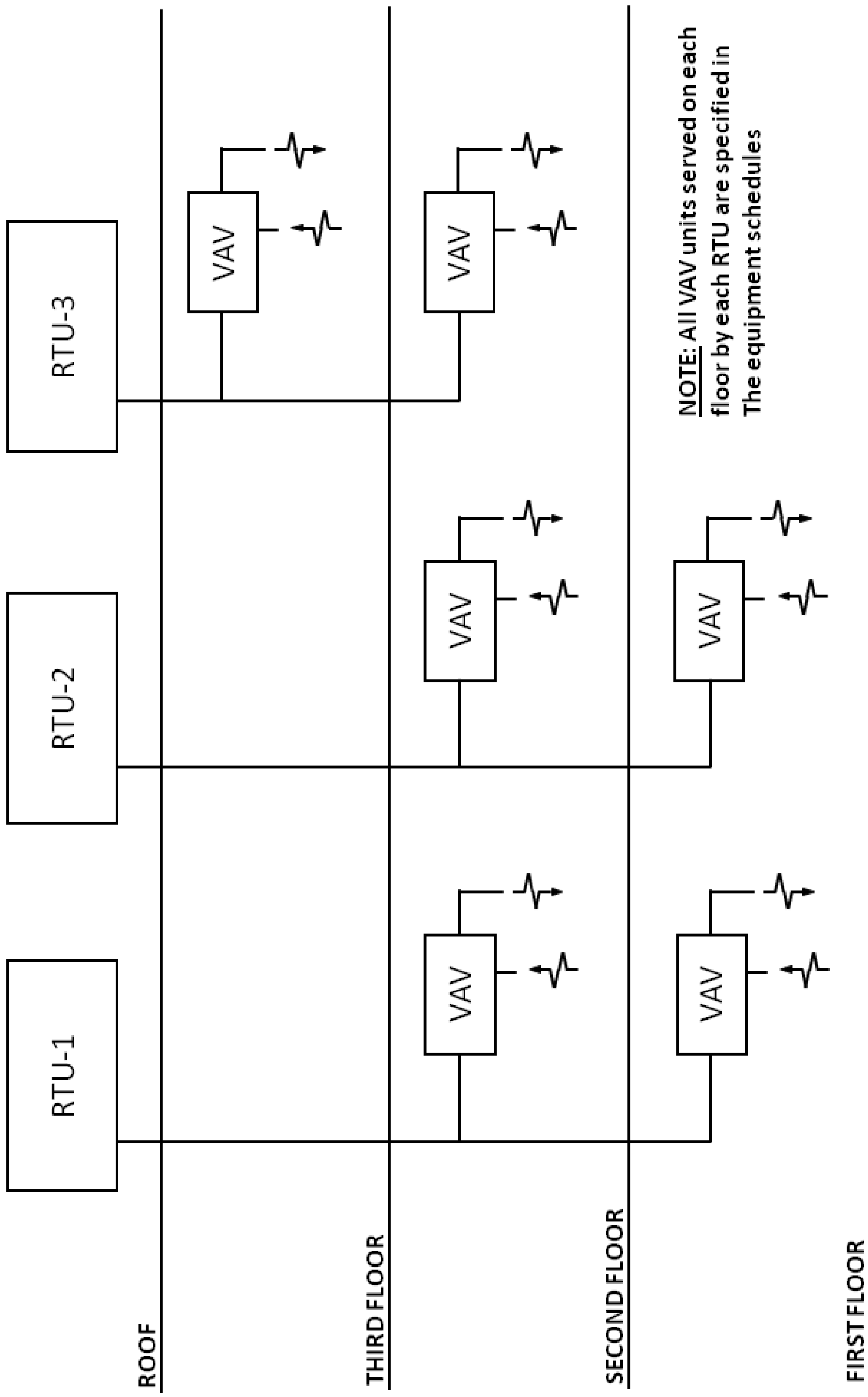

Figure 5: A schematic of the main airflow systems within the Gaige Building. Note that the VAV units on each floor represent many different units serving different spaces

Waterside Schematics

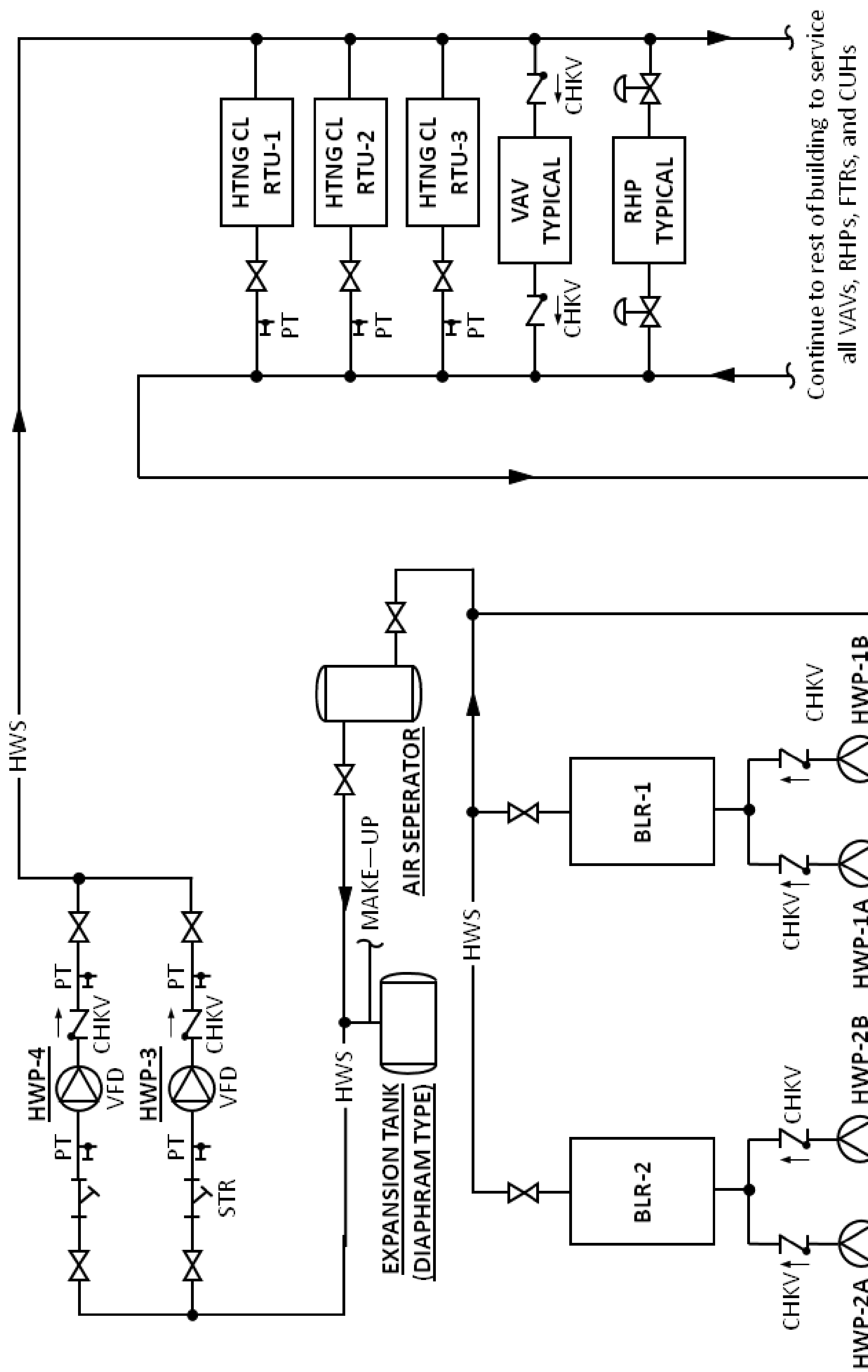

Figure 6: A schematic of the hot water system within the Gaige Building. The two boilers serve all of the rooftop units and VAV boxes' heating coils within the building

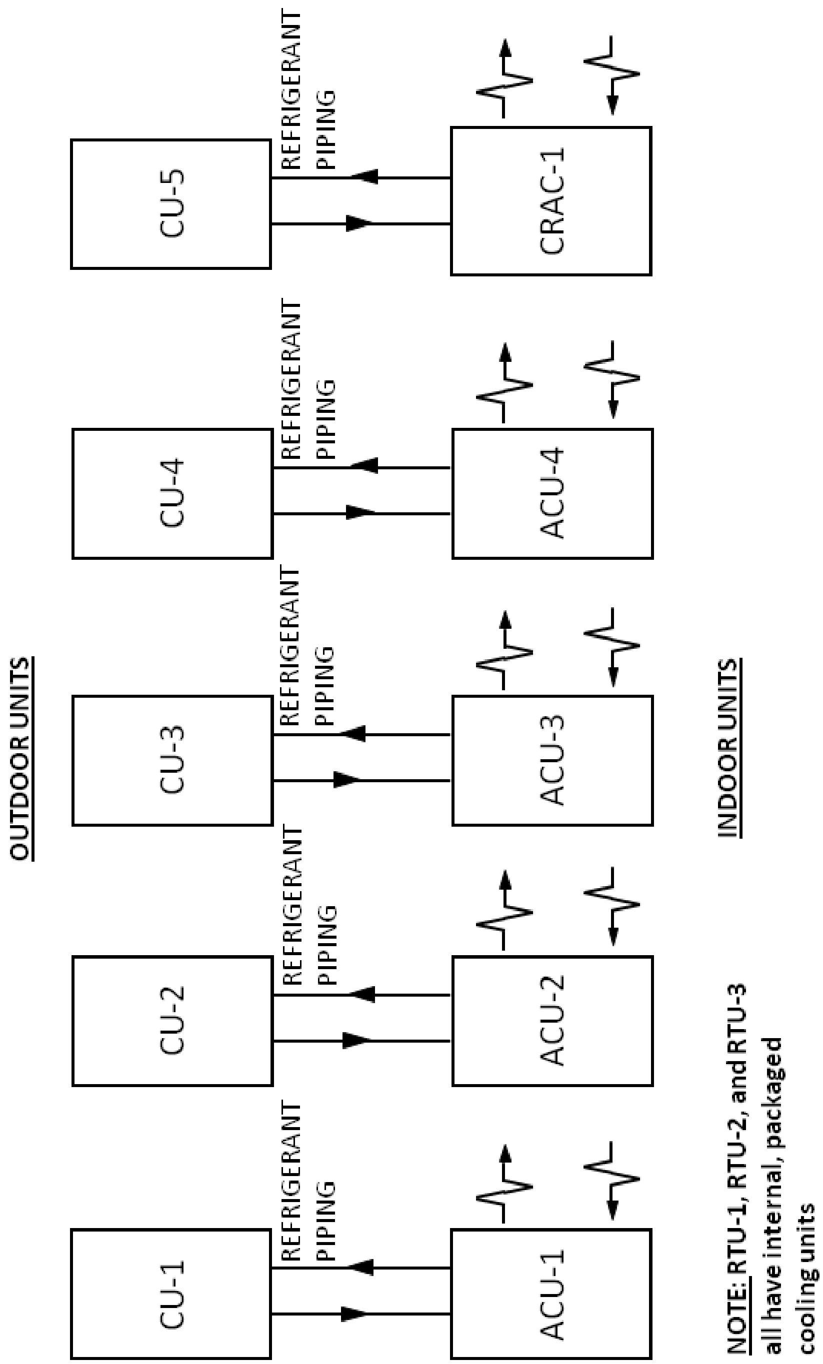

Figure 7: A schematic of the chilled water/refrigerant system within the Gaige Building. No central cooling equipment is provided, so each air conditioning unit is served by a separate air-cooled chiller

Conceptual System Operation (include specific ref. to schematics)

In the Gaige Building's mechanical system, the system operation can be broken down logically into three parts: ventilation, space heating, and space cooling. First, as seen in the airflow schematic (Figure five), the ventilation for the Gaige Building is performed by the three packaged rooftop units. In each space, either a CO2 or an occupancy sensor is provided. In the more densely populated spaces, such as the classrooms, laboratories, and other spaces, CO2 sensors are provided, but in the lower occupancy spaces, occupancy sensors are the only sensors provided. This is so ventilation air can be adjusted based upon the number of people in the room in the densely populated spaces. For the lower occupancy spaces, like most of the offices, a simple occupancy sensor is provided with an on/off set point. This sensor will provide the maximum ventilation airflow to the space when the space is occupied (on setting) and will provide the minimum, per square foot, ventilation requirement when the space is unoccupied (off setting).

