Centralized Plant Design

The change of the heating and cooling systems to a centralized plant design was chosen for this analysis due to the combination of design choices available in a centralized plant system over an all electric direct expansion design. The economic constraints that were placed upon the design team were not considered in this design project and the comparison is for educational reasons only, not to point out flaws in the base building design.

Centralized Plant Objectives

The objective of the centralized plant design has three main goals:

- Overall reduction in energy consumption over existing system
- Decrease life cycle cost of mechanical systems over existing system
- Educational interest in Absorption chiller & centralized plant design

The discussion of achievements of these goals is discussed in the conclusion section of centralized plant design.

Design Strategies

The new mechanical system will incorporate a centralized chiller-heater and waterside free cooling. These changes will require the removal of the existing Unitary DX cooling and electric heating rooftop units and the addition of air handlers, cooling towers, heat exchangers, pumps and an absorption chiller-heater. The following sections outline design criteria and selection for this new equipment.

Absorption Chiller-Heater Design

Chiller-heaters have three operating modes: cooling-only, heating-only, and simultaneous heating and cooling. The direct-fired type of absorption chiller utilizes natural gas or liquid propane to provide heat for the high temperature generator used in the absorption refrigeration cycle. The primary advantage of this system is that there is only one unit that serves in place of the traditional separate boiler and chiller plants.

The cooling-only mode operates as a typical double effect absorption chiller would with a gas-fired high temperature generator and absorber replacing the compressor, see Figure 6 below.

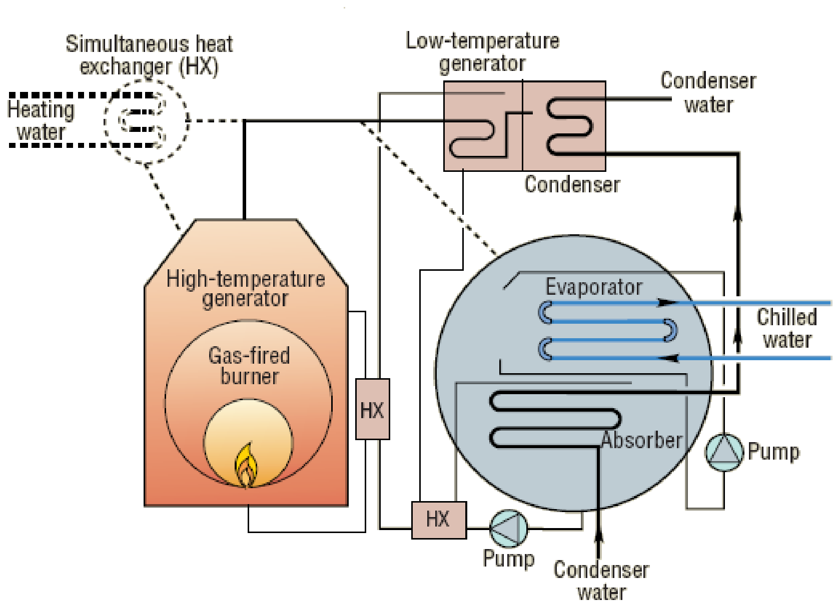

Figure 6 – Cooling-only mode of a Double Effect Direct-fired Absorption Chiller

The heating-only mode bypasses the condenser used in cooling and utilizes the main evaporator as a condenser. A changeover and downtime is required to switch from cooling-only to heating-only mode because of this. See Figure 7 below for a schematic of the chiller-heater in heating-only.

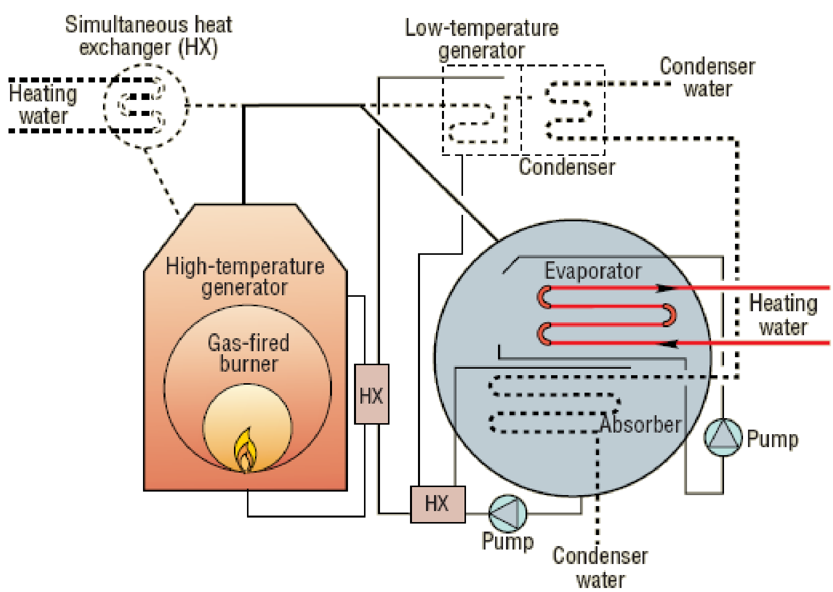

Figure 7 – Heating-only mode of a Double Effect Direct-fired Absorption Chiller

The simultaneous heating and cooling mode operates as a typical double effect absorption chiller would with a gas-fired high temperature generator, but a heat exchanger is added in parallel between the high and lower temperature generators to produce hot water. See Figure 8 below for a schematic of the simultaneous heating and cooling mode.

