The American Swedish Institute

Minneapolis, MN

Final Thesis Report: Mechanical Alternative Systems Analysis

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Date: 4.4.12

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Abstract

The American Swedish Institute

Minneapolis, MN

Project Information

Size:	75,000 square feet
Cost:	$13.5 million
Stories:	3 above grade
Construction:	January 2011 - May 2012
Delivery:	Design - Bid - Build
Occupancy:	Cultural Center

Project Team

Owner:	The American Swedish Institute
Architect:	HGA Architects and Engineers
Construction Manager:	Adolfson & Peterson Construction
Mechanical Engineer:	HGA Architects and Engineers
Structural Engineer:	HGA Architects and Engineers
Electrical Engineer:	HGA Architects and Engineers

Construction & Architecture

The American Swedish Institute, Turnblad Mansion, finished construction in 1910 in Minneapolis, MN. The Turnblad Mansion was originally designed to give the Swedish community a place to gather and share their heritage throughout the public. Over the years, the American Swedish Institute felt that the original facilities were not sufficient to where they saw the Institute going. They decided to add an addition to the building, the Nelson Cultural Center, to showcase Swedish architecture and sustainability.

Structural Systems

- The main lateral force resisting system, in the cultural center is a combination of steel bracing and reinforced CMU shear walls.
- Foundation system is typically 5", 4000 psi un-reinforced slab on grade with 6", 4000 psi reinforced slab on grade and 2" topping in the northern middle portion of the foundation.
- The structural framing of the mansion is steel frame construction with exterior load bearing walls.

Electrical and Lighting Systems

- (1) 1000 KVA pad-mounted transformer.
- Secondary transformer is a 277/480 V, three phase, with four-wire power to a 1600A Main Panel Board.
- A 277/480V, 600A, three-phase, four-wire panel shall provide electrical power to the new panels.
- Recessed, pendant, & track lighting are used throughout with the majority of areas utilizing T6 and T8 fluorescent lamps.

Mechanical Systems

- Geothermal source closed loop heat pump system. Loop field size is ~ 1 ton per well hole with a nominal well depth of 250 feet for the (96) well holes.
- (48) heat pumps.
- (2) B & G base-mounted series 1510 pumps for the condenser water system ~ 525 gpm each, 100' head, 20 horsepower.
- (1) Makeup Air Unit at 8,000 CFM.

Krysta Skinner | Mechanical

http://www.engr.psu.edu/ae/thesis/portfolios/2012/KLS5301/index.html

Executive Summary

The Variable Air Volume (VAV) and chilled beam alternatives analyzed in this report are intended to reduce the annual energy consumption of the mechanical system for the American Swedish Institute. Included in the VAV alternative analysis are the cooling and heating loads, annual energy consumption, annual utility breakdown, emission factors for utilities used, mechanical space occupied, initial annual costs, and the life-cycle cost of the system. The load and energy analysis completed for the VAV system shows the loads experienced on the equipment during peak operation, the equipment energy consumption for both electricity and natural gas and emissions for those utilities. First cost analysis of the equipment compares the variations between the VAV system and the existing heat pump system. 30 year life-cycle costs for the VAV system were compared to the original system based on the net present values of each.

An analysis similar to the VAV system was completed for the chilled beam system to compare the energy results to the original heat pump system. The chilled beam analysis includes the cooling and heating loads, annual energy consumption, annual utility breakdown, emission factors, mechanical space occupied, equipment selected, chilled beam calculations, initial costs, and 30 year life-cycle for the building. Load and energy analysis for the chilled beams illustrate the loads experienced on the building and equipment during peak operation and equipment energy consumption for both electricity and natural gas usage which are compared to the original system. The first cost analysis for the chilled beam system includes the equipment selected and was compared to the VAV and existing heat pump systems. A 30 year life-cycle cost was completed for the chilled beam alternative with the net present value calculated compared to the original system.

Both alternatives were compared to each other as well as to the original system to determine the best system based on loads, energy usage, first costs, and life-cycle costs. From the results analyzed in this report it was determined that the VAV alternative was the best solution for the American Swedish Institute. Below are the main points demonstrating the results for the depth analysis.

VAV Alternative:

- 68% reduction in fan and pump energy use compared to the existing heat pumps
- 15% decrease in energy use in comparison to the original heat pump system
- $427,371 additional costs for this alternative
- Annual energy savings of $12,992.50 per year

Chilled Beam Alternative

- 13% less building consumption per year than the original system
- 66% reduction in fan and pump energy than the existing heat pumps
- $517,122 additional investment with this option than the original
- Annual energy savings of $10,062.02 per year

The architectural and structural breadths were focused on the redesign of the walkway connecting the mansion and addition with an extensive or intensive green roof to replace the existing roof. After completion of all structural calculations, a final conclusion was made for the recommendation of an extensive green roof to replace the existing roof. An extensive green roof reflects the green roofs currently in place on the second story roof of the addition and demonstrate the Swedish landscape and sustainability concepts. The extensive green roof costs $7/sf less than the intensive option. Total loads experienced on the roof would increase by 6 psf in comparison to the existing roofing therefore not comprising the structural integrity. This new roof would use 3 inch 16 gauge steel roof deck which can handle a maximum load of 118 psf which is more than capable to handle the calculated load.

Acknowledgements

I would like to thank the many people who were involved with helping me complete my senior thesis project and supporting me throughout the past year.

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Stephen Treado;

All my family and friends for their continuing support.

Building Introduction

The American Swedish Institute, scheduled to complete construction in June 2012, is a 34,000 square feet addition and 27,500 square feet renovation, cultural center and museum project located in Minneapolis, MN. The building consists of multi-purpose and public spaces for the community to gain knowledge about Swedish culture. Serving as one of the top facilities for learning about Swedish history in the United States; the Turnblad Mansion illustrates the history, architecture and art custom to Sweden culture. Two buildings, the existing Turnblad Mansion and the Nelson Cultural Center that is currently under construction, on the premises will be connected by an enclosed walkway on ground level. The project currently taking place includes the renovation of the mansion's lower level and construction of the Nelson Cultural Center addition, designed by HGA Architects and Engineers. Construction costs approximately $13.5 million for the work completed on the mansion and addition.

Originally designed to the give the Swedish community a place to gather; the Turnblad Mansion has become a place for everyone to gather to see Swedish heritage. Over the years the American Swedish Institute felt that the original facilities were insufficient to where they saw the institute heading in the future. They decided to add an additional building, the Nelson Cultural Center to the property. Both buildings will be used as cultural spaces containing a café, retail, meeting spaces, offices, and classrooms.

A major architectural feature of the mansion is the solarium facing towards the addition. The Nelson Cultural Center respects the original architecture of the mansion by considering contemporary and traditional Swedish aesthetics. Located on the undeveloped lot south of the mansion, the addition has a series of modular architectural forms covered in dark slate tiles and large windows. The Nelson Cultural Center has a singular, accessible and visible main entrance that faces toward the mansion. This entrance shows all the activities occurring in the cultural center. Additionally, the cultural center demonstrates the sustainable design that is often seen in Sweden culture by incorporating a green roof into the design. Both buildings focus on a center landscaped courtyard with trees and plants chosen for Minnesota and to reflect Swedish landscapes.

A Make-up Air Unit serves fresh air to all the spaces in the addition and existing mansion which is distributed through multiple heat pumps located throughout the building. Heat pumps are supplied with water from the geothermal system located on the site of the American Swedish Institute. The American Swedish Institute is under consideration for LEED Certification throughout the construction process with a target for LEED Gold.

Mechanical System Overview

The American Swedish Institute contains a Make-up Air Unit that provides conditioned outside air to all occupied interior spaces for the addition and existing mansion. Heating and cooling needs for the building are provided by a geothermal source closed loop heat pump system. The system contains ninety-six well holes with a depth of 250 feet and approximately one ton capacity per hole. Heat pumps are used throughout the building and are served outdoor air from the Make-up Air Unit. Air from the unit is supplied from several VAV (Variable Air Volume) boxes throughout the building with the additional air being recirculated from the ceiling plenum by the return air from occupied spaces.