Space Ventilation

The airflow is modulated to each of these spaces using variable air volume boxes. These boxes control the airflow to a space, accounting for both ventilation and load requirements. In figure five, the VAV boxes are simply shown as one unit on each floor. As seen in the note, these are in reality many units that serve individual spaces with individual space conditions. First, a thermostat is provided in each zone controlled by a VAV box. This thermostat helps communicate the present building load to the VAV box, and the VAV box adjusts the amount of air being delivered to the space to meet the present load requirements. When cooling is required, the VAV box will completely cover this load. Air is delivered to the VAV boxes at a temperature of 55 degrees F, and the amount of this air is adjusted to meet the cooling load. If heating is required, the auxiliary heating coil will be set to on, and air will be delivered at a temperature between 80 and 112 degrees, depending on the VAV box characteristics. The thermostat will help to modulate a control valve for the auxiliary heating coil using a PI control loop design.

Space Conditioning

Along with controlling the load, the VAV boxes also have a minimum set point for airflow, to ensure that enough ventilation air is being delivered to each space. This set point, based upon occupancy and area, is a minimum airflow, based upon the specific space requirement and the amount of overall outside air and return air that is coming into the rooftop unit serving the VAV box. With these controls, energy efficiency is achieved, while still meeting ventilation requirements throughout the building.

In spaces where the reheat capacity of the auxiliary coil in the VAV box is not enough to meet the maximum cooling load of a space, radiant baseboard heat and radiant panels are provided next to the exterior windows for the additional required heating. Again, a local thermostat within the mechanical zone will control the perimeter heating with an analog input to the perimeter heating valve. As well, the entering and discharge temperatures to the VAV boxes will be monitored, and where perimeter heating is present, the auxiliary heating coil and the perimeter heating coil will coordinate to meet the required space heating. The differing occupancy set points associated with spaces will be input into the VAV control logic as well. When the spaces are unoccupied, the design set points are shifted to unoccupied values, and when occupied, set points are set to more stringent values. As well, a special holiday heating set point is provided for even lower heating values. An optimal start algorithm is also programmed into the unit to allow the system to recover from a less stringent design set point. This provides for system warm-up and cool-down.

Overall System Control

Along with the large amount of controls from the Building Automation System at the zone level, all of the required flows must be communicated back through the system to the variable speed boiler pumps, the rooftop unit exhaust, outside, and return air fans, and the rooftop units' heating and condenser coils. First, as the VAV boxes modulate space airflow to meet both space conditioning and ventilation requirements, the return air fan, exhaust air fan, and outside air fan must all adjust their speed to match these requirements as well. Then, since the airflow condition is changing, the rooftop unit's packaged heating and cooling coils much be modulated to meet the conditioning requirements of the outside air being brought into the building. These coils are controlled by temperature sensors placed up and downstream of the heating and cooling coils. This allows for the coils to adjust control valves that modulate their flow to meet the current system demand. This will help to ensure that air will always be delivered from the rooftop units at 55 degrees F and 50% relative humidity.

Finally, the rooftop units are equipped with an economizer that allows for the potential of 'free cooling'. When outside air conditions are right, or in a specific range around design supply set points, an economizer cycle will be activated. This economizer cycle will allow more outside air into the system through predefined control logic. Since the outside air is at a set point that requires little to no other conditioning, instead of conditioning the return air back down to set point conditions of 55 degress F and 50% RH, more outside air is allowed in, and more return air is exhausted. Also, the enthalpy wheel is coordinated to stop operation at these conditions, since the outside air is already close to desirable set point conditions. The economizer also acts as an override to minimum ventilation system airflow requirements, since it will be naturally providing more air than is necessary to building spaces.

As well, the boiler system is equipped with variable speed pumps that control the overall flow to the hot water system, depending upon needs of the individual heating coils. Constant speed pumps are provided that serve the boilers (see figure six, HWP 1A, 1B, 2A, and 2B) which will constantly provide system pumping requirements. Then, a system bypass is provided to allow for the variable speed pumps (see figure six, HWP 3 and 4), to modulate flow while still having a balanced system. Finally, the boilers will monitor entering and leaving water temperatures, and they will modulate their delivered heat output to ensure that the leaving water temperature is maintained at a 180 degree F set point. By reducing the amount of hot water supplied based upon the specific loading conditions for the individuals spaces, energy can be saved by providing what is needed, and pumping energy can be saved by not pumping more hot water than the spaces call for.

Finally, the chillers in the Gaige Building are all separate, air-cooled chillers, and all are controlled separately. For the rooftop units, each is provided with an internal condenser coil and scroll compressor. The compressor is then modulated to meet the required cooling load of the unit. The leaving air temperature is monitored from the rooftop unit, and if it changes from 55 degrees F, then the compressor will modulate to meet the current load. For each of the individual air conditioning units in the telecommunications rooms, the unit is served by a separate roof mounted air-cooled chiller, as can be seen in figure seven, the chiller schematic. The cooling capacity of the chiller modulates the temperature of the refrigerant being delivered to the air conditioning unit to meet specific space conditions. A thermostat is placed in the zone, and that thermostat communicates with the chiller to modulate refrigerant temperature, and in return, supply air temperature. Some of the air conditioning units are also equipped with a supply fan that has multiple speeds, to increase the level of control and flexibility. The different fan speeds are tied into the control logic to ensure that the proper space conditioning is being provided.

Mechanical Operation History

From the Gaige Building, the modeling done for the design of the building is important, but the most valuable energy information can be found in actual energy bills from the building. The COO at Penn State Berks was contacted, and below is the energy consumption information provided for the Gaige Building. First, in figure eight, the overall utility cost for the Gaige Building for the past year is given. Then, both natural gas and electricity are shown separately in figures nine and ten.

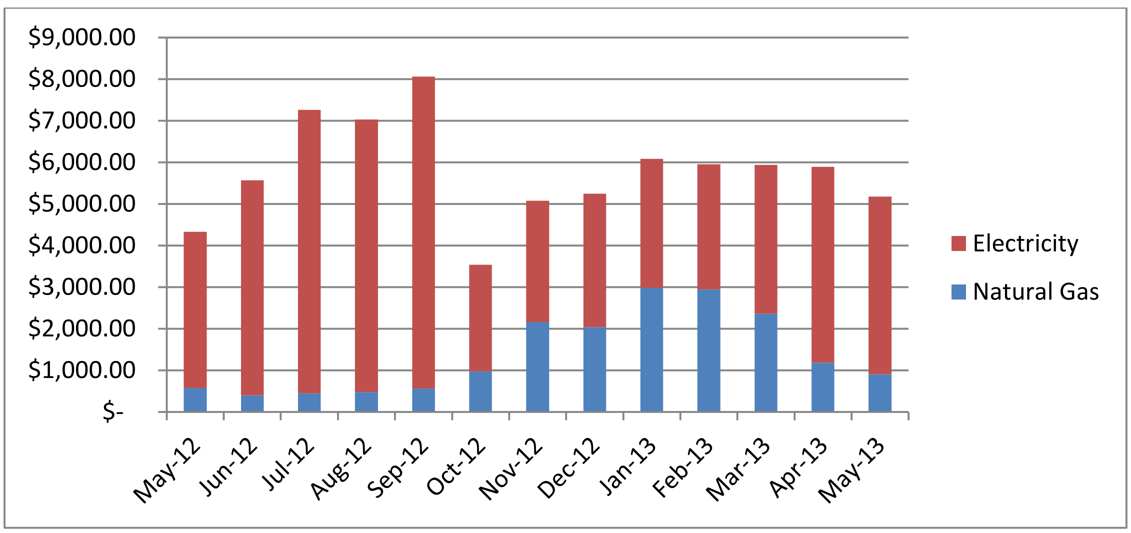

Figure 8: Actual utility cost for the Gaige building from May 2012 to May 2013

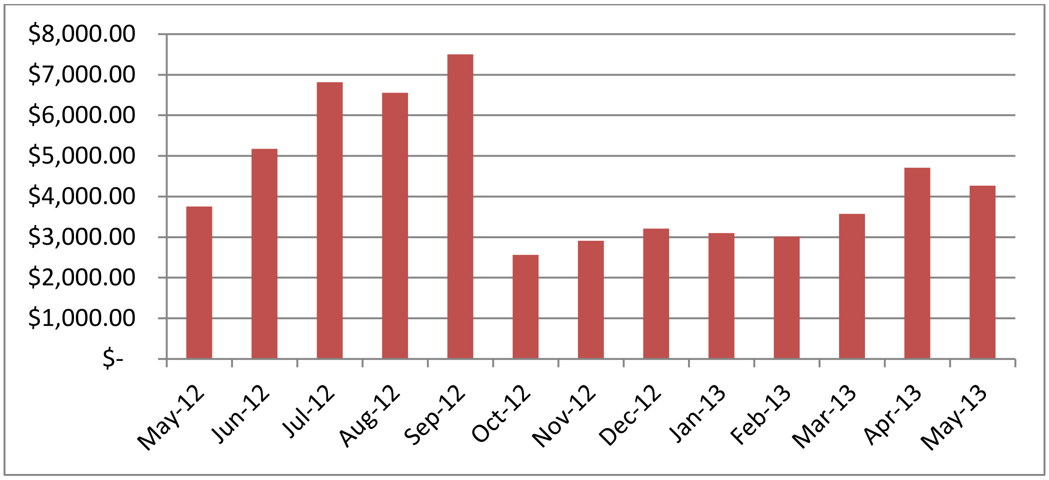

Figure 9: Actual electricity utility cost for the Gaige building from May 2012 to May 2013

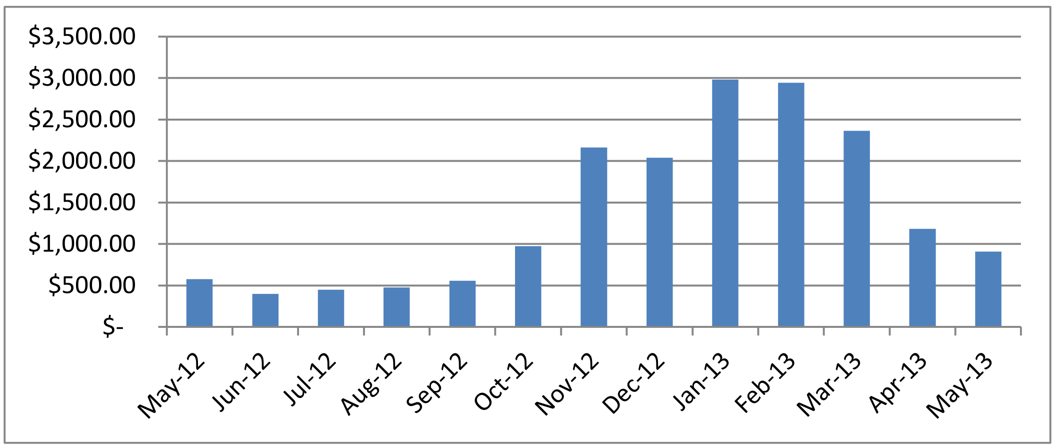

Figure 10: Actual natural gas utility cost for the Gaige building from May 2012 to May 2013

Once this new data was obtained, first, new cost factors were input into the previous Trace 700 model. The new natural gas and electricity costs were taken to be the average of the costs from the past year of data, and then the annual energy costs were estimated. Below, in table nineteen, the modeled results with the updated utility costs are compared to the actual charges from the Gaige building bills from June 2012 to May 2013.