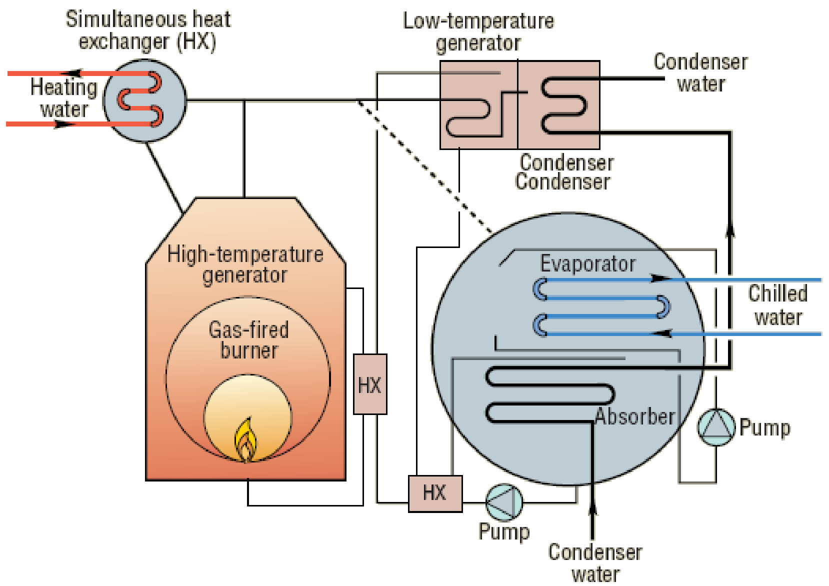

Figure 8– Simultaneous heating and cooling mode of a Double Effect Direct-fired Absorption Chiller

Since these systems can provide simultaneous heating and cooling, the chiller-heater cannot be sized based solely upon the peak cooling load. This simultaneous process reduces the effect of both the heating and cooling capabilities since the heat exchanger used to provide hot water reduces the generator heat output in the absorption refrigeration cycle displayed in the Figure 8 above. Because of this combined operation, the chiller-heater should be sized to meet the peak cooling load at approximately 80% of its total capacity to provide excess capacity for producing hot water at part load conditions. See capacity chart in Figure 9 below for an idea of how this tradeoff works.

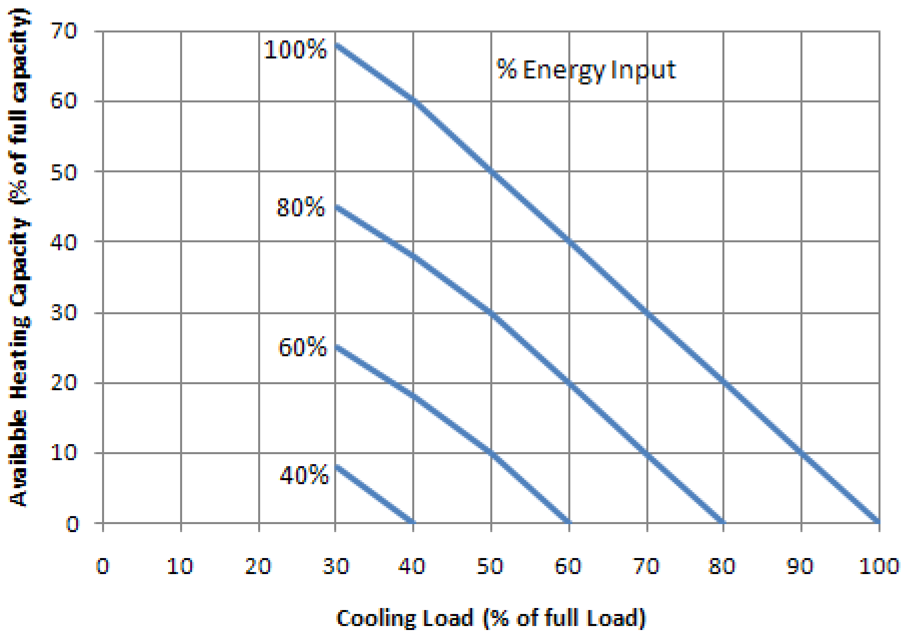

Figure 9 – Simultaneous Heating and Cooling Capacities Based on Energy Input from Carrier's Absorption Design Guide

Chiller-Heater Selection

The peak cooling load was calculated to be 367 tons in Trane Trace 700. Based upon this calculation and the method described above, the plant size that would best fit the heating and cooling loads would be a cooling design load of approximately 458 tons. Two 240 ton chiller-heaters (230 tons actual) were used in the new centralized plant for two main reasons:

- System redundancy
- Ability to meet base load with one chiller-heater.

The design day 24 hour cooling demand profile is graphed in Figure 10 below. It is shown that the base load is approximately 60 tons of cooling in summer conditions. One 240 ton chiller can drop down to 30% of its total capacity to meet this base load, whereas if the system consisted of one 480 ton chiller, it would have to drop to 15% of its total capacity. This low capacity is not recommended due to very low efficiencies.