Geothermal heat pumps are the primary source for providing heating and cooling used in the American Swedish Institute. Any additional heating required for the museum comes from two 20 HP Fulton condensing boilers located in the lower level of the addition. One Make-up Air Unit (MAU) located in the lower level of the addition is used to supply conditioned outside air to the VAV boxes. This MAU supplies 8,000 cfm to the 21 VAV boxes located in the building. Each VAV box serves multiple heat pumps on each level of the addition and mansion. Additional air to the heat pumps comes from return air in the ceiling plenum from the occupied spaces, that is then recirculated. The American Swedish Institute uses 48 heat pumps throughout the addition and existing structure which are coupled with the geothermal system.

Mechanical Design Objectives

Major design requirements given by the owner included that the addition reflect sustainability practices used throughout the Swedish culture. The basic sustainability goals were defined as exceeding existing energy codes, low lifetime costs, maintaining good indoor air quality and a healthy environment, and decreasing long-term operating costs of the building. With these requirements defined the remodeling of the existing mansion would improve the energy efficiency of the building as well as meeting LEED Gold for the addition. The renovation and new construction would be in compliance with ASHRAE Standards and building codes for the state of Minnesota.

There are also many design factors that were taken into consideration with the type of building the American Swedish Institute is and the location of the building, Minneapolis, MN. Due to this location the design required more heating days compared to cooling days. Another design factor would be the large areas of glass used for the addition, as well as, the poor construction of the mansion. The glass used on the addition is clear low e glass with dark anodized aluminum thermally broken frames to assist in decreasing the heat loss and infiltration for the building. Another factor would be the 7,000 sq. ft. sloping green roofs used on the addition that would prevent significant amounts of heat loss and heat gain to and from the interior spaces to the environment and storm water run-off to the site.

Energy Sources

Primary heating for the building is electric and natural gas. Heat pumps are used for heating in conjunction with a boiler that is used for supplemental heating if the system calls for more heat during the winter. All of the cooling for the American Swedish Institute is supplied by the various heat pump systems throughout the building that use electricity.

All electric and gas rates were based off of the values provided by Xcel Energy for the state of Minnesota. $11.19/kW from June to September and $ 7.79 from October to May is used for the electrical rate. The rate of $0.59/therm from April to October and $0.65 from November to March was used for natural gas. A more specific breakdown for the utility costs is shown in Tables A.1-A.2 located in Appendix A.

Design Conditions

The indoor and outdoor air conditions for the American Swedish Institute were taken from ASHRAE Handbook of Fundamentals 2009 for Minneapolis, MN. Temperature values used for this location were 0.4% and 99.6%. For the summer an outdoor air dry bulb temperature of 91°F and an outdoor air wet bulb temperature of 73.2°F, were used. Outdoor dry bulb temperature for the winter is -14.9°F. This weather data can be seen in Appendix B.

Design Ventilation Requirements

Since the American Swedish Institute uses a MAU that provides conditioned outdoor air to all the heat pumps via VAV boxes, the MAU was used for analysis of the building ventilation system. The MAU was analyzed based on the specific zones for the heat pump systems since, the total fresh air would be considered the same for the overall MAU or the individual heat pump systems and VAV boxes added together. There were also no typical zones for the building since the American Swedish Institute is a museum/cultural center, therefore all zones were analyzed.

Comparison of the minimum ventilation calculated in Technical Assignment 1 to the design documents shows the calculated cfm value is greater than the 8,000 cfm MAU used. The calculated value from the ventilation rate procedure was 10,427 cfm which means the design is undersized by ASHRAE's standards. A possible cause of this over estimation could be from the use of population values provided in ASHRAE Standard 62.1 which could cause an excess amount of outdoor air required to those spaces; that could be less or more to the spaces if the program was known. This could cause an over or under estimation for the spaces since the actual occupancy for these areas was not provided. From this calculation the efficiency of the whole system was calculated at 74% although, the actual efficiency of the system may be much higher. An additional reason for the overestimation could come from any adjustments done by the engineers after the loads were calculated for all the spaces.

Design Load Estimates

For the American Swedish Institute seven systems, all water source heat pumps, were assumed to exist throughout the mansion and addition. A system was considered a floor in either the addition or mansion to simplify calculations. There were three systems assigned to the addition and four systems assigned to the existing mansion. Each system shown in Tables 1.1 and 1.2 was analyzed using Trane TRACE 700 based on %OA, cfm/ft2, cfm/ton, ft2/ton, and occupancy.

Cooling Loads for Heat Pumps						
		%OA	cfm/ft^2	cfm/ton	ft^2/ton	Occupancy
Addition Level	Lower	7.6	0.50	459.16	916.63	18
	First	19.7	0.99	316.02	319.42	280
	Second	15.9	1.41	347.60	246.31	220
Existing Level	Lower	31.0	0.59	279.17	473.37	228
	First	11.3	0.75	389.52	518.97	34
	Second	7.2	1.18	415.85	351.87	29
	Third	12.0	0.71	385.25	541.91	22

Table 1.1: Cooling Loads for Heat Pumps

Heading Loads for Heat Pumps			
		%OA	cfm/ft²
Addition Level	Lower	7.6	0.50
	First	25.0	0.99
	Second	15.9	1.41
Existing Level	Lower	31.0	0.59
	First	11.3	0.75
	Second	7.2	1.18
	Third	12.0	0.71

Table 1.2: Heating Loads for Heat Pumps

The %OA for the seven heat pump systems range from 7.2% - 31.0% this can be seen in Tables 1.1 and 1.2 for both cooling and heating above. The two systems that have the highest amount of outdoor air are the heat pumps in the lower level of the mansion and the first level of the addition shown above in Table 1.1. A possible reason for the higher values for outdoor air could be from the assumed schedules used. With the actual occupancy schedules for the building the %OA would be adjusted to the proper values, but these areas would still be higher due to the type of spaces on these levels. These heat pump systems are also serving a larger number of spaces compared to the other systems in the building; this causes a large %OA for the larger occupancy rates in those areas of the building. Other systems in the building have a reasonable amount of %OA for the building although the values would be more accurate with the actual schedules for these spaces.

A typical rule of thumb used for museums is 250-350 ft²/ton. Comparison of this rule of thumb to the actual values calculated from the model it is seen that the ft²/ton is much higher than the typical values ranging from 246.31-916.63 ft²/ton; these can be seen in Table 1.1. The calculated values seem reasonable for the type of spaces being modeled, since the American Swedish Institute is not considered to be a typical museum building. Additionally, the higher ft²/ton values could also be from the assumption made about the schedules and the poor construction of the mansion. These values are also higher, due to the large number of gallery and archive spaces in the addition and existing mansion that are classified as critical spaces. The heat pump for the lower level addition has the largest amount of ft²/ton at 916.63. This heat pump system has the largest amount of archive and gallery storage spaces therefore requiring more conditioned air supplied to these spaces to moderate humidity and temperature levels. Overall, the systems with large ft²/ton would be more reasonable with proper schedules for the spaces and correct occupancy rates, but from these results the values seem accurate for these types of spaces.