Annual Energy Cost Information		
Modeled (Trace 700)		
Natural Gas	$	23,396.00
Electricity	$	85,404.00
Actual Cost from Billing		
Natural Gas	$	17,431.31
Electricity	$	53,390.19

Table 19: Annual energy costs for both the Trace 700 model and actual data from the Gaige Building

As in can be seen in the table above, the natural gas ends up being very reasonable, but the electricity consumption is over predicted. Knowing that the major electrical loads are due to cooling equipment and for electricity receptacle loads, to determine where the short falling occurs, a plot showing the electrical demand per month is need. By showing both modeled and actual demand on a monthly basis, it can be seen whether this short coming is seen in the winter months, when cooling is needed, or if it is a consistent year round under prediction, which would be due to an error in receptacle loads most likely. This evaluation is shown below in figure eleven. Also, the same comparison is given for natural gas consumption in figure twelve.

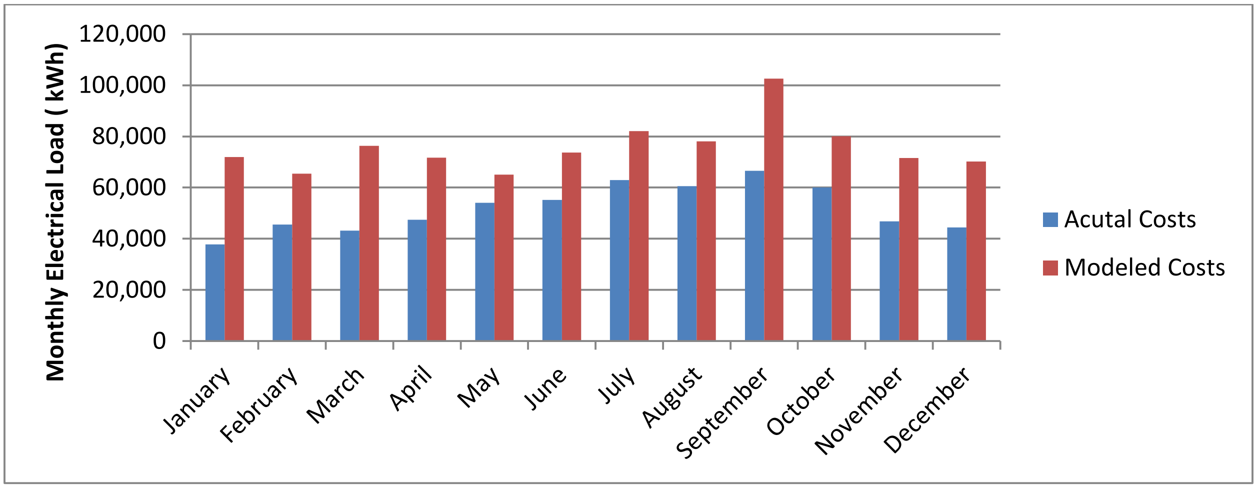

Figure 11: Actual vs. modeled electricity consumption on the monthly basis

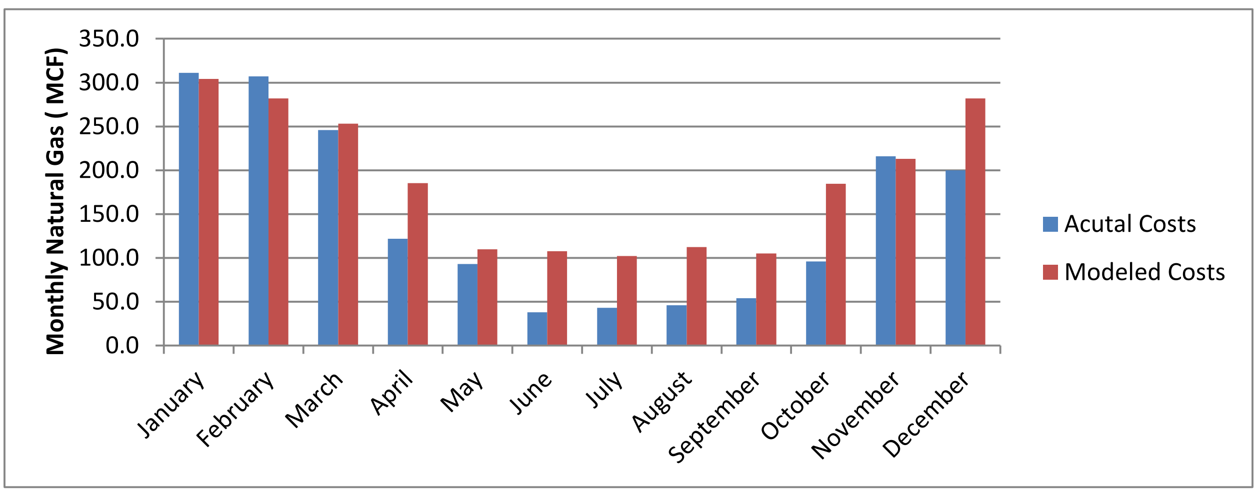

Figure 12: Actual vs. modeled natural gas consumption on a monthly basis

After this comparison, it is clear that some of the over prediction of the natural gas consumption is probably due to a load that is present during the summer months of June, July, and August that should not be present. The main take away from this analysis is the difference in the electrical loads. It seems that the electrical load overestimation is mainly due to an overestimation of receptacle like loads. It can be seen that the most difference is found during the months from November through March, where the receptacle loads will dominate the electricity consumption since cooling is not as high during the summer months. Further work must be done to verify exactly what assumption is not correct in the cooling data inputs into the model vs. the electrical receptacle loads. With further validation, an accurate and valid model of the Gaige Builidng can be replicated. Once this is done, the model can be used to further analyze and determine the validity of various design changes to the Gaige Building.

Once the various loading issues are resolved, a model of the Gaige Building will be created using standard construction types, glazing amounts, and system design that is outlined in ASHRAE standard 62.1 and 90.1. With this model, the design and future design changes for the Gaige Building can be compared against an ASHRAE standard building. As well, this will help to assess the future requirements associated with LEED and the 30% reduction from the ASHRAE Baseline construction required by Penn State. The modeling analysis for this report will be very useful in future analysis of the Gaige Building and future analysis of changes in the Gaige Building's design.

Existing Mechanical System Summary

Overall, the current mechanical system well reflects the guidelines set forth in the design of the Gaige Building. First, it adequately meets baseline requirements for ventilation, and the heating, cooling, and airflow systems incorporate variable speed pumps and variable air volume boxes to help provide more energy efficiency to the building's design. As well, an enthalpy wheel helps to recapture energy that would normally be exhausted. An economizer cycle is also provided to capture the potential for 'free cooling' from the outside air temperature. Finally, a very key state of the art building automation system is provided, which provides much communication from zone loads to overall system equipment. This advanced communication helps to improve the overall energy efficiency of the system. Despite the fact that the system 'lives up' to standards set forth, that is not to say that various improvements could be made to the design.

With this system, various improvements can be seen. First, most of the cooling for the entire building is provided by individual compressors in the specific rooftop units, and with individual air-cooled chillers serving the individual air conditioning units for the telecommunication and server rooms. A centralized chiller should be considered to determine if any efficiency could be gained. This efficiency increase will have to be balanced with the smaller size of the building, reducing the gains possible from efficiency increases, along with the increase in initial first-costs. Also, I recommend that geothermal heating and cooling be looked into for this building. The Berks campus is located in an area that has additional site that could be used for these wells, and its location in Pennsylvania is a good location for favorable geothermal ground temperatures. This switch to geothermal would drastically reduce the energy demands for the building, although, it would increase the initial system costs. The benefit of this system should be analyzed in further work.

Finally, for the centralized cooling and geothermal proposals, I recommend that not only a building wide analysis be conducted, but a campus wide analysis be conducted for the Penn State Berks campus. By combining all the buildings into one central geothermal well system, or by simply providing centralized heating and cooling for the entire campus from a central location, much more drastic energy efficiency could be seen, through economies of scale. As well, buildings with differing load profiles and schedules, for example a classroom building and a dormitory building, could combine to produce an overall campus load profile that is much flatter throughout the day and year, allowing a central system to operate in a more constant range, at peak equipment efficiencies. All of this will need to be thoroughly analyzed in future work.

LEED Analysis

The Leadership in Energy Efficient Design (LEED) Rating System for New Construction aims to transform the built environment through the promotion of environmentally conscious choices during building design and construction. The following report is a summary of the Gaige Building's design in comparison to the LEED rating system. This report identifies each credit area possible in the LEED rating system, identifies the Gaige Building's compliance with the requirement, and presents a total number of credits earned through the rating system. After construction and review, the Gaige Building was awarded LEED Gold rating through the system. This is a difficult achievement, and below will be discussed how this rating was earned. The rating system used in this report is for the current edition of LEED, so there are slight differences between the rating system for the design of the Gaige Building and the ratings system in which this building was judged. The differences and are discussed and newly proposed methods of research the same LEED Gold rating is proposed as well.

Sustainable Sites

Below is a summary of the credits earned in the LEED rating system's sustainable sites category. In order to achieve any credits in this category, the one prerequisite must be met. Overall, the Gaige Building was able to achieve eleven credits in sustainable sites.

Total Earned: 11 Points

Prerequisite 1: Construction Activity Pollution Prevention

In the Gaige Building's design, plans were put in place to adequately control pollution, soil erosion, water sedimentation, and airborne dust generation during construction activities. This was demonstrated through the submittal of a LEED template during design, and a control narrative, describing, planning, and outlining what would be, and was, done to prevent such problems.

Points Achieved: 0 of 0 (Required)

Credit 1: Site Selection

The site of the Gaige Building does not meet any of the prohibited site requirements set forth in this credit of the LEED rating system.

Points Achieved: 1 of 1

Credit 2: Development Density and Community Connectivity

Due to the lack of the Gaige Building's proximity to a large urban community, or its close proximity to housing, basic services, and location of a previously developed site, the Gaige Building could not comply with these credit requirements.

Points Achieved: 0 of 5

Credit 3: Brownfield Redevelopment

The site on which the Gaige Building was to be constructed was not deemed contaminated or defined as a brownfield site, so no credits could be earned for this category.