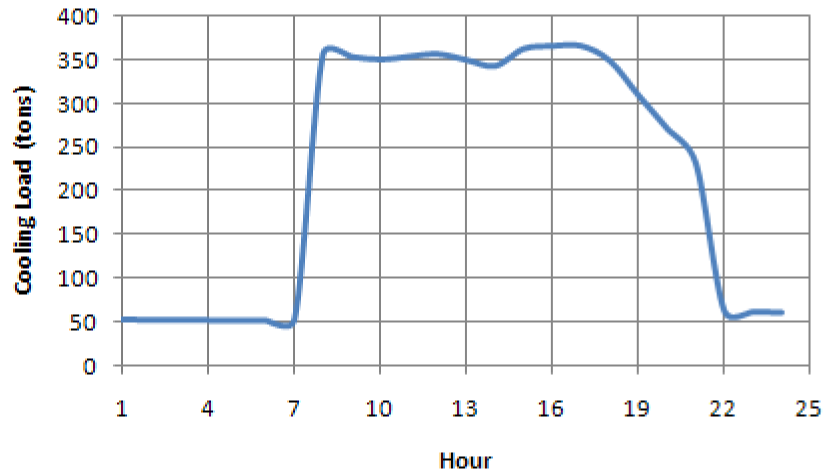

Figure 10 – Daily Cooling Plant Demand Profile (tons)

Pumping Selection

Since there are nine heating and cooling coils that the chiller-heaters are supplying, a four-pipe primary/secondary pumping system will be utilized to distribute the hot and chilled water. A variable primary flow system was considered but dismissed due to complications with modeling variable flow rates in the evaporator of a chiller-heater system. So a primary secondary system was chosen. See Figure 13 for a schematic of the centralized plant system.

Cooling Tower Selection

The cooling towers were selected using Marley UPDATE cooling tower selection software. Table 5 displays the numbers used in selecting each of the cooling towers. See Appendix C for data sheets on the cooling tower selection. The towers were set to have two speed fans to achieve performances similar to variable speed fans, with less cost.

Table 5 – Cooling Tower Selection Criteria

Cooling Tower Selection Criteria			
# of Towers	GPM	Range	Fan Type
2	450	10°F	50/50 2 speed

Air Handler Selection

The air handlers for the centralized system serve the same zones as the existing unitary system to provide necessary heating and cooling. This was unchanged due to the variability in peak load between the zones, as they are on different ends of the building. This design makes the first cost of the equipment smaller and can reduce the amount of energy used by the system. The zones are divided into two zones per floor for floors one to three and one zone for the cellar level. See Figure 11 for a graphic displaying the zones and levels described.

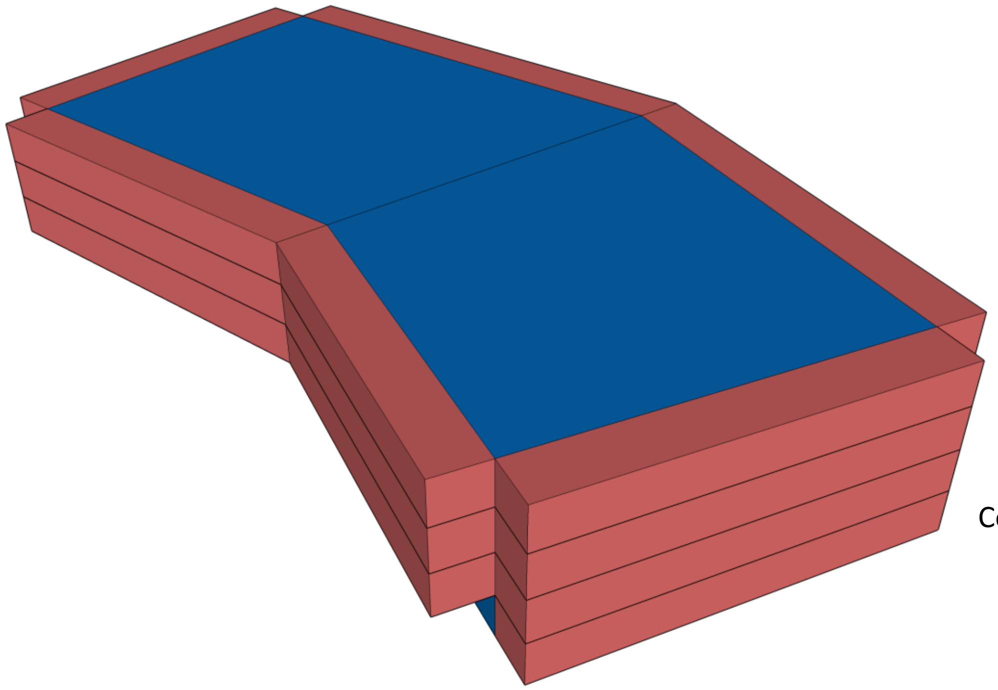

Figure 11 – Zone Layout Schematic – All Floors

The air handlers replace the existing DX unitary rooftop units and provide a reduction in weight and cost. The new air handlers are VAV rooftop air handlers with total enthalpy wheels and powered exhaust. The basis of design is an AAON RN 40 Air handler. See Table 6 for an overview of the air handler specifications.