Design Cooling		
Plant	**System**	**Peak Load (tons)**
Cooling	A-Lower HP	8.5
	A-First HP	35.0
	A-Second HP	28.7
	T-Lower HP	24.9
	T-First HP	19.5
	T-Second HP	24.7
	T-Third HP	12.2
Total		**153.5**

Table 1.3: Peak Design Cooling Load

Design Heating		
Plant	**System**	**Peak Load (MBH)**
Heating	A-Lower HP	58.4
	A-First HP	428.8
	A-Second HP	255.8
	T-Lower HP	300.3
	T-First HP	347.7
	T-Second HP	399.4
	T-Third HP	217.2
Total		**2,007.6**

Table 1.4: Peak Design Heating Load

The peak design cooling loads for the American Swedish Institute occur in July, this can be seen in Table 1.3 above. Comparison of the heating loads in the existing mansion building to the addition it is seen that the loads in the mansion are much larger than the heating loads in the addition, which can seen above in Table 1.4. This is accurate since the construction of the mansion is older and considered to be below average in comparison to the addition. It can also be seen that the lower levels in both the mansion and addition are much smaller than the upper levels since the lower levels are located below grade and have less heat loss to the surroundings. Large heating loads were calculated for the first level of the addition due to the large portions of glazing on those two levels. Similar to the other results for the seven systems the results would be more accurate for heating and cooling with actual occupancy rates and schedules used for the zones in the building.

Design Energy Usage Estimate

An energy analysis was performed on the American Swedish Institute to determine the annual energy consumption and operating costs of the mechanical plant for the building. The mechanical engineer on the project has not performed an energy analysis at this time, due to time being spent on other projects. There are no utility bills or data provided for the American Swedish Institute since it is currently under construction. Electric and gas rates were based off of the values provided by Xcel Energy for Minnesota. A value of $11.19/kW from June to September and $ 7.79 from October to May is used for the electrical rate. The rate of $0.59/therm from April to October and $0.65 from November to March was used for natural gas, these rates can also be seen in Appendix A.

The energy analysis also required the building schedule which was not provided by HGA Architects and Engineers. Due to this, the schedules were determined from the hours of operation provided on the American Swedish Institute website. These schedules are provided in Tables C.1-C.3 in Appendix C. During the week the mechanical systems operate at 100% from 7 a.m. – 8 p.m. since the museum is open until 8 p.m. on Wednesdays therefore determining the schedule for the other days of the week.

After entering the schedules and energy rates into Trace an energy analysis was performed for the American Swedish Institute. The energy consumption annually for the building is shown in Table 2.1 below. Primary heating for the building is electric and natural gas since heat pumps are used for heating as well as, a boiler that is used for supplemental heating if the heat pumps need assistance for the colder days during the winter. All of the cooling for the American Swedish Institute is supplied by the various heat pump systems throughout the building that use electricity for cooling; where the cooling compressors use the majority of the energy for cooling. The fans for the heat pump systems used throughout the building also account for a large amount of electricity usage.

Energy Consumption Summary					
System		**Elec (kWh)**	**Gas (kBtu)**	**Total(kBtu/yr)**	**% Total**
Primary Heating	Primary Heating	77,902	66,748	332,626	10.4
	Other	2,309	-	7,881	0.3
Primary Cooling	Cooling Compressor	141,479	-	482,867	15.1
	Tower/Cond Fans	1,239	-	4,228	0.1
	Other	141	-	482	0.0
Auxiliary	Supply Fans	125,639	-	428,806	13.4
	Pumps	59,909	-	204,468	6.4
Lighting	Lighting	490,330	-	1,673,496	52.3
Receptacle	Receptacles	18,843	-	64,310	2.0
Total		**917,790**	**66,748**	**3,199,165**	**100.0**

Table 2.1: Energy Consumption Summary

When looking at the total percentages for the American Swedish Institute's energy consumption per year, it is seen that heating, cooling, auxiliary, and lighting are the largest totals for energy consumption. To verify that the totals in Table 2.1 are correct the American Swedish Institute's information was compared to typical public assembly's energy consumption provided by the Department of Energy. Shown in Figure 2.1 below is the typical distribution of energy in a public assembly building, which is similar to the usage of the addition and mansion. This figure shows that the heating load (44 %) accounts for the largest amount of energy usage in the building followed by cooling (15 %), lighting (10 %), and miscellaneous (9 %) loads.

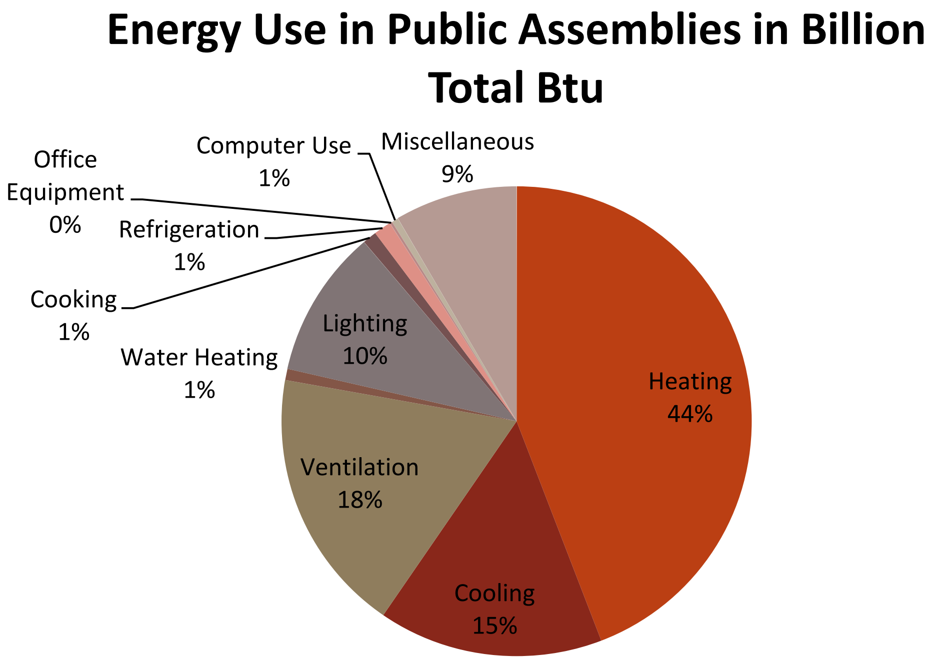

Figure 2.1: Energy Use in Public Assemblies

Comparison of these values to the American Swedish Institute model values, the calculated values in Trace are higher for lighting and lower for heating than the average values. Heating loads for the building are much lower compared to the average values, this can be explained because of the use of a geothermal heat pump system instead of a 100 % boiler system used to supply heating to the building. Cooling and miscellaneous loads compare very closely to the values found from Trace and vary only by a couple of percentages. However, the lighting loads for the American Swedish Institute are much larger than the average values. A possible reason for this is the American Swedish Institute's use being a museum and gallery space where artwork is on display, with lighting being provided with different lighting fixtures. Also, since museum's make up such a small amount of the public assembly sector for commercial buildings the lighting loads could vary greatly due to the type of building the American Swedish Institute is.

An analysis was also completed for the main mechanical components operation during peak loads. The peak electrical loads for the water source heat pump and boiler are shown below in Table 2.2. Since the water source heat pumps operate similar to chillers they are expected to have the largest percentage of electrical load during peak hours which is verified below. The boiler uses a very small amount of electricity since it runs primarily on natural gas. Lighting also makes up a large amount of the electrical load on the American Swedish Institute.

Electrical Peak Load			
System		**Electrical Demand (kW)**	**% Total**
Cooling	Water Source Heat Pump	100.59	52.27
Heating	Boiler	21.14	10.98
Fan Equip	A-Lower HP	1.03	0.53
	A-First HP	2.92	1.52
	A-Second HP	2.63	1.37
	T-Lower HP	1.83	0.95
	T-First HP	2.00	1.04
	T-Second HP	2.71	1.41
	T-Third HP	1.24	0.64
Misc.	Lighting	55.97	29.08
	Equipment	2.15	1.12
Total		**194.21**	**100.0**

Table 2.2: Electrical Peak Load Summary

The monthly energy consumption for the American Swedish Institute is shown in Appendix D. The information provided includes the on peak consumption and on peak demand for electricity and gas. Overall building consumption is 50,582 Btu/ (ft^2*year) this is a total building consumption of 3.199x10^9 Btu/year.