Points Achieved: 0 of 1

Credit 4.1: Alternative Transportation—Public Transportation Access

Due to the strict site constraints on the Gaige Building, since it had to be located on the Penn State Berks Campus, the site is not in proximity to public transportation access. This does not allow the Gaige Building to qualify for any credits for alternative transportation.

Points Achieved: 0 of 6

Credit 4.2: Alternative Transportation—Bicycle Storage and Changing Rooms

The Gaige Building did not seek to provide any bicycle changing rooms in its design, so it did not earn any credits from credit 4.2.

Points Achieved: 0 of 1

Credit 4.3: Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles

In the design of the Gaige Building, three preferred parking spaces are provided for fuel efficient vehicles. This parking meets the 5% of total vehicle parking capacity for the building, so the three credits are earned. Since this parking could be used for multiple buildings, this is taken into account for the LEED credit 4.3 calculations for compliance.

Points Achieved: 3 of 3

Credit 4.4: Alternative Transportation—Parking Capacity

For the site at the Gaige Building, no new parking spaces were added to the site for the construction of the Gaige Buildings, which meets the requirements for these credits through option three explained in this credit.

Points Achieved: 2 of 2

Credit 5.1: Site Development—Protect or Restore Habit

During construction and design of the Gaige Building, this credit was sought out, but no credits were awarded upon review. The owner, the Pennsylvania State University, set aside 48,580 SF of combined site and off-site area as space to be planted with native or adaptive species. Included in this area is a large portion of adjacent woodlands that is to be preserved during the life of the building. It was determined that using off-site space is not the intent of this credit, and therefore, no points were awarded.

Points Achieved: 0 of 1

Credit 5.2: Site Development—Maximize Open Space

For this credit, the minimum requirements for open space on a site must be exceeded by 25% to gain compliance with this credit. On the site of the Gaige Building, 71,020 SF of open space is provided. According to the local code requirements, this minimum requirement is exceeded by 130.2%, far surpassing that goal.

Points Achieved: 1 of 1

Credit 6.1: Stormwater Design—Quantity Control

A stormwater management plan for the Gaige Building demonstrates that through the proposed design, there will be no net increase in runoff, as compared to calculations made based upon pre-project conditions. These calculations were based upon the one and two year 24 hour storm events. With these design considerations, this credit's requirements are satisfied.

Points Achieved: 1 of 1

Credit 6.2: Stormwater Design—Quality Control

The Gaige Building includes a stormwater management system that captures at least 90% of the annual rainfall that becomes runoff. With this collection, the captured rainwater is also treated so that at least 80% of the post-development total suspended solids are removed.

Points Achieved: 1 of 1

Credit 7.1: Heat Island Effect—Non-roof

Of the non-roof paving materials, 59.22% are highly reflective materials, reducing the heat island effect caused by the site. 14,440 SF of the 24,380 SF of total non-roof impervious surfaces are paved with non-colored concrete, which meets these requirements.

Points Achieved: 1 of 1

Credit 7.2: Heat Island Effect—Roof

For the Gaige Building, SRI approved roofing material is used in the design of the building's roof. Excluding openings from mechanical equipment, 87.88% of the roof uses this compliant material, satisfying the 75% requirement for this credit.

Points Achieved: 1 of 1

Credit 8: Light Pollution Reduction

Controls to provide for reduced power to lights within sight of building openings are not provided in the Gaige Building. Also, no controls to provide for shading of building openings between 11pm and 5am are given, so this credits is not earned by the Gaige Building.

Points Achieved: 0 of 1

Water Efficiency

This next section outlines how the current design of the Gaige Building satisfies the credit requirements from the water efficiency section of the LEED rating system for new construction and significant building renovations. First, the required prerequisites are stated, and then compliance with each credit is evaluated. A final total of ten points was earned in this category

Total Earned: 10 Points

Prerequisite 1: Water Use Reduction

The Gaige Building meets the 20% aggregate reduction for water use. The mere fact that the Gaige Building complies for more strict credits requirements, such as credits for water use reduction, demonstrates its compliance. Potable water use for the site has been reduced by 92.7%. Overall, much more than a 20% reduction is achieved.

Points Achieved: 0 of 0 (Required)

Credit 1: Water Efficient Landscaping

No permanent irrigation system was included in the design of the building, therefore, this eliminates the potable water consumption of the building for landscape maintenance. As well, a plan is provided for the temporary irrigation of plants during the initial planting period, which also provides to meet this credit requirement. As well, the temporary requirement does not exceed the 18 month allowed period, so that four credits can be earned.

Points Achieved: 4 of 4

Credit 2: Innovative Wastewater Technologies

The Gaige Building, through many different strategies, has reduced its wastewater potable water consumption by 100%. Through the use of low-flow fixtures and through the rainwater storage and reuse system, no potable water will be required for this building's wastewater, therefore far exceeding the 50% requirement set forth by this credit.

Points Achieved: 2 of 2

Credit 3: Water Use Reduction

Since the wastewater has been so far reduced, the aggregate water use reduction is calculated to be 92.7% overall. This far exceeds the requirements set forth is this credit. To earn the total four credits, a 40% reduction must be achieved, which is met.

Points Achieved: 4 of 4

Energy and Atmosphere

The following section outlines strategies utilized by the Gaige Building for compliance with the credits associated with the energy and atmosphere section of the LEED 2009 Rating System for New Construction. This section primarily focuses on energy consumption and generation associated with the Gaige Building, control of refrigerants, and control of building loads. Below is a summary of these credits and the Gaige Building's compliance. A final total of eight credits is earned in this category.

Total Earned: 8 Points

Prerequisite 1: Fundamental Commissioning of Building Energy Systems

The specified LEED fundamental commissioning requirements are provided for and met by the Gaige Building. A narrative prepared during building design and a report containing the results from the commissioning process was created and provided. Finally, post construction, the commissioning plan and field report were provided to meet the requirements for this prerequisite.

Points Achieved: 0 of 0 (Required)

Prerequisite 2: Minimum Energy Performance

To achieve this credit, buildings must be compliant with sections 5.4, 6.4, 7.4, 8.4, 9.4, and 10.4 of ASHRAE Standard 90.1-2004. This requires that a model of the building demonstrate satisfactory completion of this requirement. As found in previous technical reports, the building is in compliance with these sections of ASHRAE 90.1. As well, from previous technical reports, H.F. Lenz Company created a Carrier HAP model of the building to prove that the building performs better than a baseline model construction. The Gaige Building far meets the 10% reduction from ASHRAE Standard 90.1 baseline requirements.

Points Achieved: 0 of 0 (Required)

Prerequisite 3: Fundamental Refrigerant Management

Refrigerant chosen for the Gaige Building are not prohibited refrigerants outlined in this credit (CFC based), not contributing towards the stratospheric ozone depletion.

Points Achieved: 0 of 0 (Required)

Credit 1: Optimize Energy Performance

For this credit, the whole building energy simulation compliance path was chosen, using the previously mentioned Carrier HAP model to prove compliance with this credit. After review from the building's energy model, a total reduction of building energy was found to be 23.6%. With this energy reduction, as proven by the energy model, it qualifies the Gaige Building for a total of six credits earned.

Points Achieved: 6 of 19

Credit 2: On-site Renewable Energy

No on-site renewable energy sources were included in the design of the Gaige Building, so no credits for this category are earned.

Points Achieved: 0 of 7

Credit 3: Enhanced Commissioning

The enhanced commissioning requirements for this credit are met by the Gaige Building. A copy of the commissioning contract was also submitted as proof of these requirements. As well, the commissioning agent for the project is a qualified according to the qualifications set out in this credit.

Points Achieved: 2 of 2

Credit 4: Enhanced Refrigerant Management

Refrigerants were used in the construction of the Gaige Building, so option one was not met. As well, option two for compliance with this credit was not pursued, so no credits were awarded.

Points Achieved: 0 of 2

Credit 5: Measurement and Verification

No measurement or verification system is in place to monitor the energy use of the building to meet requirements set forth by credit five. Therefore, no credits are awarded.

Points Achieved: 0 of 3

Credit 6: Green Power

No contracts are set up to purchase green power, generated from green sources, for a portion of the building's energy consumption. This does not allow any credits to be awarded to the Gaige Building.

Points Achieved: 0 of 2

Materials and Resources

The materials and resources of the LEED rating system aims to encourage the use of existing building resources during renovations, and the use of recycled content in new construction and major renovations to existing buildings. Also, this section encourages the limiting and proper management and disposal of construction based waste. Below outlines the Gaige Building's compliance with the materials and resources credits, as well as the prerequisite. Five points were earned from this section.

Total Earned: 5 Points

Prerequisite 1: Storage and Collection of Recyclables

Properly sized and located areas dedicated to the collection and storage of recycled materials, providing for the collection of cardboard, paper, plastic, glass, and metals. A narrative describing the recycling strategy as well as a photograph has been provided to demonstrate compliance.

Points Achieved: 0 of 0 (Required)

Credit 1.1: Building Reuse—Maintain Existing Walls, Floors, and Roof

Since the Gaige Building was a new construction, no credits could be earned in this category. No exiting building was available for reuse.

Points Achieved: 0 of 3

Credit 1.2: Building Reuse—Maintain Existing Interior Nonstructural Elements

Since the Gaige Building was a new construction, no credits could be earned in this category. No exiting building was available for reuse.

Points Achieved: 0 of 1

Credit 2: Construction Waste Management

Using calculations based on a project specific diversion rate, the Gaige Building diverts 525,380 tons of on-site generated waste from landfills. This amount comes in at 85% of this total waste, which qualifies the Gaige Building for two credits in this category. A narrative for the project was submitted for waste management, to help demonstrate compliance.

Points Achieved: 2 of 2

Credit 3: Materials Reuse

No significant amounts of salvaged, refurbished, or reused building materials were included in the design of the Gaige Building. Without these materials, the five or ten percent of total building materials was not satisfied, so no credits were earned for this category.

Points Achieved: 0 of 2

Credit 4: Recycled Content

In the details of the Gaige Building's design, 20.38% of the materials used have been manufactured using recycled materials. This number is calculated based upon value of the material. A narrative along with the architects cost estimate and proper manufacturer certification of all recycled materials have been provided to ensure compliance. With this credit, two points were awarded towards LEED certification.

Points Achieved: 2 of 2

Credit 5: Regional Materials

From initial calculations, it was shown that 21.34% of the building's materials can be deemed as regional materials, coming from within 500 miles of the project site. On further determination of compliance, it was seen that not all materials provided proper documentation. With the materials that lacked proper documentation removed from the calculation, only 18.96% of the materials can be proven to be considered regional materials, allowing for one credit to be earned.

Points Achieved: 1 of 2

Credit 6: Rapidly Renewable Materials

This credit was not sought out in the construction of the Gaige Building. The 2.5% minimum requirement for use of rapidly renewable materials was not met, and no credits were pursued or earned for this category.

Points Achieved: 0 of 1

Credit 7: Certified Wood

The wood-based materials in the Gaige Building were not chosen to be certified according to the Forest Stewardship Council's principles and criteria, so no credits were earned in this category.