Table 6 – Air Handler Requirements

Air Handler Requirements			
Air Handlers	CFM	Cooling (tons)	Heating (MBH)
AHU-1-1	22005	52.1	309.7
AHU-1-2	21260	42.5	262.8
AHU-2-1	21230	52.1	309.7
AHU-2-2	22755	39.3	259.8
AHU-3-1	22000	50.6	307.9
AHU-3-2	22000	42	292.4
AHU-C-2	27087	63.3	264.1
Café 1 & 2	3630	11.9	91.3
Fitness	3920	10.6	129

Free Waterside Cooling Design

During cool weather, the outside ambient wet bulb temperature can help save energy in systems that utilize cooling towers. The temperature of water coming from the cooling tower can be used with a heat exchanger to provide cooling for the chilled water returning to the chilled water plant without running the thermal compressor of the absorption chiller. Free cooling can be used to save energy whenever the outside wet-bulb temperature drops below the required chilled water set-point of approximately 46 degrees Fahrenheit. The heat exchanger specifications are listed in Table 7. Figure 12 is an example of a plate and frame heat exchanger.

Table 7 – Free Waterside Heat Exchanger Requirements

LMTD Calculation			
T_{hotin}	=	85	°F
T_{hotout}	=	95	°F
T_{coldin}	=	65	°F
$T_{coldout}$	=	46	°F
LMTD	=	**34.3**	°F
NTU_{hot}	=	0.29	
NTU_{cold}	=	0.55	
h_{hot}	=	750	
h_{cold}	=	750	
ΔP	=	15	psig
U	=	**219.5**	btuh/ft^2

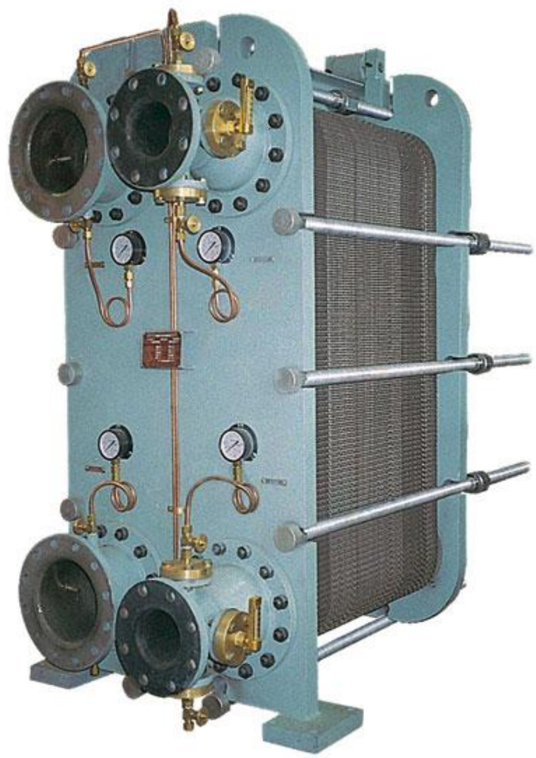

Figure 12 – Plate and Frame Heat Exchanger

Centralized Plant Analysis

The new centralized plant will require a new piping system to deliver hydronic heating and cooling to the rooftop air handling unit along with condenser water to the cooling towers on the rooftop. Space for the absorption chiller heater and plate and frame heat exchanger for free cooling will also have to be made inside the building. See Figure 13 below for a schematic of both heating and cooling systems in the central plant. Only the secondary pumps are shown on the schematic for clarity.