After the energy usage was complete, the annual cost for operation of the building was calculated. The annual cost breakdown for electricity is shown below in Table 2.3*.* As seen in the table below, electricity is the major expenditure for the American Swedish Institute with a cost of $73,720.36. Overall operational cost for the building is $74,537.63 per year.

Annual Utility Breakdown		
Source	**Energy (10^6 Btu/yr)**	**Cost ($/yr)**
Electricity	3,132.4	73,720.36
Gas	66.7	817.27
Total	**3,199**	**74,537.63**

Table 2.3: Annual Utility Breakdown

Monthly costs for the American Swedish Institute are shown in Figure 2.2 below. As seen in the graph below, there is fluctuation in the spring and fall months as the systems are supplying both heating and cooling. This could be due to the mechanical systems having to deal with the warmer and cooler temperatures that occur in those months.

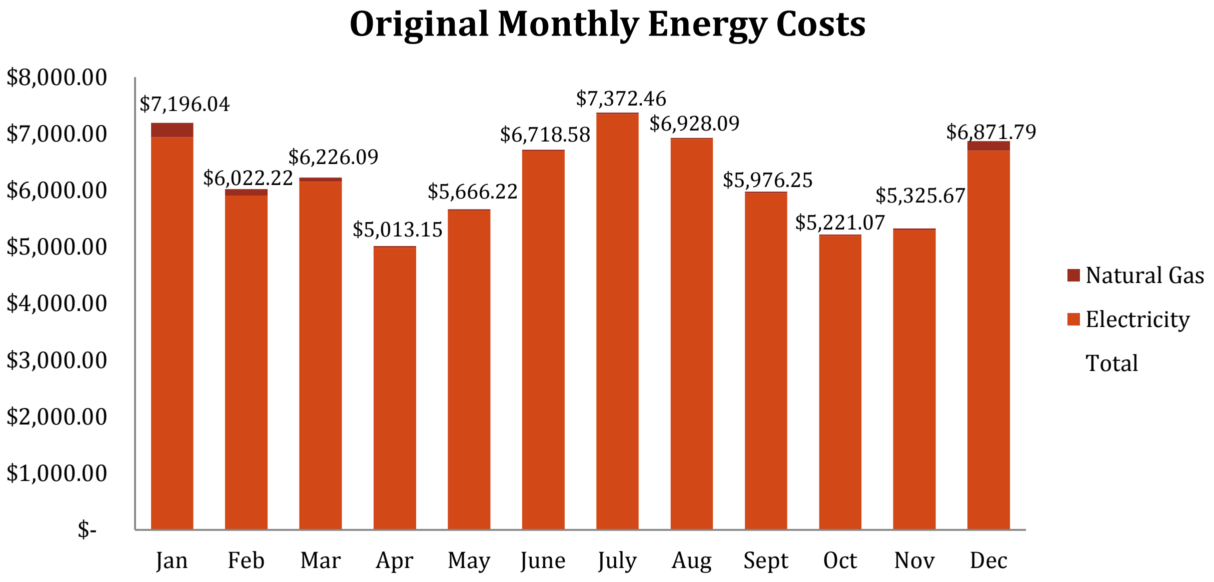

Figure 2.2: Monthly Energy Costs

After completion of the energy analysis for the American Swedish Institute the annual emissions footprint was determined. This information was found from the reference document Regional Grid Emission Factors 2007, where emission factors were determined for electricity and natural gas based on location. The location for the American Swedish Institute is determined to be Eastern since the building is located in Minneapolis, MN and can be seen below in Figure 2.3. The respective electrical emission factors for Eastern were then used to determine the annual pounds of CO_2, NO_x, SO_x, PM10; results for these pollutants are shown below in Table 2.4 for electricity. The natural gas emission factors were also determined for the boiler used in the American Swedish Institute; the results for the natural gas pollutants can be seen in Table 2.5 below.

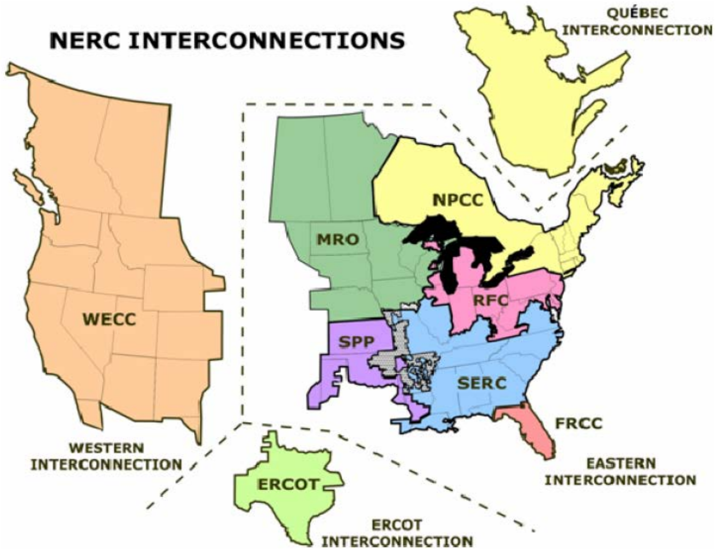

Figure 2.3: United States Electrical Grid Interconnections

Electricity Emission Factors				
Pollutant	**lb of pollutant per kWh of electricity**	**Electric kWh per year**	**lb of pollutant**	**tons of pollutant**
CO_2	1.64	917,790	1,505,176	683
NO_x	3.00E-03		2,753	1
SO_x	8.57E-03		7,865	4
PM10	9.26E-05		85	-

Table 2.4: Emission Factors for Electricity

Natural Gas Emission Factors				
Pollutant	**Natural Gas per 1,000 cf**	**Natural Gas cf**	**lb of pollutant**	**tons of pollutant**
CO_2	1.22E+02	667	81,374	37
NO_x	1.11E-01		74	-
SO_x	6.32E-04		-	-
PM10	8.40E-04		6	-

Table 2.5: Emission Factors for Natural Gas

Mechanical System Cost

Although the costs for each piece of equipment were not available, the overall cost for the total mechanical system was given. The American Swedish Institute's total mechanical system first cost is approximately $2,749,134 and accounts for 21% of the total building cost, this includes all HVAC, plumbing, and fire suppression equipment and accessories. Costs for HVAC equipment and accessories are $42,334 and $0.90/sq. ft. The reason for the lower costs of the HVAC systems to the other mechanical systems is due to the fact that heats pumps were used throughout the building and did not require return ductwork to be run through the ceiling plenums back to an air handling unit. HVAC costs are also lower since the designed system uses fewer VAV boxes and requires less labor to install this equipment. Plumbing systems were the most expensive at a cost of $2,568,000 and $54.59/sq. ft. This system accounts for all piping that is run to the heat pumps from the geothermal system and plumbing throughout the building. With an increased requirement for labor and installation of the piping, the cost for plumbing is significantly higher than the other systems. Fire suppression accounts for $138,000 and $2.95/sq. ft.

Since the main mechanical system is geothermal and requires earthwork to be done on the site, the cost of this construction phase was taken into consideration. These costs were $327,808 and $6.97/sq. ft. and account for 3% of the total cost of the project. If this system was not geothermal, the earthwork and plumbing costs would be significantly less.

Mechanical costs for the heat pump system were recalculated based on RSMeans 2012 by assumptions made for mechanical equipment selected from drawings and schedules. The new first cost for the American Swedish Institute is approximately $2,031,979 which can be seen in Appendix E. This calculated number is less than the number given from HGA Architects and Engineers this is due to the assumptions made for equipment and will be used for comparison of the two alternatives first costs. Cost per square foot is $45.16.