Points Achieved: 0 of 1

Indoor Environmental Quality

The indoor environmental quality section of the LEED rating system aims to ensure a healthy and quality indoor environmental quality. This section addresses indoor air quality, thermal comfort, day lighting, and verification and monitoring of this quality. Below is a section describing each credit, addressing the different areas of overall indoor environmental quality. Below, the Gaige Building's compliance with each of the credits is discussed.

Total Earned: 11 Points

Prerequisite 1: Minimum Indoor Air Quality Performance

The Gaige Building is in compliance with the minimum requirements set forth in ASHRAE Standard 62.1-2004, which qualifies the Gaige Building to meet requirements for credits in the indoor environmental quality section.

Points Achieved: 0 of 0 (Required)

Prerequisite 2: Environmental Tobacco Smoke (ETS) Control

The Gaige Building is classified as an ETS free environment, not allowing smoking within the building. Also, all designated smoking areas outside of the building are at a minimum of 25 feet from all building entries, air intakes, and operable windows. This qualifies the Gaige Building to meet this prerequisite for credits from the indoor environment quality section.

Points Achieved: 0 of 0 (Required)

Credit 1: Outdoor Air Delivery Monitoring

Carbon Dioxide concentrations are monitored using CO2 sensors in all densely populated spaces within the Gaige Building. As well airflow measurement devices are provided for each ventilation system for less densely populated spaces. Monitoring systems will also provide an alarm if conditions vary from 10% of the design set points. These features of the design meet the requirements for the credit.

Points Achieved: 1 of 1

Credit 2: Increased Ventilation

No effort was made to increase the ventilation rate for the Gaige Building above standards set in ASHRAE Standard 62.1. Thus, the credit for increased ventilation was not earned.

Points Achieved: 0 of 1

Credit 3.1: Construction Indoor Air Quality Management Plan—During Construction

An indoor air quality management plan made according to SMACNA guidelines. All conditioning units in operation during construction were run with a minimum filtration rating of MERV-8. As well, once construction was completed, the air filters for equipment run during construction were replaced to their design values for building operation. Finally, photographs highlighting the indoor environmental quality practices during construction were provided to demonstrate the compliance with this credit.

Points Achieved: 1 of 1

Credit 3.2: Construction Indoor Air Quality Management Plan—Before Occupancy

Before initial occupancy of the building, the ventilation system provided the building with a minimum of 3,500 cubic feet of outdoor air per square foot of the Gaige Building's floor area. This was in compliance with LEED for the version of the rating system when the building was constructed. If this rating system would have been required, the Gaige Building could easily be adjusted to allow for the newly required 4,500 cubic feet per square foot. As well, the minimum ventilation flow rates, or at least 0.3 CFM/SF until a total of 14,000 cubic feet per square foot of the building had been reached after occupancy of the building.

Points Achieved: 1 of 1

Credit 4.1: Low-Emitting Materials—Adhesives and Sealants

All indoor adhesives and sealants in the design and construction of the Gaige Building are within compliance with VOC limits of referenced standards by the LEED rating system. Therefore, the credit for adhesives and sealants is met.

Points Achieved: 1 of 1

Credit 4.2: Low-Emitting Materials—Paints and Coatings

All paints and coatings used in the Gaige Building satisfy maximum allowable VOC requirements allowed for compliance with this credit. Therefore, this credit is achieved.

Points Achieved: 1 of 1

Credit 4.3: Low-Emitting Materials—Flooring Systems

All carpets specified and installed in the Gaige Building are in compliance with the CRI Green Label Plus Program, and no carpet pads are used, so the Gaige Building qualifies for this credit.

Points Achieved: 1 of 1

Credit 4.4: Low-Emitting Materials—Composite Wood and Agrifiber Products

Indoor wood and agrifiber products in the Gaige Building, and other composites, do not contain any added urea-formaldehyde. Documentation was provided to document the compliance of this credit.

Points Achieved: 1 of 1

Credit 5: Indoor Chemical and Pollutant Source Control

All entryways, room separations, and ventilation systems utilize the required control measures for chemical and pollutants as specified for compliance with this credit. This prevents cross-contamination between building spaces and the outdoors.

Points Achieved: 1 of 1

Credit 6.1: Controllability of Systems—Lighting

According to the Gaige Building's design, 100% of all occupants are able to adjust lighting levels to suit individual preferences and tasks. As well, the shared multi-occupant spaces provide for enough lighting controls to suit the activities to be performed within the specified space. These controllability measures meet the requirements to earn this credit.

Points Achieved: 1 of 1

Credit 6.2: Controllability of Systems—Thermal Comfort

Although thermal comfort control systems are provided within the Gaige Building, they do not meet up to the 50% controllability of the building's occupants. Many of the offices in the Gaige Building are grouped in pairs of three, so only one setting can be used for each group of offices. Since this level of controllability is not provided, this credit is not awarded.

Points Achieved: 0 of 1

Credit 7.1: Thermal Comfort—Design

Since this Gaige Building was designed in accordance with ASHRAE Standard 55, the project meets the specified requirements for this credit. As well, a narrative was provided specifying how this building was designed in accordance with this criteria.

Points Achieved: 1 of 1

Credit 7.2: Thermal Comfort—Verification

Although certain monitoring systems are provided for the Gaige Building, no thermal comfort monitoring system is provided. Therefore, this credit is not achieved.

Points Achieved: 0 of 1

Credit 8.1: Daylight and Views—Daylight

From the design of the Gaige Building, it is calculated that at minimum of 81.11% of all of the regularly occupied spaces in the Gaige Building are provided with at least 25 footcandles. This meets the 75% minimum requirement specified for this credit.

Points Achieved: 1 of 1

Credit 8.2: Daylight and Views—Views

Although much daylight is included in the Gaige Building, the building does not meet the minimum requirement of providing direct access to daylight views in 90% of the building's occupied spaces. Since this is not provided, the credit is not achieved.

Points Achieved: 0 of 1

Innovation in Design

The section below identifies the credits earned by the Gaige Building for innovations in the building's design. One credit, for a total of up to five credits, can be earned for each innovation, above and beyond that specified in the current LEED rating system. Each of these credits is described below, as well as an additional credit if a LEED accredited professional in a principle member of the design team.

Total Earned: 5 Points

Credit 1: Innovation in Design

For the innovation in design credits, a point can be earned for each technological innovation incorporated into the design of the Gaige Building, for up to a total of five credits. First, one credit for the Gaige Building is earned through the innovative and exemplary compliance for the water efficiency credit number two. The potable water savings goal of 100% demonstrates such an innovation in design. As well, for credit number three in water efficiency, since the potable water use for sewage conveyance was reduced by 92.7%, this also qualifies for a second credit in innovation in design for the Gaige Building.

Also, one more credit was pursed, creating integration between the technologies used in the Gaige Building and education. First, a program was incorporated into the Penn State Berks curriculum to design the signage that would be used in the Gaige Building. This would promote the educational value of the green building features of the project. Also, to achieve an innovation credit for education, an additional requirement was to plan a guided tour for the Gaige Building to educate others visiting the building. With these programs, one innovation in design credit was earned. Finally, a green housekeeping program was developed and implemented at the Gagie Building. This program includes custodial training, written operation requirements for staff, and standards by which to measure whether certain products, progress and goals are being achieved through the programs operation. This final credit brings the Gaige Building up to a total of four credits for innovation in design.

Points Achieved: 4 of 5

Credit 2: LEED Accredited Professional

The Gaige Building was designed, and LEED certification was achieved using a LEED accredited professional. This inclusion of such a certified professional meets the requirements for this credit.

Points Achieved: 1 of 1

Regional Priority

This section discussed the regional priority credits as defined by the United States Green Building Council. These credits are not new credit requirements, but additional credits can be earned based upon a projects location and what credits it has already completed. For each area, six priority credit areas are defined, and one extra point can be earned for each priority credit that is met by the building. Below is a summary of this compliance for the Gaige Building.

Total Earned: 3 Points

Credit 1: Regional Priority

For the Gaige Building, according to the LEED database for regional priority credits online, the following six categories are deemed as a priority based upon the location of the Gaige Building: Optimize Energy Performance, On-Site Renewable Energy, Alternative Transportation-Public Transportation Access, Site Development-Protect or Restore Habitat, Stormwater Design-Quality Control, and Innovative Wastewater Technologies. Of these credits, the Gaige Building met the requirements for credits earned in the Optimize energy Performance, Stormwater Design-Quality Control, and Innovative Wastewater Technologies. With these credits met, three extra regional priority credits can be claimed.

Points Achieved: 3 of 4

LEED Summary

Below is a table that summarized the overall compliance of the Gaige Building in terms of the LEED 2009 Rating System for New Construction.

Credit Category	Credits Earned
Sustainable Sites	11 points
Water Efficiency	10 points
Energy and Atmosphere	8 points
Materials and Resources	5 points
Indoor Environmental Quality	11 points
Innovation in Design	5 points
Regional Priority	3 points
Total Credits Earned:	**53 points**

From the overall LEED analysis, the Gaige Buidling earned a total of 53 points, qualifying it for LEED Silver certification. If seven more points could be earned, the Gaige Building would be able to achieve LEED Gold certification according to the LEED 2009 Rating System for New Construction. Under the previous version of the LEED Rating System, which was what the Gaige Building's LEED system, the Gaige Building achieved 39 points, qualifying it for LEED Gold rating. Due to the changes in the LEED rating system, if this building were to be designed and built now, it would not meet up to the LEED Gold standards.

If Gold certification were to be sought under the new system, various suggestions could help to earn the required seven points. First, the credits for Site Development-Protect or Restore Habitat should be pursued. Not only was this credit attempted and denied, this credit also would provide for a regional priority credit, increasing the rating by two points, up to 55 points overall. As well, since in the previous rating system, the maximum number of innovation in design credits was four, one more innovation in the Gaige Building's design could be claimed as the final fifth credit, increasing the total to 56. With proper documentation of the regional materials used on the project, one more credit for regional materials could be earned, bringing the total up to 57 points. Finally, it would be recommended that the additional 3 credits for LEED Gold certification come from Optimize energy Performance Credit. If the Building's energy reduction would increase from 23.6% to at least 28%, then LEED Gold rating could be achieved.