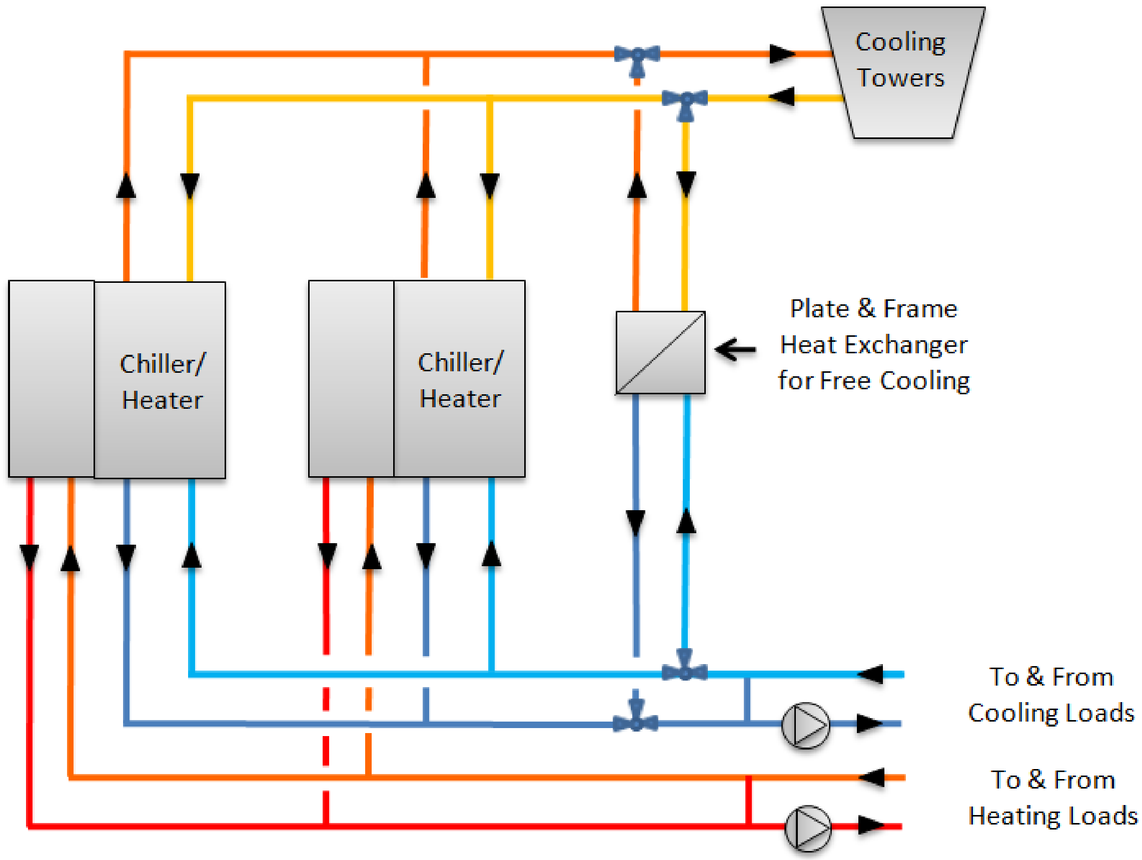

Figure 13 – Centralized Plant Schematic

The long term flexibility of the central plant system is also a benefit to the building owner; when technologies become more efficient and available the building can be easily retrofitted for a new system after the life cycle of the current system. The centralized chiller-heater with cooling tower was chosen for its anticipated improvement in energy efficiency, smaller shaft space requirements, diversification of primary energy sources and for educational purposes. The system will maintain its ability to simultaneously heat and cool in different parts of the building, provide adequate thermal comfort to building occupants, and provide minimum ventilation.

ASHRAE 90.1 Compliance

ASHRAE 90.1-2007 prescribes minimum requirements for the building envelope, HVAC systems, service water heating, power, lighting and electric motor efficiency. The compliance calculations below are applied to the equipment in the newly design chiller-heater plant. The location of the building falls into climate zone 5A. Tables 8, 9 and 10 test these requirements.

Table 8 – Equipment Compliance

Minimum Efficiencies - AHSRAE 90.1 Section 6						
	Actual IPLV	Actual COP	Minimum IPLV	Minimum COP	Pass/Fail	System Type
AB-1	1.09	1.14	1.00	1.00	Pass	Absorption double effect, Direct-fired

Table 9 – Fan Power Compliance

Fan Power Limitation - ASHRAE 90.1 Section 6					
Fan Name	Fan Type	[CFM]	HP	$CFM_s \cdot x$	Pass/Fail
AHU-C-2	Variable	27087	25	39.60	Pass
AHU-1-1	Variable	22005	20	29.78	Pass
AHU-1-2	Variable	21260	25	33.00	Pass
AHU-2-1	Variable	21230	20	29.78	Pass
AHU-2-2	Variable	22755	25	33.00	Pass
AHU-3-1	Variable	21230	20	27.45	Pass
AHU-3-2	Variable	22755	20	30.00	Pass
AC-2	Variable	4200	3	6.30	Pass
AC-3	Variable	2500	2	3.75	Pass
AC-4	Variable	2500	2	3.75	Pass
ERV-1	Variable	3400	5	5.10	Pass
EF-C-1	Constant	1085	0.33	1.19	Pass
EF-C-2	Constant	150	0.15	0.17	Pass
EF-C-3	Constant	150	0.15	0.17	Pass
EF-C-4	Constant	350	0.18	0.39	Pass
EF-C-5	Constant	150	0.15	0.17	Pass
EF-C-6	Constant	450	0.23	0.50	Pass
EF-C-7	Constant	200	0.21	0.22	Pass
EF-C-8	Constant	350	0.18	0.39	Pass
EF-C-9	Constant	350	0.18	0.39	Pass
EF-1-1	Constant	465	0.42	0.51	Pass
EF-1-2	Constant	465	0.42	0.51	Pass
EF-2-1	Constant	465	0.42	0.51	Pass
EF-2-2	Constant	465	0.42	0.51	Pass
EF-3-1	Constant	465	0.42	0.51	Pass
EF-3-2	Constant	465	0.42	0.51	Pass
EF-1	Constant	2600	0.5	2.86	Pass
EF-2	Constant	3000	0.75	3.30	Pass
EF-3	Constant	1400	0.33	1.54	Pass
EF-4	Constant	700	0.25	0.77	Pass

Table 10 – Building Envelope Compliance

Section 5.2 - Building Envelope						
Opaque Elements			Area	U-Factor	Required U-Factor	Pass/Fail
Roof - Insulation Entirely Above Deck			41,500	0.046	0.048	Pass
Walls - Above-grade			31,136	0.05	0.09	Pass
Walls - Below-grade			6,845	0.1	0.119	Pass
Floors - Slab-on-Grade Floors			1,010	0.7	0.86	Pass
Fenestration Vertical Glazing	Area	U-Factor	SGHC	Required U-Factor	Required SGHC	Pass/Fail
Cellar level	16432	0.046	0.249	0.55	0.4	Pass
Floors 1-3	1535	0.49	0.697	0.55	0.4	Pass
Doors	402	0.49	0.697	0.8	0.4	Pass

ASHRAE 62.1 Compliance

An analysis using ASHRAE 62.1-2007 is shown in Table 11 below. ASHRAE 62.1-2007 prescribes the minimum amount of outdoor air to be supplied to building spaces. As noted, the system as designed exceeds the minimum outdoor air requirements in all of the building air systems by a minimum of 30%, earning LEED-NC 2.2 EQ Credit 2 - Increased Ventilation.