Mechanical Space Requirements

Summarized in Table 3.1 are the areas of the American Swedish Institute that are occupied by mechanical system. Included in this summary are the mechanical room in the lower level of the addition and the shaft spaces located on all levels of the mansion and addition. Approximately 1% of the total building area is occupied by the mechanical system.

Section	Area (ft^2)
Addition	604
Mansion	19
Total	623

Table 3.1: Area Occupied by Mechanical Space

System Operations and Schematics

Ventilation

Make-up Air Unit 1 is a dedicated outdoor air-handling unit controlled with direct digital control (DDC) actuators. The on-board controls will be provided for the heat pump refrigeration system so a constant discharge air temperature is provided to the building. Supply of make-up air will vary depending on the demand and pressurization required from the variable air volume boxes. To modulate air flow in the supply ductwork a DDC air pressure reference will be located approximately 2/3 distance from the fan. The system shall start and stop based on an occupancy schedule to provide adequate make-up air to all spaces. On-board heat pump controls in the packaged unit shall modulate the refrigeration system to provide conditioned air discharged at a temperature of 55°F in summer and 62°F in winter. A supplemental hot water heating coil is provided for additional heating for the heat pump system to modulate discharged air at the temperatures indicated above.

For protection of the system four methods are used; freeze, high-temperature, smoke control, and high pressure. The fan will start if the duct temperature is above 37°F, otherwise a signal will be sent to the freeze alarm and need manually reset. Fan shall start if duct temperature is below 120°F otherwise the high temperature alarm will be signaled and the fan will quit operation. Fan will stop operation if products of combustion are detected in the duct. Additionally, fan will stop when static pressure rises above excessive-static-pressure set point.

All VAV boxes are controlled with DDC to provide minimum ventilation requirements and building pressurization. Two VAV boxes, one located in the lower level of the mansion and the other on the second level of the addition shall maintain constant outdoor air flow with no control to reduce air flow of 160 cfm and 90 cfm, respectively. Upon sensing a negative building pressure condition, the DDC system shall open all VAV boxes towards fully open until building is positively pressurized in comparison to the outdoors. System shall reverse operation to prevent over-pressurization of the building. Refer to Figure 4.1 for a schematic of MAU-1.

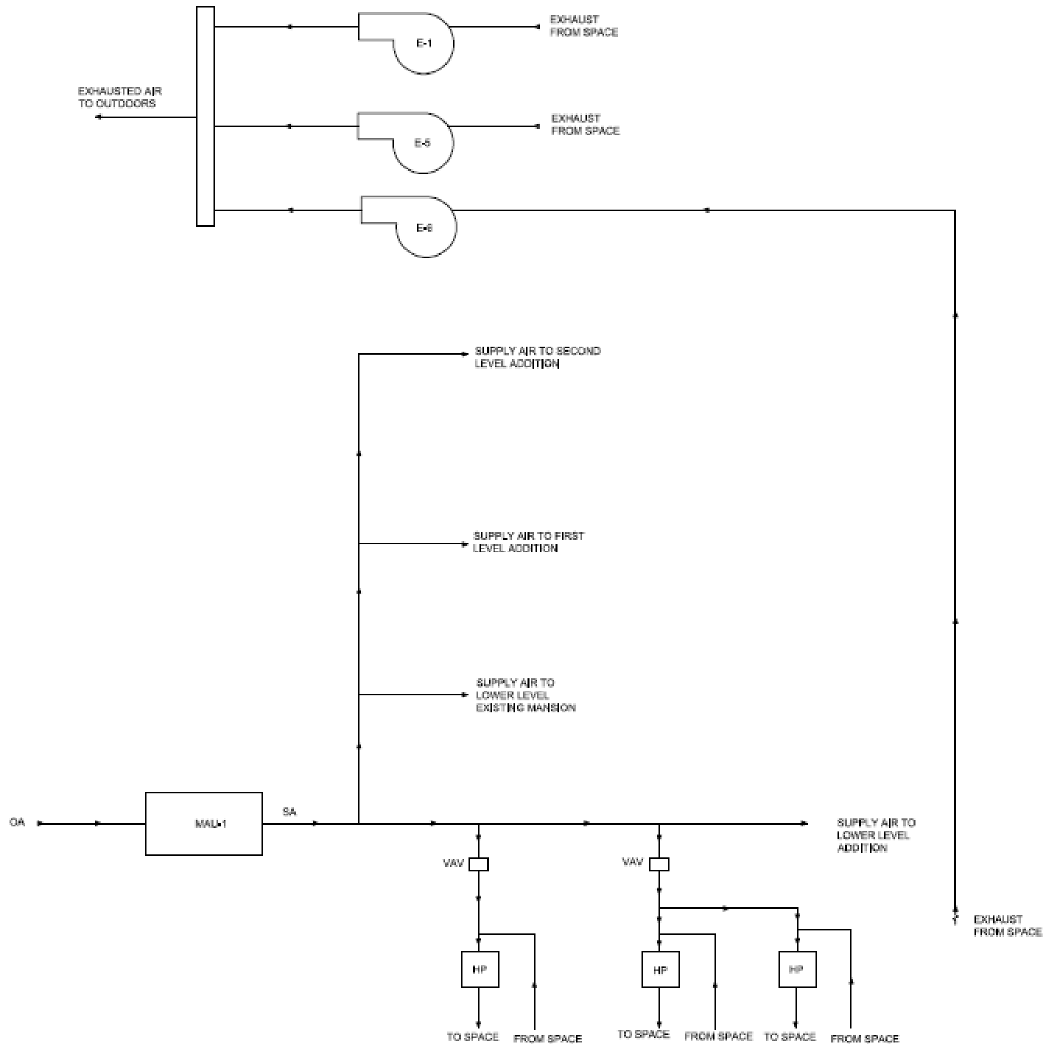

Figure 4.1: Ventilation Schematic

Geothermal

Piping shall be routed from the geothermal wells into the building to valves and monitor controls. Primary circulating pumps CWP-1 and CWP-2 shall be constant speed for the well field loop with variable speed drives for pumps CWP-3 and CWP-4. Temperature sensors shall be interfaced with the DDC system for continuous monitoring of temperature of each of the circuit pipes from the geothermal field and primary and secondary supply and return mains. Primary condenser water pumps shall run continuously alternating the operation of the pumps for equal run time. Failure of one pump will signal an alarm through the DDC system. Secondary condenser water pumps operate in the same manner and will be provided with variable speed drives for each. Refer to Figure 4.2 for a schematic of the geothermal system.