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Appendix A: Table 6.3 Ventilation Calculations

Ventilation Air CalculationsL: RTU-1														
Space	Space Type	A_z (SF)	P_z (people)	R_a (CFM/SF)	R_a*A_z (CFM)	R_p (CFM/person)	R_p*P_z (CFM)	V_{bz} (CFM)	E_z	V_{oz} (CFM)	V_{pz} (CFM)	Z_{pz}	E_v (zone)
Learning Loft Q206	Lounge	1499	30	0.18	269.82	7.5	225	495	0.8	619	2000	0.31	0.84
Resource Q205	Office	205	2	0.06	12.3	5	10	22	0.8	28	220	0.13	1.00
Classroom 244	Classroom	902	28	0.12	108.24	10	280	388	0.8	485	1200	0.40	0.75
Classroom 245	Classroom	856	31	0.12	102.72	10	310	413	0.8	516	1230	0.42	0.73
Classroom 246	Classroom	1269	58	0.12	152.28	10	580	732	0.8	915	1600	0.57	0.76
Classroom 247	Classroom	1010	46	0.12	121.2	10	460	581	0.8	727	1500	0.48	0.67
Classroom 248	Classroom	764	31	0.12	91.68	10	310	402	0.8	502	920	0.55	0.60
Classroom 249	Classroom	789	25	0.12	94.68	10	250	345	0.8	431	820	0.53	0.62
Learning Loft Q102	Lobby	2612	30	0.06	156.72	5	150	307	0.8	383	920	0.42	0.73
Corridor Q103	Corridor	478	0	0.06	28.68	0	0	29	0.8	36	100	0.36	0.79
Classroom 120	Classroom	805	31	0.12	96.6	10	310	407	0.8	508	1150	0.44	0.71
Classroom 121	Classroom	1587	60	0.12	190.44	10	600	790	0.8	988	1750	0.56	0.77
Seminar Classroom 122	Classroom	406	20	0.12	48.72	10	200	249	0.8	311	580	0.54	0.61
Bits & Bytes Café 123	Cafeteria	740	20	0.18	133.2	7.5	150	283	0.8	354	1200	0.30	0.86
HRIM Lab Kitchen 123A	Kitchen	492	2	0.12	59.04	7.5	15	74	0.8	93	260	0.36	0.79
Retail 123B	Cafeteria	191	2	0.12	22.92	10	20	43	0.8	54	270	0.20	0.95
Lobby F102	Lobby	635	5	0.06	38.1	5	25	63	0.8	79	500	0.16	0.99
Electrical Lab 116	Laboratory	804	21	0.18	144.72	10	210	355	0.8	443	780	0.57	0.84
Super/Assistant 115	Office	169	1	0.06	10.14	5	5	15	0.8	19	120	0.16	0.99
Equipment Storage 115A	Storage	307	0	0.12	36.84	0	0	37	0.8	46	150	0.31	0.84
Engineering Automation 114	Laboratory	1007	20	0.18	181.26	10	200	381	0.8	477	920	0.52	0.63
Electronics Lab 113	Laboratory	750	20	0.18	135	10	200	335	0.8	419	800	0.52	0.63
Learning Resource Center 111	Classroom	394	5	0.12	47.28	10	50	97	0.8	122	540	0.23	0.92
Lounge 111A	Lounge	315	5	0.18	56.7	7.5	37.5	94	0.8	118	500	0.24	0.91
Seminar Classroom 112	Classroom	501	25	0.12	60.12	10	250	310	0.8	388	700	0.55	0.78
	Totals:		**518**		**2399**		**4847.5**						

Summary for RTU-1	
Diversity (D):	100%
V_{ou} (CFM):	7247
Overall Ev (minimum):	0.60
Final V_{ot} (CFM):	11993

Ventilation Air CalculationsL: RTU-2														
Space	Space Type	A_z (SF)	P_z (people)	R_a (CFM/SF)	R_a*A_z (CFM)	R_p (CFM/person)	R_p*P_z (CFM)	V_{bz} (CFM)	E_z	V_{oz} (CFM)	V_{pz} (CFM)	Z_{pz}	E_v (zone)
Open Source Computer Lab 209	Computer Lab	712	17	0.12	85.44	10	170	255	0.8	319	740	0.43	0.72
Lobby F201	Lobby	444	5	0.06	26.64	5	25	52	0.8	65	120	0.54	0.61
Department Resource Q207	Lobby	288	0	0.06	17.28	5	0	17	0.8	22	50	0.43	0.72
Lobby F204	Lobby	87	0	0.06	5.22	5	0	5	0.8	7	30	0.22	0.93
Networking Computer Lab 208	Computer Lab	701	17	0.12	84.12	10	170	254	0.8	318	800	0.40	0.75
Server Room 207/IT Storage 207A	Storage	325	0	0.12	39	0	0	39	0.8	49	320	0.15	1.00
IT Storage 203	Storage	376	0	0.12	45.12	0	0	45	0.8	56	140	0.40	0.75
General Purpose Computer Lab 204	Computer Lab	1024	35	0.12	122.88	10	350	473	0.8	591	1200	0.49	0.66
Emerging Technology Lab 206	Laboratory	696	17	0.18	125.28	10	170	295	0.8	369	800	0.46	0.69
Corridor Q201	Corridor	980	0	0.06	58.8	0	0	59	0.8	74	260	0.28	0.87
General Purpose Computer Lab 205	Computer Lab	856	29	0.12	102.72	10	290	393	0.8	491	1320	0.37	0.78
Corridor Q101	Corridor	900	0	0.06	54	0	0	54	0.8	68	200	0.34	0.81
Corridor Q104	Corridor	310	0	0.06	18.6	0	0	19	0.8	23	90	0.26	0.89
Super/Assist Office 107	Office	102	1	0.06	6.12	5	5	11	0.8	14	70	0.20	0.95
Lobby F103	Lobby	465	5	0.06	27.9	5	25	53	0.8	66	140	0.47	0.68
Lobby F104	Lobby	105	0	0.06	6.3	5	0	6	0.8	8	30	0.26	0.89
Lobby F105	Lobby	106	0	0.06	6.36	5	0	6	0.8	8	30	0.27	0.89
Prototype Lab 108	Laboratory	1534	50	0.18	276.12	10	500	776	0.8	970	1750	0.5544	0.82
Receiving 109/Storage 109A	Shipping/Receiving	425	0	0.12	51	10	0	51	0.8	64	420	0.15	1.00
Design Lab 103	Laboratory	785	24	0.18	141.3	10	240	381	0.8	477	1000	0.48	0.67
Projects Lab 106	Laboratory	956	24	0.18	172.08	10	240	412	0.8	515	1000	0.52	0.63
Research Lab 104	Laboratory	518	20	0.18	93.24	10	200	293	0.8	367	690	0.53	0.62
Measurement Lab 105	Laboratory	975	24	0.18	175.5	10	240	416	0.8	519	1410	0.37	0.78
	Totals:		268		1741.02		2625						

Summary for RTU-3	
Diversity (D):	100%
V_{ou} (CFM):	**4366**
Overall Ev (minimum):	0.61
Final V_{ot} (CFM):	**7133**

Ventilation Air CalculationsL: RTU-3														
Space	Space Type	A_z (SF)	P_z (people)	R_a (CFM/SF)	R_a*A_z (CFM)	R_p (CFM/person)	R_p*P_z (CFM)	V_{bz} (CFM)	E_z	V_{oz} (CFM)	V_{pz} (CFM)	Z_{pz}	E_v (zone)
Faculty Office 336 & Q304	Office	509	1	0.06	30.5	5	5	35.5	1.0	35.5	155	0.23	0.92
Department Resource 328	Corridor	116	0	0.06	7.0	0	0	7.0	1.0	7.0	70	0.10	1.00
Faculty Office 333, 334 & 335	Office	277	3	0.06	16.6	5	15	31.6	1.0	31.6	330	0.10	1.00
Faculty Office 330, 331 & 332	Office	273	3	0.06	16.4	5	15	31.4	1.0	31.4	330	0.10	1.00
Faculty Office 329	Office	123	1	0.06	7.4	5	5	12.4	1.0	12.4	280	0.04	1.00
Conference 325	Conference	154	3	0.06	9.2	5	15	24.2	1.0	24.2	140	0.17	0.98
Faculty Office 324, 326 & 327	Office	294	5	0.06	17.6	5	25	42.6	1.0	42.6	360	0.12	1.00
Corridor Q303	Corridor	621	0	0.06	37.3	0	0	37.3	1.0	37.3	200	0.19	0.96
Lobby F301	Lobby	456	0	0.06	27.4	5	0	27.4	1.0	27.4	450	0.06	1.00
Lobby F304	Lobby	97	0	0.06	5.8	5	0	5.8	1.0	5.8	50	0.12	1.00
Corridor Q305	Corridor	99	0	0.06	5.9	0	0	5.9	1.0	5.9	50	0.12	1.00
Copy/Fax/Printer 322	Office	95	1	0.06	5.7	5	5	10.7	1.0	10.7	130	0.08	1.00
Faculty Office 319	Office	131	1	0.06	7.9	5	5	12.9	1.0	12.9	120	0.11	1.00
Corridor Q301	Corridor	800	0	0.06	48.0	0	0	48.0	1.0	48.0	240	0.20	0.95
Corridor Q306	Corridor	48	0	0.06	2.9	0	0	2.9	1.0	2.9	20	0.14	1.00
Corridor Q307A	Corridor	95	0	0.06	5.7	0	0	5.7	1.0	5.7	30	0.19	0.96
Faculty Office 320, 321, & 323	Office	299	3	0.06	17.9	5	15	32.9	1.0	32.9	360	0.09	1.00
Faculty Office 304	Office	114	1	0.06	6.8	5	5	11.8	1.0	11.8	110	0.11	1.00
Faculty Office 305 & 306	Office	221	2	0.06	13.3	5	10	23.3	1.0	23.3	320	0.07	1.00
Conference 317	Conference	150	3	0.06	9.0	5	15	24.0	1.0	24.0	120	0.20	0.95
PT Faculty Office 313	Office	133	1	0.06	8.0	5	5	13.0	1.0	13.0	100	0.13	1.00
Faculty Office 303 & 303A	Office	244	1	0.06	14.6	5	5	19.6	1.0	19.6	230	0.09	1.00
Conference 311A	Conference	150	3	0.06	9.0	5	15	24.0	1.0	24.0	120	0.20	0.95
Admin. Assistant 307A	Office	133	1	0.06	8.0	5	5	13.0	1.0	13.0	160	0.08	1.00
Chancellors Office 307B	Office	321	1	0.06	19.3	5	5	24.3	1.0	24.3	440	0.06	1.00
Reception 307	Reception Areas	476	4	0.06	28.6	5	20	48.6	1.0	48.6	330	0.15	1.00
Conference 311	Conference	205	4	0.06	12.3	5	20	32.3	1.0	32.3	200	0.16	0.99
Faculty Offices 315, 316, 318	Corridor	295	3	0.06	17.7	0	0	17.7	1.0	17.7	360	0.05	1.00
Faculty Office 310, 312 & 314	Corridor	285	3	0.06	17.1	0	0	17.1	1.0	17.1	360	0.05	1.00
Corridor Q202	Corridor	1307	0	0.06	78.4	0	0	78.4	1.0	78.4	220	0.36	0.79
Faculty Office 309	Office	115	1	0.06	6.9	5	5	11.9	1.0	11.9	165	0.07	1.00
Seminar Classroom 308	Classroom	634	25	0.12	76.1	10	250	326.1	1.0	326.1	1500	0.22	0.93
Storage 209A	Computer	100	1	0.06	6.0	5	5	11.0	1.0	11.0	150	0.07	1.00