Table 11 – Ventilation Calculation

ASHRAE 62.1 Ventilation Calculation							
	Area ft^2	∑Voz CFM	Vpz Total CFM	Vot Total CFM	Voa Actual CFM	Pass/Fail	% Increase
AHU-C-2	18095	1615	27087	1794	2400	Pass	34%
AHU-1-1	17520	1851	22005	2058	2700	Pass	31%
AHU-1-2	18125	1999	21260	2221	2900	Pass	31%
AHU-2-1	18665	1853	21230	2059	2700	Pass	31%
AHU-2-2	19305	2384	22755	2649	3500	Pass	32%
AHU-3-1	18665	1853	22000	2059	2700	Pass	31%
AHU-3-2	19305	2384	22000	2649	3500	Pass	32%
Café	1957	595	3630	595	800	Pass	34%
Fitness	2150	521	3920	522	700	Pass	34%

Usable Space Breakdown

The required space for new mechanical equipment in HITT Contracting Headquarters had little impact on the usable building square footage. 1.44% of the total building usable square footage is allotted to mechanical systems. The large air handling units that the system uses are located on the roof, freeing up space on the usable floors below. The bulk of the square footage that is taken up by the system is from the new mechanical room created in the cellar. This, along with a dropped acoustical tile ceiling and shafts descending from the rooftop air handling units, provides ample space on floors one to three. See Table 12 below for a total breakdown of the lost usable square footage and per floor. Figure 17 below displays a typical floor with the mechanical shaft areas highlighted in blue.

Table 12 - Lost Usable Square Footage

	Total ft^2	Mech ft^2	% Lost Usable Space
Cellar	20245	1329	6.56%
1st Floor	37500	93	0.25%
2nd Floor	37500	197	0.53%
3rd Floor	37500	288	0.77%
Total	132745	1907	1.44%

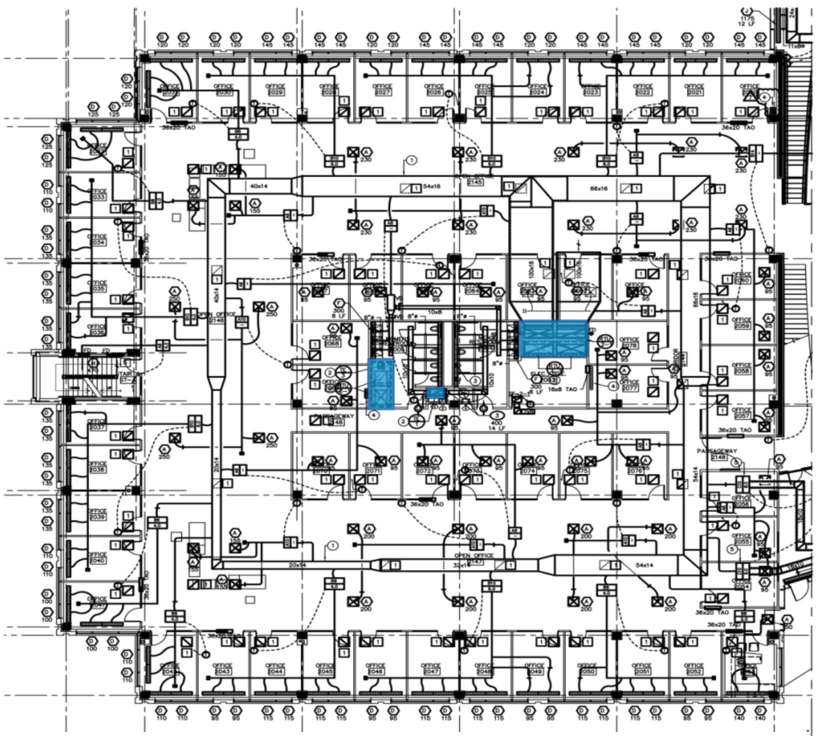

Figure 17 - Typical Floor Mechanical Spaces

Energy Analysis

The results from Trane Trace 700 of the new monthly consumption of electricity and natural gas are displayed Figures 14 and 15. The natural gas usage for the building peaks in the summer months when natural gas prices are at a minimum. The natural gas also helps to alleviate increases in on peak consumption of electricity during the months of June, July, August and September and levels out the annual electricity consumption from month to month as shown in Figure 14 below. Figure 16 displays the breakdown of the energy usage by type in the new centralized system. See Appendix A for a breakdown of the energy usage by month.