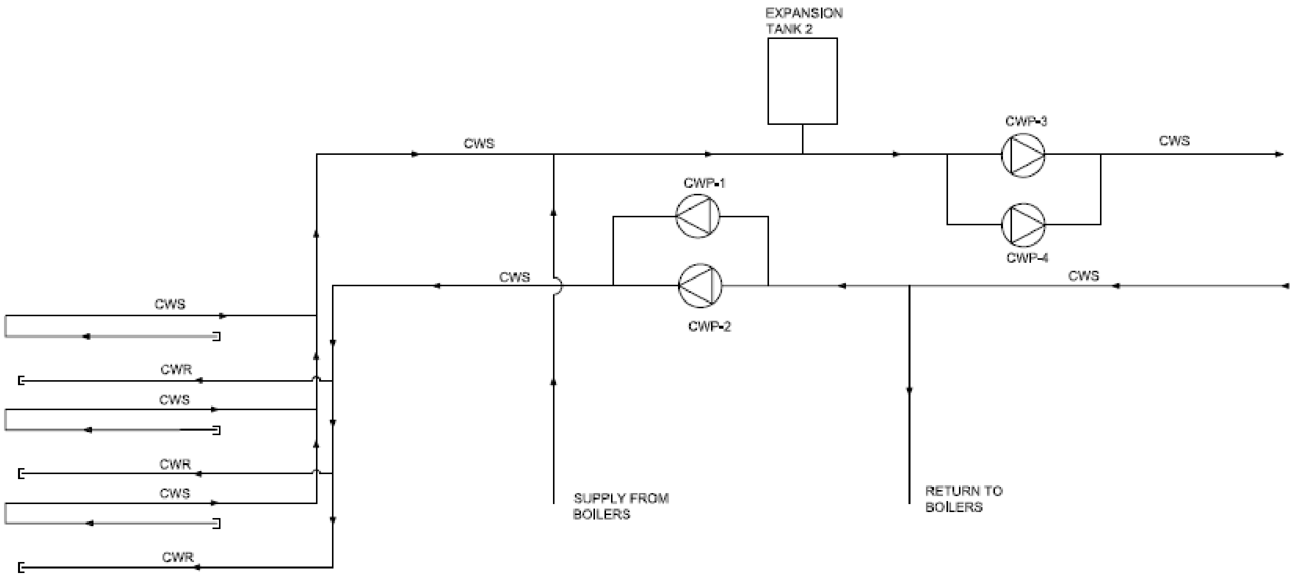

Figure 4.2: Geothermal Schematic

Hot Water

Two condensing boilers B-1 and B-2 are controlled by DDC. Upon proof of flow through a water flow proving switch, boiler will fire. With capability of receiving a 0-10V or 4-20mA setpoint signal from the BAS to employ a reset schedule. Modulation of heating mixing valve to blend hot water with the condenser water system serving heat pumps shall occur upon indication from DDC sensor. Water supply outlet temperature shall reset depending on outdoor temperature from 60°F to -16°F with a HWS temperature of 100°F and 140°F, respectively.

Supplemental heating system shall be interconnected with the secondary water system to raise the temperature of the condenser water system if needed. When supply condenser water temperature is at or less than 50°F, modulate mixing valve to begin mixing hot water from the boiler into the condenser water loop. Injecting hot water from the boiler until the water temperature of the loop is 55°F. Modulating the valves to close once supply water temperature reaches and exceeds 55°F.

The DDC system shall vary the speed of the hot water pumps and signal the boiler system controls to energize. Prior to this, water flow must be proven at the operating boiler flow switch before allowing the boiler to fire. Lead pump shall be energized at outdoor air temperatures below 65°F; above 65°F pump shall be shut-off unless, manually overridden through the DDC system. A modulating motorized bypass control valve shall allow the operating pump to operate below 20% of maximum flow during low or no load conditions. Upon a boiler receiving signal to start and water flow is provided, burner shall fire and start draft fans. When boiler is signaled to shut off, the control valve closes. Refer to Figure 4.3 for a schematic of B-1 and B-2.

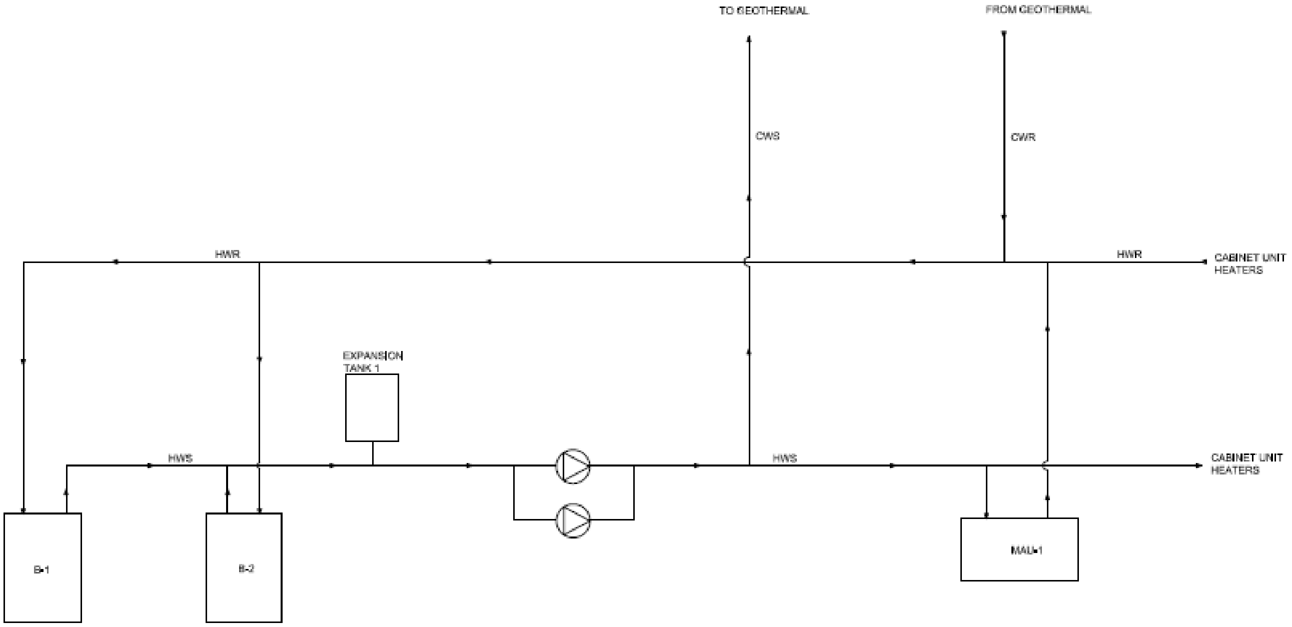

Figure 4.3: Hot Water Schematic

Condenser Water

Heat pumps serve all occupied areas of the building and provide heating and cooling to all spaces. All heat pumps shall be provided with condenser water from the ground source geothermal systems. A DDC system that includes thermostats shall be used to interface control of valves to all heat pumps. Allowance of manual override of 4-hours by the DDC system to allow for after hours use is provided by the heat pump program. Heat pumps shall be energized based on demand required by space, until load is satisfied. Refer to Figure 4.4 for a schematic of the condenser water system.

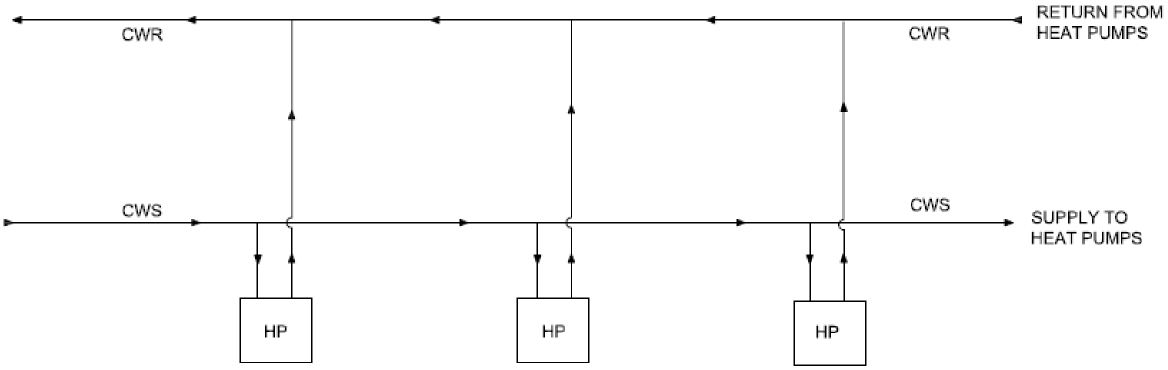

Figure 4.4: Condenser Water Schematic

ASHRAE Standard 62.1-2007 Analysis Section 5 and 6 Summary

The HVAC design of the American Swedish Institute is in compliance with Section 5 of ASHRAE Standard 62.1-2007 and in the majority of cases exceeds the minimums set by the standard. This can be contributed to the fact that the American Swedish Institute is applying for LEED certification.