Ventilation Air CalculationsL: RTU-3-continued														
Space	Space Type	A_z (SF)	P_z (people)	R_a (CFM/SF)	R_a*A_z (CFM)	R_p (CFM/person)	R_p*P_z (CFM)	V_{bz} (CFM)	E_z	V_{oz} (CFM)	V_{pz} (CFM)	Z_{pz}	E_v (zone)
Storage 210A	Storage	180	0	0.12	21.6	0	0	21.6	1.0	21.6	220	0.10	1.00
Admin. Assistant 210B	Office	182	1	0.06	10.9	5	5	15.9	1.0	15.9	220	0.07	1.00
Directors Office 210	Office	201	1	0.06	12.1	5	5	17.1	1.0	17.1	390	0.04	1.00
Faculty Office 211, 212 & 213	Office	260	3	0.06	15.6	5	15	30.6	1.0	30.6	330	0.09	1.00
Faculty Office 214, 215, & 216	Office	263	3	0.06	15.8	5	15	30.8	1.0	30.8	330	0.09	1.00
Faculty Office 219, 218 & 217	Office	261	3	0.06	15.7	5	15	30.7	1.0	30.7	420	0.07	1.00
Faculty Office 221, 223 & 224	Office	264	3	0.06	15.8	5	15	30.8	1.0	30.8	330	0.09	1.00
Faculty Office 220	Office	95	1	0.06	5.7	5	5	10.7	1.0	10.7	120	0.09	1.00
Mail Support 222	Shipping/Receiving	130	1	0.12	15.6	10	10	25.6	1.0	25.6	110	0.23	0.92
Faculty Office 226, 228 & 225	Office	277	3	0.06	16.6	5	15	31.6	1.0	31.6	330	0.10	1.00
PT Faculty Lounge 229	Lounge	292	1	0.18	0.0	7.5	7.5	60.1	1.0	60.1	440	0.14	1.00
Faculty Office 232, 233 & 230	Office	271	3	0.06	16.3	5	15	31.3	1.0	31.3	330	0.09	1.00
Conference 231	Conference	155	3	0.06	9.3	5	15	24.3	1.0	24.3	140	0.17	0.98
Faculty Office 236, 238, & 235	Office	262	3	0.06	15.7	5	15	30.7	1.0	30.7	330	0.09	1.00
Faculty Office 237, 239, & 241	Office	360	3	0.06	21.6	5	15	36.6	1.0	36.6	260	0.14	1.00
Faculty Office 242 & 240	Office	172	2	0.06	10.3	5	10	20.3	1.0	20.3	220	0.09	1.00
	Totals:		**109**		**818.8**		**647.5**						

Summary for RTU-3	
Diversity (D):	100%
V_{ou} (CFM):	**1466**
Overall Ev (minimum):	0.79
Final V_{ot} (CFM):	**1848**

Appendix B: Appendix A (62.1) Ventilation Calculaitons

Ventilation Air CalculationsL: RTU-1														
Space	Space Type	A_z (SF)	P_z (people)	R_a (CFM/SF)	R_a*A_z (CFM)	R_p (CFM/person)	R_p*P_z (CFM)	V_{bz} (CFM)	E_z	V_{oz} (CFM)	V_{pz} (CFM)	Z_{pz}	E_v (zone)
Learning Loft Q206	Lounge	1773	30	0.18	319.14	7.5	225	544	0.8	680	2000	0.34	1.01
Resource Q205	Office	205	2	0.06	12.3	5	10	22	0.8	28	220	0.13	1.23
Classroom 244	Classroom	902	28	0.12	108.24	10	280	388	0.8	485	1200	0.40	0.95
Classroom 245	Classroom	856	31	0.12	102.72	10	310	413	0.8	516	1230	0.42	0.93
Classroom 246	Classroom	1269	58	0.12	152.28	10	580	732	0.8	915	1600	0.57	0.78
Classroom 247	Classroom	1010	46	0.12	121.2	10	460	581	0.8	727	1500	0.48	0.87
Classroom 248	Classroom	764	31	0.12	91.68	10	310	402	0.8	502	920	0.55	0.81
Classroom 249	Classroom	789	25	0.12	94.68	10	250	345	0.8	431	820	0.53	0.83
Learning Loft Q102	Lobby	2884	30	0.06	173.04	5	150	323	0.8	404	920	0.44	0.91
Corridor Q103	Corridor	478	0	0.06	28.68	0	0	29	0.8	36	100	0.36	0.99
Classroom 120	Classroom	805	31	0.12	96.6	10	310	407	0.8	508	1150	0.44	0.91
Classroom 121	Classroom	1587	60	0.12	190.44	10	600	790	0.8	988	1750	0.56	0.79
Seminar Classroom 122	Classroom	406	20	0.12	48.72	10	200	249	0.8	311	580	0.54	0.82
Bits & Bytes Café 123	Cafeteria	740	20	0.18	133.2	7.5	150	283	0.8	354	1200	0.30	1.06
HRIM Lab Kitchen 123A	Kitchen	492	2	0.12	59.04	7.5	15	74	0.8	93	260	0.36	1.00
Retail 123B	Cafeteria	191	2	0.12	22.92	10	20	43	0.8	54	270	0.20	1.15
Lobby F102	Lobby	635	5	0.06	38.1	5	25	63	0.8	79	500	0.16	1.20
Electrical Lab 116	Laboratory	804	21	0.18	144.72	10	210	355	0.8	443	780	0.57	0.78
Super/Assistant 115	Office	169	1	0.06	10.14	5	5	15	0.8	19	120	0.16	1.20
Equipment Storage 115A	Storage	307	0	0.12	36.84	0	0	37	0.8	46	150	0.31	1.05
Engineering Automation 114	Laboratory	1007	20	0.18	181.26	10	200	381	0.8	477	920	0.52	0.83
Electronics Lab 113	Laboratory	750	20	0.18	135	10	200	335	0.8	419	800	0.52	0.83
Learning Resource Center 111	Classroom	394	5	0.12	47.28	10	50	97	0.8	122	540	0.23	1.13
Lounge 111A	Lounge	315	5	0.18	56.7	7.5	37.5	94	0.8	118	500	0.24	1.12
Seminar Classroom 112	Classroom	501	25	0.12	60.12	10	250	310	0.8	388	700	0.55	0.80
	Totals:		518		2465		4847.5				20730		

Summary for RTU-1	
Diversity (D):	100%
V_{ou} (CFM):	7313
Overall Ev (minimum):	0.78
Final V_{ot} (CFM):	9367

Ventilation Air CalculationsL: RTU-2														
Space	Space Type	A_z (SF)	P_z (people)	R_a (CFM/SF)	R_a*A_z (CFM)	R_p (CFM/person)	R_p*P_z (CFM)	V_{bz} (CFM)	E_z	V_{oz} (CFM)	V_{pz} (CFM)	Z_{pz}	E_v (zone) (Appendix A)
Open Source Computer Lab 209	Computer Lab	712	17	0.12	85.44	10	170	255	0.8	319	740	0.43	0.91
Lobby F201	Lobby	444	5	0.06	26.64	5	25	52	0.8	65	120	0.54	0.81
Department Resource Q207	Lobby	288	0	0.06	17.28	5	0	17	0.8	22	50	0.43	0.91
Lobby F204	Lobby	87	0	0.06	5.22	5	0	5	0.8	7	30	0.22	1.13
Networking Computer Lab 208	Computer Lab	701	17	0.12	84.12	10	170	254	0.8	318	800	0.40	0.95
Server Room 207/IT Storage 207A	Storage	325	0	0.12	39	0	0	39	0.8	49	320	0.15	1.19
IT Storage 203	Storage	376	0	0.12	45.12	0	0	45	0.8	56	140	0.40	0.94
General Purpose Computer Lab 204	Computer Lab	1024	35	0.12	122.88	10	350	473	0.8	591	1200	0.49	0.85
Emerging Technology Lab 206	Laboratory	696	17	0.18	125.28	10	170	295	0.8	369	800	0.46	0.88
Corridor Q201	Corridor	980	0	0.06	58.8	0	0	59	0.8	74	260	0.28	1.06
General Purpose Computer Lab 205	Computer Lab	856	29	0.12	102.72	10	290	393	0.8	491	1320	0.37	0.97
Corridor Q101	Corridor	900	0	0.06	54	0	0	54	0.8	68	200	0.34	1.01
Corridor Q104	Corridor	310	0	0.06	18.6	0	0	19	0.8	23	90	0.26	1.09
Super/Assist Office 107	Office	102	1	0.06	6.12	5	5	11	0.8	14	70	0.20	1.15
Lobby F103	Lobby	465	5	0.06	27.9	5	25	53	0.8	66	140	0.47	0.87
Lobby F104	Lobby	105	0	0.06	6.3	5	0	6	0.8	8	30	0.26	1.08
Lobby F105	Lobby	106	0	0.06	6.36	5	0	6	0.8	8	30	0.27	1.08
Prototype Lab 108	Laboratory	1534	50	0.18	276.12	10	500	776	0.8	970	1750	0.5544	0.7919
Receiving 109/Storage 109A	Shipping/Receiving	425	0	0.12	51	10	0	51	0.8	64	420	0.15	1.19
Design Lab 103	Laboratory	785	24	0.18	141.3	10	240	381	0.8	477	1000	0.48	0.87
Projects Lab 106	Laboratory	956	24	0.18	172.08	10	240	412	0.8	515	1000	0.52	0.83
Research Lab 104	Laboratory	518	20	0.18	93.24	10	200	293	0.8	367	690	0.53	0.82
Measurement Lab 105	Laboratory	975	24	0.18	175.5	10	240	416	0.8	519	1410	0.37	0.98
	Totals:		**268**		**1741.02**		**2625**				**12610**		

Summary for RTU-3	
Diversity (D):	100%
V_{ou} (CFM):	**4366**
Overall Ev (minimum):	0.79
Final V_{ot} (CFM):	**5514**

Ventilation Air CalculationsL: RTU-3														
Space	Space Type	A_z (SF)	P_z (people)	R_a (CFM/SF)	R_a*A_z (CFM)	R_p (CFM/person)	R_p*P_z (CFM)	V_{bz} (CFM)	E_z	V_{oz} (CFM)	V_{pz} (CFM)	Z_{pz}	E_v (zone)
Faculty Office 336 & Q304	Office	509	1	0.06	30.5	5	5	35.5	1.0	35.5	155	0.23	0.88
Department Resource 328	Corridor	116	0	0.06	7.0	0	0	7.0	1.0	7.0	70	0.10	1.01
Faculty Office 333, 334 & 335	Office	277	3	0.06	16.6	5	15	31.6	1.0	31.6	330	0.10	1.01
Faculty Office 330, 331 & 332	Office	273	3	0.06	16.4	5	15	31.4	1.0	31.4	330	0.10	1.01
Faculty Office 329	Office	123	1	0.06	7.4	5	5	12.4	1.0	12.4	280	0.04	1.07
Conference 325	Conference	154	3	0.06	9.2	5	15	24.2	1.0	24.2	140	0.17	0.94
Faculty Office 324, 326 & 327	Office	294	5	0.06	17.6	5	25	42.6	1.0	42.6	360	0.12	0.99
Corridor Q303	Corridor	621	0	0.06	37.3	0	0	37.3	1.0	37.3	200	0.19	0.92
Lobby F301	Lobby	456	0	0.06	27.4	5	0	27.4	1.0	27.4	450	0.06	1.05
Lobby F304	Lobby	97	0	0.06	5.8	5	0	5.8	1.0	5.8	50	0.12	0.99
Corridor Q305	Corridor	99	0	0.06	5.9	0	0	5.9	1.0	5.9	50	0.12	0.99
Copy/Fax/Printer 322	Office	95	1	0.06	5.7	5	5	10.7	1.0	10.7	130	0.08	1.03
Faculty Office 319	Office	131	1	0.06	7.9	5	5	12.9	1.0	12.9	120	0.11	1.00
Corridor Q301	Corridor	800	0	0.06	48.0	0	0	48.0	1.0	48.0	240	0.20	0.91
Corridor Q306	Corridor	48	0	0.06	2.9	0	0	2.9	1.0	2.9	20	0.14	0.97
Corridor Q307A	Corridor	95	0	0.06	5.7	0	0	5.7	1.0	5.7	30	0.19	0.92
Faculty Office 320, 321, & 323	Office	299	3	0.06	17.9	5	15	32.9	1.0	32.9	360	0.09	1.02
Faculty Office 304	Office	114	1	0.06	6.8	5	5	11.8	1.0	11.8	110	0.11	1.00
Faculty Office 305 & 306	Office	221	2	0.06	13.3	5	10	23.3	1.0	23.3	320	0.07	1.04
Conference 317	Conference	150	3	0.06	9.0	5	15	24.0	1.0	24.0	120	0.20	0.91
PT Faculty Office 313	Office	133	1	0.06	8.0	5	5	13.0	1.0	13.0	100	0.13	0.98
Faculty Office 303 & 303A	Office	244	1	0.06	14.6	5	5	19.6	1.0	19.6	230	0.09	1.02
Conference 311A	Conference	150	3	0.06	9.0	5	15	24.0	1.0	24.0	120	0.20	0.91
Admin. Assistant 307A	Office	133	1	0.06	8.0	5	5	13.0	1.0	13.0	160	0.08	1.03
Chancellors Office 307B	Office	321	1	0.06	19.3	5	5	24.3	1.0	24.3	440	0.06	1.05
Reception 307	Reception Areas	476	4	0.06	28.6	5	20	48.6	1.0	48.6	330	0.15	0.96
Conference 311	Conference	205	4	0.06	12.3	5	20	32.3	1.0	32.3	200	0.16	0.95
Faculty Offices 315, 316, 318	Corridor	295	3	0.06	17.7	0	0	17.7	1.0	17.7	360	0.05	1.06
Faculty Office 310, 312 & 314	Corridor	285	3	0.06	17.1	0	0	17.1	1.0	17.1	360	0.05	1.06
Corridor Q202	Corridor	895	0	0.06	53.7	0	0	53.7	1.0	53.7	220	0.24	0.87
Faculty Office 309	Office	115	1	0.06	6.9	5	5	11.9	1.0	11.9	165	0.07	1.04
Seminar Classroom 308	Classroom	634	25	0.12	76.1	10	250	326.1	1.0	326.1	1500	0.22	0.89
Storage 209A	Computer	100	1	0.06	6.0	5	5	11.0	1.0	11.0	150	0.07	1.04