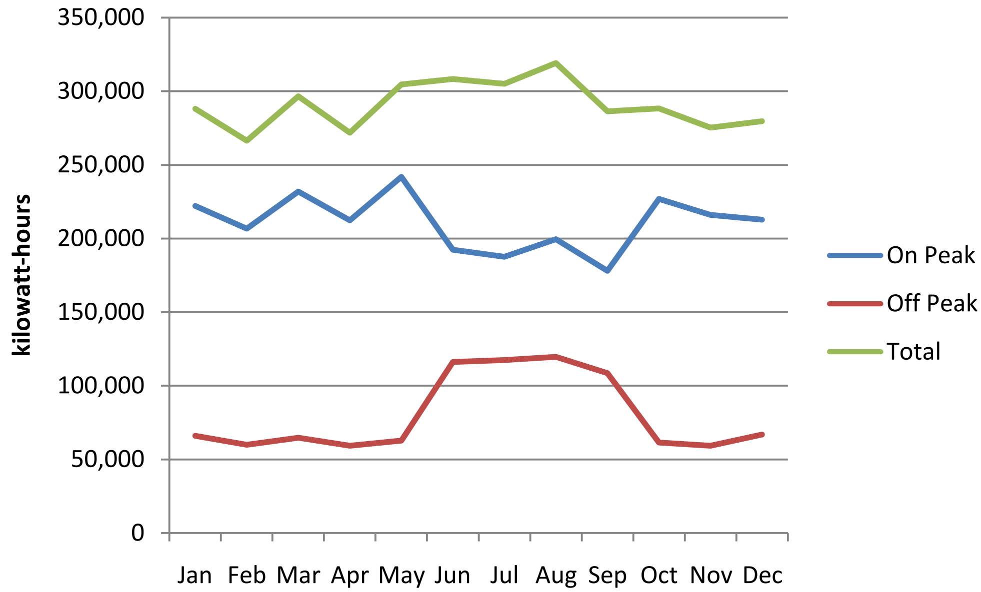

Figure 14 – New Monthly Electricity Consumption

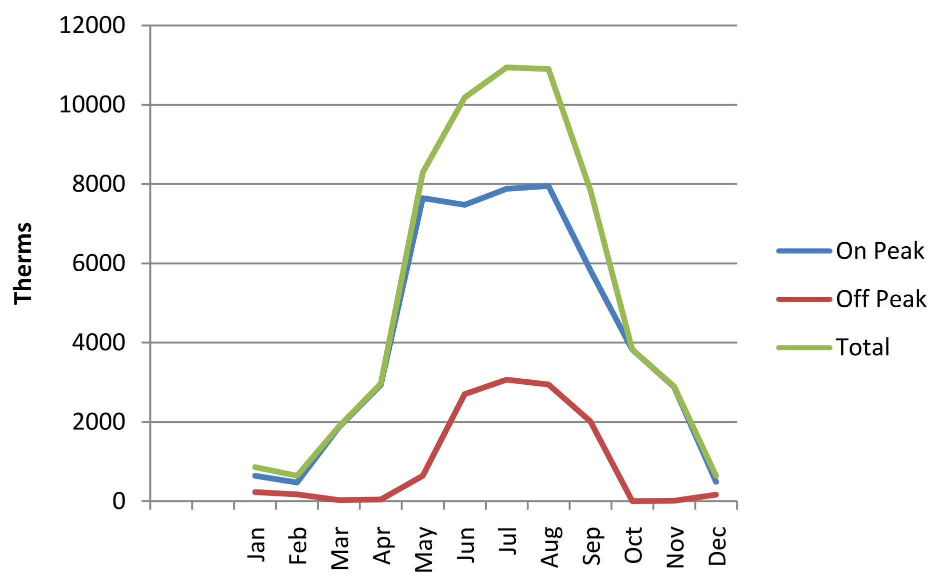

Figure 15 – New Monthly Natural Gas Consumption

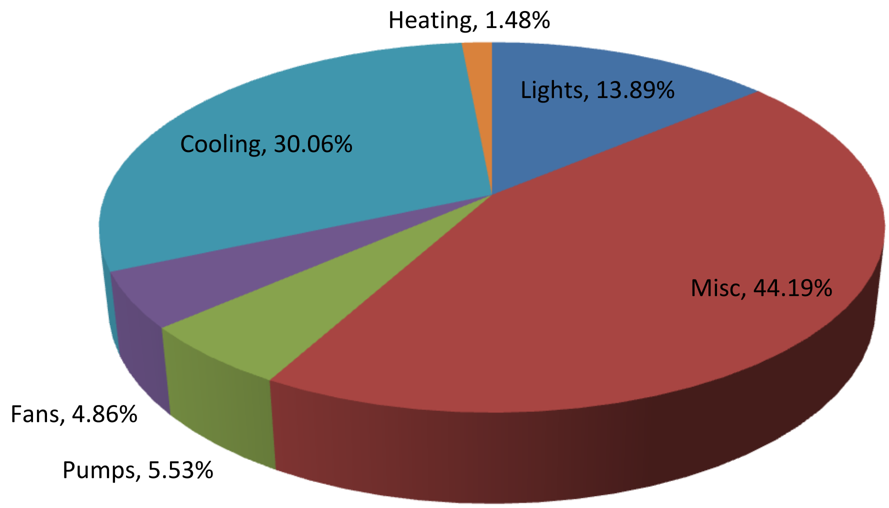

Figure 16 – Breakdown of New Energy Consumption by Type

Economic Analysis

This section displays the calculations associated with the comparison of the first costs, operating costs, and life cycle costs of the existing system with the new centralized system. The life cycle cost analysis was performed for both systems with a simple interest rate of 6% over 20 years. The results show that the simple payback period for the system is approximately 17 years. Maintenance for this system was assumed to be similar to that of the existing system for this analysis. Utility rates are also listed below for reference in Tables 13 and 14. The annual energy cost for the new system was calculated to be $322,556 or $2.38 per square foot with a cooling cost of $0.44 per square foot.