The minimum ventilation requirements of the American Swedish Institute are over the 8,000 cfm designed MAU. 10,427 cfm was calculated using the ventilation rate procedure which, could have been caused by the use of ASHRAE Standard 62.1 to analyze the population for the zones. As well as the efficiency of the system as a whole being at a calculated value of 74% even though, the actual efficiency of the system could be much higher. This could have also been caused by adjustments done by engineers after the loads were calculated for the spaces. With these numbers being adjusted correctly for the zones and system as a whole, the ventilation air would be in compliance with ASHRAE Standard 62.1 Section 6.

ASHRAE Standard 90.1-2007 Analysis Section 5-10 Summary

To determine the compliance of the American Swedish Institute with ASHRAE Standard 90.1-2007 the prescriptive method was used under all applicable sections. Overall, the American Swedish Institute is in compliance with the standard with a few exceptions. The two sections that do not comply fully with Standard 90.1 are building envelope properties and pump motor efficiency. The below grade walls are not in compliance with standard since there is a lack of insulation for those walls and with a simple addition of insulation the heat transfer could be corrected. All the pumps have Variable Speed Drives to adjust the RPM for the required load.

The American Swedish Institute has submitted an application for LEED certification with a maximum potential of receiving LEED Gold at the end of construction. Therefore, the overall energy efficiency of the American Swedish Institute was a major design consideration throughout the project with almost complete compliance with ASHRAE Standard 90.1. Compliance with the standard could be reached with a few minor adjustments to the building envelope and horsepower for the Make-up Air Unit.

LEED Analysis Summary

The Leadership in Energy and Environmental Design (LEED) certification system is broken into six different sections. Only two sections were analyzed for this building; Energy & Atmosphere and Indoor Air Quality. The American Swedish Institute is registered with the USGBC under LEED for New Construction Version 2.2 with a total of 53 potential points, which could possibly achieve a LEED Platinum rating. However, the project team and owner's goal is to cost-effectively achieve a LEED Gold rating. A summary is provided for the projected points for the mechanical systems in this section.

Energy and Atmosphere

For the Energy & Atmosphere division, three prerequisites must be fulfilled to be considered further for any points in this section. The American Swedish Institute meets the prerequisites and is estimated to receive 13 points.

Indoor Environmental Quality

To be considered for the Indoor Environmental Quality category of LEED, two prerequisites must be fulfilled. The American Swedish Institute meets the prerequisites and is estimated to receive 14 points for this section.

Mechanical System Evaluation

The primary goal for the new construction and renovation of the American Swedish Institute was to incorporate the sustainable design of the Swedish culture to make a more energy efficient facility. MAU-1 serves the varying space types for both the existing mansion and the addition. Due to the main occupancy of the building being museum and gallery spaces, certain areas had to be designed with better control of humidity and temperature levels.

After review of ventilation rates, energy usage, and overall construction and operating costs, the design of the American Swedish Institute can be considered very efficient and will exceed the owner's expectations upon completion. From the results found in Technical Report 1, it was determined that the ventilation rates would be more accurate with the proper occupancy rates and schedules. Overall, the American Swedish Institute exceeds the minimum requirements established in ASHRAE Standards 62.1 and 90.1. Results from Technical Report 2 were compared to average national values and provided realistic results for a building of this type. Comparison of the energy usage and performance to the average, it was found that the American Swedish Institute performs better than the average due to the efficient geothermal system used. Although the system is highly efficient for heating in the cool winter months in Minnesota there is a possible opportunity for improvement. If return ducts were used instead of all the air being returned to the ceiling plenum, an energy recovery wheel could be used to preheat the air flow prior to the air being supplied to the heat pumps. This would need further research to verify that this method is a chance for possible improvement.

The mechanical system takes up a very small percentage of usable space; because of this any modifications to the current mechanical system will increase the amount of lost usable space.

The annual utility cost of the American Swedish Institute is $74,537.63 to operate. Electrical annual costs $73,720.36 which is reasonable for a system that relies heavily on electricity to power the mechanical equipment. $817.27 is spent annually on natural gas for the American Swedish Institute which is accurate since the boilers are used only for supplemental heating.

Overall construction cost of the mechanical system is $2,749,134 and accounts for 21% of the total building costs; this includes costs for all HVAC, plumbing, and fire suppression equipment and accessories. Majority of the mechanical system costs come from the plumbing equipment and accessories that include, the geothermal system and heat pump piping that runs throughout the building. Since the majority of the mechanical costs are plumbing, the cost of earthwork was also reviewed since it is a geothermal system. Costs for earthwork are $327,808 and account for 3% of the total cost of the project.

The owner and the project team are seeking a LEED Gold rating for the American Swedish Institute. Upon assessment of the mechanical system to the LEED v2.2 rating system the American Swedish Institute has a possibility to receive 53 potential points and have a LEED Platinum rating upon final review by the USGBC, exceeding both the owner and team's expectations. 27 of the potential points come from the mechanical system's compliance with the Energy & Atmosphere and Indoor Environmental Air Quality categories. Maintainability of the geothermal system will be difficult since the well field is planned to be covered with parking lots on the Southern portion of the site. Therefore, initial installation and testing prior to completion of construction are very important. Although the geothermal system will be difficult to maintain the MAU, boilers, heat pumps, and VAV boxes are easily accessible throughout the building in the mechanical room or in the ceiling's above occupied spaces.

In general, the mechanical system of the American Swedish Institute is a highly efficient system for the museum. Although the system is highly efficient there are still possibilities for other design options to decrease life cycle costs and annual energy usage for the American Swedish Institute.

Proposed Alternatives

For the proposed redesign of the mechanical system for the American Swedish Institute two alternatives will be reviewed to determine the more efficient and cost effective method. The first alternative will be water-to-water heat pumps with Variable Air Volume (VAV) boxes, this method is discussed below. Method 2, also discussed below is water-to-water heat pumps coupled with chilled beams. Two breadth studies, architectural and structural, will also be completed for the walkway connecting the addition to the mansion.

Method 1: Water-to-Water Heat Pumps with Variable Air Volume Boxes

As described in the original method, the American Swedish Institute supplies conditioned air to VAV boxes from a Make-up Air Unit to individual heat pumps. This alternative method shall still use the geothermal system currently in place but incorporate water-to-water heat pumps in combination with VAV boxes to condition the spaces.

Calculations will be completed to determine the sizes and number of the VAV boxes needed for the zones, and the size of the water-to-water heat pumps needed for the addition and mansion. The amount of usable space that will be lost by incorporating an air handler and VAV boxes will also be determined. Additionally the size of the air handler to be used for this system shall be found. As well as the initial first cost and annual cost for the VAV boxes, water-to-water heat pumps, and air handling unit. Energy and cost results shall be compared to the original system design and the second alternative to determine the most energy efficient and cost effective choice.

Method 2: Water-to-Water Heat Pumps with Chilled Beams

This alternative shall be proven as an even more efficient method to the original system with the combination of water-to-air heat pumps and VAV boxes and the first alternative with water-to-water heat pumps and VAV boxes. For this method the geothermal system shall still be used and will convert all water-to-air heat pumps in the addition and mansion to water-to-water heat pumps to be used with active chilled beams and a dedicated outdoor air unit.

A study will be completed to determine the number and size of chilled beams needed for the addition and mansion. Additionally the size of the water-to-water heat pumps and dedicated outdoor air unit required for the American Swedish Institute shall be determined. As well as the initial first cost and annual cost for the active chilled beams, dedicated outdoor air unit and water-to-water heat pumps compared to the existing system. Energy and cost results shall be compared to the original system design and the first alternative to demonstrate the most energy and cost effective choice.

Breadth Topics

Architectural Breadth: Green Roof Addition

The mansion and addition are connected by a 10’4” wide hallway that runs 45’ from the studio classroom and hallway in the addition to the corridor in the mansion; this hallway can be seen highlighted in orange in Figure 5.1 below. To incorporate more of the sustainable design seen in Swedish culture for the American Swedish Institute, the roof of this hallway is another prime location for an additional green roof.