Ventilation Air CalculationsL: RTU-3-continued															
Space	Space Type	A_z (SF)	P_z (people)	R_a (CFM/SF)	R_a*A_z (CFM)	R_p (CFM/person)	R_p*P_z (CFM)	V_{bz} (CFM)	E_z	V_{oz} (CFM)	V_{pz} (CFM)	Z_{pz}	E_v (zone)
Storage 210A	Storage	180	0	0.12	21.6	0	0	21.6	1.0	21.6	220	0.10	1.01
Admin. Assistant 210B	Office	182	1	0.06	10.9	5	5	15.9	1.0	15.9	220	0.07	1.04
Directors Office 210	Office	201	1	0.06	12.1	5	5	17.1	1.0	17.1	390	0.04	1.07
Faculty Office 211, 212 & 213	Office	260	3	0.06	15.6	5	15	30.6	1.0	30.6	330	0.09	1.02
Faculty Office 214, 215, & 216	Office	263	3	0.06	15.8	5	15	30.8	1.0	30.8	330	0.09	1.02
Faculty Office 219, 218 & 217	Office	261	3	0.06	15.7	5	15	30.7	1.0	30.7	420	0.07	1.04
Faculty Office 221, 223 & 224	Office	264	3	0.06	15.8	5	15	30.8	1.0	30.8	330	0.09	1.02
Faculty Office 220	Office	95	1	0.06	5.7	5	5	10.7	1.0	10.7	120	0.09	1.02
Mail Support 222	Shipping/Receiving	130	1	0.12	15.6	10	10	25.6	1.0	25.6	110	0.23	0.88
Faculty Office 226, 228 & 225	Office	277	3	0.06	16.6	5	15	31.6	1.0	31.6	330	0.10	1.01
PT Faculty Lounge 229	Lounge	292	1	0.18	0.0	7.5	7.5	60.1	1.0	60.1	440	0.14	0.97
Faculty Office 232, 233 & 230	Office	271	3	0.06	16.3	5	15	31.3	1.0	31.3	330	0.09	1.02
Conference 231	Conference	155	3	0.06	9.3	5	15	24.3	1.0	24.3	140	0.17	0.94
Faculty Office 236, 238, & 235	Office	262	3	0.06	15.7	5	15	30.7	1.0	30.7	330	0.09	1.02
Faculty Office 237, 239, & 241	Office	360	3	0.06	21.6	5	15	36.6	1.0	36.6	260	0.14	0.97
Faculty Office 242 & 240	Office	172	2	0.06	10.3	5	10	20.3	1.0	20.3	220	0.09	1.02
Support 234	Corridor	212	0	0.06	12.7	0	0	12.7	1.0	12.7	221	0.06	1.05
Dept. Resourses Q203	Corridor	201	0	0.06	12.1	1	0	12.1	1.0	12.1	222	0.05	1.06
Q302	Corridor	82	0	0.06	4.9	0	0	4.9	1.0	4.9	221	0.02	1.09
	Totals:		109		823.8		647.5				13384		

Summary for RTU-3	
Diversity (D):	100%
V_{ou} (CFM):	**1471**
Overall Ev (minimum):	0.87
Final V_{ot} (CFM):	**1699**

Appendix C: Lost Mechanical Space Calculations

First Floor		
Mechanical Spaces	Area	Totals
M118	642	
P110	423	
T110	95	
P102	54	**1214**
Other Spaces	Area	Totals
Learning Loft Q102	2884	
Corridor Q103	478	
Classroom 120	805	
Classroom 121	1587	
Seminar Classroom 122	406	
Bits & Bytes Café 123	740	
HRIM Lab Kitchen 123A	492	
Retail 123B	191	
Lobby F102	635	
Electrical Lab 116	804	
Super/Assistant 115	169	
Equipment Storage 115A	307	
Engineering Automation 114	1007	
Electronics Lab 113	750	
Learning Resource Center 111	394	
Lounge 111A	315	
Seminar Classroom 112	501	
Corridor Q101	900	
Corridor Q104	310	
Super/Assist Office 107	102	
Lobby F103	465	
Lobby F104	105	
Lobby F105	106	
Prototype Lab 108	1534	
Receiving 109/Storage 109A	425	
Design Lab 103	785	
Projects Lab 106	956	
Research Lab 104	518	
Measurement Lab 105	975	
F105	68	
Z102	360	
R101	231	
R102	231	

R101A	48	
R102A	43	
J101	39	
F101	161	
Z101	325	**21152**

Percent Lost Space 5.4%

Second Floor		
Mechanical Spaces	Area	Totals
Server Room 207/IT Storage 207A	325	
P202	54	
ELV201	102	481
Other Spaces	Area	Totals
Learning Loft Q206	1773	
Resource Q205	205	
Classroom 244	902	
Classroom 245	856	
Classroom 246	1269	
Classroom 247	1010	
Classroom 248	764	
Classroom 249	789	
Open Source Computer Lab 209	712	
Lobby F201	444	
Department Resource Q207	288	
Lobby F204	87	
Networking Computer Lab 208	701	
IT Storage 203	376	
General Purpose Computer Lab 204	1024	
Emerging Technology Lab 206	696	
Corridor Q201	980	
General Purpose Computer Lab 205	856	
Storage 209A	100	
Storage 210A	180	
Admin. Assistant 210B	182	
Directors Office 210	201	
Faculty Office 211, 212 & 213	260	
Faculty Office 214, 215, & 216	263	
Faculty Office 219, 218 & 217	261	
Faculty Office 221, 223 & 224	264	
Faculty Office 220	95	

Mail Support 222	130	
Faculty Office 226, 228 & 225	277	
PT Faculty Lounge 229	292	
Faculty Office 232, 233 & 230	271	
Conference 231	155	
Faculty Office 236, 238, & 235	262	
Faculty Office 237, 239, & 241	360	
Faculty Office 242 & 240	172	
Corridor Q202	894	
Support 234	212	
Corridor Q203	201	
Z202	323	
R201	247	
R202	234	
R202A	38	
R201A	58	
J201	46	
Z201	309	20019

Percent Lost Space 2.3%

Third Floor		
Mechanical Spaces	Area	Totals
P303	51	
T301	88	
337 (Roof Access)	44	183
Other Spaces	Area	Totals
Department Resource 328	116	
Faculty Office 333, 334 & 335	277	
Faculty Office 330, 331 & 332	273	
Faculty Office 329	123	
Conference 325	154	
Faculty Office 324, 326 & 327	294	
Corridor Q303	621	
Lobby F301	456	
Lobby F304	97	
Corridor Q305	99	
Copy/Fax/Printer 322	95	
Faculty Office 319	131	
Corridor Q301	800	
Corridor Q302	82	

Corridor Q306	48	
Corridor Q307A	95	
Faculty Office 320, 321, & 323	299	
Faculty Office 304	114	
Faculty Office 305 & 306	221	
Conference 317	150	
PT Faculty Office 313	133	
Faculty Office 303 & 303A	244	
Conference 311A	150	
Admin. Assistant 307A	133	
Chancellors Office 307B	321	
Reception 307	476	
Conference 311	205	
Faculty Offices 315, 316, 318	295	
Faculty Office 310, 312 & 314	285	
Faculty Office 309	115	
Seminar Classroom 308	634	
Z301	299	
Z302	332	
R301	194	
R302	183	
R301A	55	
J302	40	
R302A	40	
307E	82	8761

Percent Lost Space 2.0%

Appendix D: Trace 700 Outputs for Updated Energy Rates

Below are the relevant outputs reference in the report the Trace 700 model containing the updated energy cost rates from actual bills from the Gaige Building.

MONTHLY UTILITY COSTS

By ACADEMIC

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
					------- Monthly Utility Costs -------								
Alternative 1													
Electric													
On-Pk Cons. ($)	6,766	6,151	7,172	6,742	6,112	6,929	7,713	7,344	9,637	7,521	6,723	6,593	85,404
Gas													
On-Pk Cons. ($)	3,176	2,945	2,642	1,933	1,147	1,124	1,069	1,173	1,095	1,926	2,222	2,945	23,396
Monthly Total ($):	9,941	9,097	9,814	8,676	7,259	8,054	8,782	8,517	10,733	9,447	8,944	9,537	108,800

Building Area = 62,188 ft²

Utility Cost Per Area = 1.75 $/ft²

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

------- Monthly Energy Consumption -------

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 1	**Technical Report Two**												
Electric													
On-Pk Cons. (kWh)	71,975	65,439	76,295	71,727	65,024	73,716	82,058	78,127	102,526	80,010	71,517	70,136	908,552
On-Pk Demand (kW)	213	216	217	239	356	374	388	372	413	259	215	213	413
Gas													
On-Pk Cons. (therms)	3,134	2,906	2,607	1,908	1,132	1,109	1,054	1,158	1,081	1,900	2,193	2,906	23,088
On-Pk Demand (therms/hr)	14	14	13	12	11	11	11	11	11	12	12	13	14

Energy Consumption

Building	105,126	Btu/(ft2-year)
Source	228,025	Btu/(ft2-year)
Floor Area	51,459	ft2

Environmental Impact Analysis

CO_2	1,097,549 lbm/year
SO_2	8,539 gm/year
NOX	1,641 gm/year