Table 13 – Natural Gas Rates in Dollars per Therm by Month

Natural Gas Prices											
Jan	Feb	Mar	April	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1.0957	1.0957	0.9833	0.9833	0.9833	1.0061	0.9507	0.8579	0.9611	0.9067	0.981	1.0542

Table 14 - Dominion Virginia Power Utility Rates

On Peak Demand	14.488	$/kW Demand
Off Peak Demand	2.926	$/kW Demand
On Peak Consumption	0.0404	$/kWh
Off Peak Consumption	0.0272	$/kWh
Customer Charge(Per Month)	119.8	$/Month

Table 15 – First Cost of Mechanical Equipment

Mechanical Equipment First Costs		
	DX System	Absorption System
DX Rooftop Units	$460,280	n/a
Chiller-Heater	n/a	$255,000
Plate & Frame HX	n/a	$19,000
VAV AHU	n/a	$365,910
VAV Boxes w/ Electric Reheat	$56,000	n/a
VAV Boxes w/ Hydronic Reheat	n/a	$45,500
Cooling Towers	n/a	$17,400
Totals	$516,280	$702,810

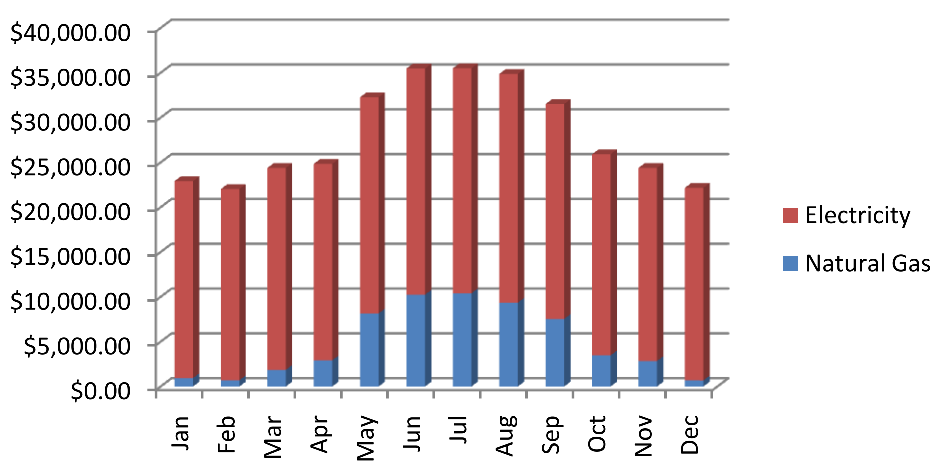

Figure 18 – Monthly Energy Costs

Table 16 – Life Cycle Cost of Mechanical Equipment

Life Cycle Cost Comparison

i=0.06	DX System	Absorption System
Year 1	$340,748	$322,556
Year 2	$340,748	$322,556
Year 3	$340,748	$322,556
Year 4	$340,748	$322,556
Year 5	$340,748	$322,556
Year 6	$340,748	$322,556
Year 7	$340,748	$322,556
Year 8	$340,748	$322,556
Year 9	$340,748	$322,556
Year 10	$340,748	$322,556
Year 11	$340,748	$322,556
Year 12	$340,748	$322,556
Year 13	$340,748	$322,556
Year 14	$340,748	$322,556
Year 15	$340,748	$322,556
Year 16	$340,748	$322,556
Year 17	$340,748	$322,556
Year 18	$340,748	$322,556
Year 19	$340,748	$322,556
Year 20	$340,748	$322,556
Net Present Worth	$3,908,353	$3,699,692
Initial Cost	$516,280	$702,810
Life Cycle Cost	$4,424,633	$4,402,502

Central Plant Conclusions

The change to a centralized plant system succeeded in all three of the goals that were set forth in the objectives section. A reduction in energy consumption was achieved as noted in the Energy Analysis section. The goal of decreasing the 20 year life cycle cost was achieved and was done so by $22,131 or 0.5%. The centralized plant system design utilizes more expensive equipment than the existing unitary system and in order to achieve the goal set forth of reducing life cycle cost would have to consume less energy in order to make up the cost difference. The initial cost of the system components were combined with the yearly operating costs calculated in Trane Trace 700. Trane Trace 700 was used to calculate both the existing and new annual energy costs. The system did make profound changes to the roof structure. See Figure 19 for a rendering of the rooftop with the new system.

It was found that the payback period of the system was 17 years, which does not fall into the ideal payback length of 2-4 years. This economic calculation was performed on the basis of