Figure 5.1: Walkway between Addition and Mansion[1]

Research will be completed to determine the materials required for the extensive and intensive green roofs; such as, waterproofing, insulation, drainage, filter fabric, growth media, plant material, water storage and irrigation. Detailed sections for the walkway will be designed for the two different types of green roofs and the existing roof to show the thicknesses for the selected materials in each roof design. Comparison of the costs for each roof design will be completed upon final selection of material.

Structural Breath: Roof Redesign

With the redesign of the hallway roof from thermoplastic single ply roofing to a green roof there will be a significant increase in the original loads calculated therefore, impacting the original hallway structure. By making the green roof open to the public the hallway must be able to support the live load plus the additional dead load. Structural calculations for the roof must be recalculated to support this additional weight.

Tools for Analysis

Mechanical Depth

Energy simulation software will be used to compare the two alternatives for the mechanical system redesign with the designed system. Trane TRACE 700 shall be the primary software used to calculate heating and cooling loads, energy usage and costs for the three mechanical systems in the American Swedish Institute. Excel will also be used to compare the design requirements for the three systems to one another to determine the most energy and cost effective choice for the building.

Architectural Breadth

To determine the appropriate size for the walkway and the green roof on the top of the hallway, AutoCAD will be used to model the proper dimensions in comparison to the rest of the building. AutoCAD shall be used for modeling of the detailed sections for the different roof types. Additionally, the green roof shall be designed in Google SketchUp to demonstrate what visitors would see from the walkway when looking into the courtyard.

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[1] The American Swedish Institute © HGA Architects and Engineers, Minneapolis, MN.

Structural Breadth

Structural calculations for the green roof addition shall be completed by hand and correlate to the depths selected for the Architectural Breadth. From the material chosen for the green roof the proper weights shall be used to determine the dead loads on the roof. ASCE-7 will be used to calculate the snow loads and live loads for the different roof types. All loads shall be recorded in a table to compare the load changes for the composition of the green roof to the original structure.

Mechanical Depth 1: Water-to-Water Heat Pumps with Variable Air Volume Boxes

Background Information

For this depth VAV boxes will be implemented to supply conditioned air to the zones in the American Swedish Institute. Water-to-water heat pumps will be used to supply water from the geothermal system to the VAV boxes to heat the air additionally before being supplied to the space. There are two different types of VAV boxes; for the purpose of this project and the requirements of the building fan powered VAV boxes will be used. Fan powered VAV boxes close their dampers to supply the minimum amount of air specified by ASHRAE from the air handling unit, in this situation 30% minimal air flow is necessary for the zones. The rest of the air needed for the zone comes from the ceiling plenum where it is pulled through the VAV box and supplied to the zone. Selection of this type of VAV box was made because currently the return air goes into the plenum and is not ducted back to the Make-up Air Unit.

With a VAV system the boxes are designed to modulate airflow to save energy depending on the heating or cooling needed for the zone. Maintenance with a VAV system is increased due to more regular cleaning and tuning to maintain the proper airflows for continual energy savings. Thus requiring more stringent maintenance by the owner on an annual basis unlike other methods; increasing the annual maintenance costs. By having more VAV boxes located throughout the building floor-to-floor heights in the addition and mansion will change to accommodate for the VAV boxes. The floor-to-floor heights may increase or stay the same depending on location of the boxes. Since larger duct sizes for the VAV boxes are needed and a larger air handler located in the mechanical room usable space decreases. This method currently does not seem very economic for the mansion since there are limited opportunities for floor-to-floor heights to change; a final conclusion will be made upon the results found. From the results it will be verified that a VAV alternative will be more expensive initially but over the life of the building have larger energy savings.

Procedure

Loads and energy usage for the American Swedish Institute were calculated with Trane TRACE 700 software to calculate the total, monthly, and annual amounts for the building. These values were compared to the original system and typical values for similar building types to verify the building simulation so an accurate conclusion could be made about the system.

Cooling and heating loads were calculated using Trane TRACE 700 for the first alternative mechanical system utilizing VAV boxes. Only one system was calculated using this alternative for the American Swedish Institute. Total cooling and heating loads including %OA, cfm/ft^2, cfm/ton, ft^2/ton, and occupancy are shown below in Tables 6.1 and 6.2, respectively.

Cooling Loads for VAV Boxes					
	%OA	cfm/ft²	cfm/ton	ft²/ton	Occupancy
Existing and Addition	22.1	0.64	313.58	487.89	831

Table 6.1: Cooling Loads for Variable Air Volume Boxes

Heating Loads for VAV Boxes		
	%OA	cfm/ft²
Existing and Addition	51.3	0.23

Table 6.2: Heating Loads for Variable Air Volume Boxes

The %OA for the VAV system falls in the range for the heat pump system with a value of 22.1% for the cooling loads which can be seen above in Table 6.1. Heating loads %OA is outside the range for the original system with a value of 51.3% shown above in Table 6.2. This could be due to the fact that the VAV boxes draw more air in the heating mode then the heat pumps do thus increasing the amount of OA brought into the building. The larger %OA for heating in the American Swedish Institute can also be associated to the construction of the mansion which will require more heat in the winter months since the building envelope is poor in comparison to the newly constructed addition.

In a typical museum design the rule of thumb used for this type of building is between 250-350 ft²/ton. Comparing this rule of thumb to the calculated value for the VAV system it is seen that the value is outside this range with a total of 487.89 ft²/ton. Although the value is higher than a typical museum there are several reasons for this discrepancy. Since the schedules had to be created based on the hours the building was open and assumptions had to be made, the value of ft²/ton could be larger. As well as the poor construction of the mansion which will require more air to compensate for the loads experienced in those rooms. Overall, this value seems appropriate for the usage of the building since it is being used as a cultural center and museum.

Design Cooling		
Plant	**System**	**Peak Load (tons)**
Cooling	Existing and Addition	129.6

Table 6.3: Peak Design Cooling Load

Design Heating		
Plant	**System**	**Peak Load (MBH)**
Heating	Existing and Addition	1,150.9

Table 6.4: Peak Design Heating Load

Peak design cooling load for the American Swedish Institute occurs in June for the VAV system which can be seen above in Table 6.3. Comparison of the building peak load for the original system and the VAV system it is seen that the peak load for cooling is lower for the VAV system which is at 129.6 tons than the original system that has a peak load at 153.5 tons. The VAV system has a lower cooling peak load than the original because VAV boxes are more efficient and modulate dampers to compensate for load changes on the building than the heat pumps currently located throughout the building. For the VAV system the peak design heat load is 1,150.9 MBH which is shown above in Table 6.4. This peak heating load value is lower than the original system as well, due to the efficiency of the VAV boxes in comparison to the heat pumps.

An energy analysis was completed for the American Swedish Institute to determine the monthly and annual energy consumption and operating costs for the VAV system alternative. Rates for electricity and natural gas were based off values provided by Xcel Energy in Minnesota. $11.19/kW from June to September and $7.79/kW from October to May were used for the electrical rate. $0.59/therm from April to October and $0.65 from November to March were used for the natural gas rate. The same schedules created for the original system were used during the analysis of the VAV system; these schedules can be seen in Tables C.1-C.3 in Appendix C.

Once the schedules and information pertaining to space types were entered into Trace, an energy analysis was performed for the VAV system. Annual energy consumption for the whole building is shown below in Table 6.5. For this alternative it is seen below, that the primary utility used for heating is natural gas instead of electricity since the VAV boxes do not require as much electricity to run as the heat pumps in the original system. The heat pumps require 77,902 kWh from electricity and 66,748 kBtu from natural gas for primary heating which is 46% more electricity and 15% less natural gas than the VAV system. Overall 33% less kBtu/yr is used for heating in the VAV system than the original heat pump system. Cooling for the American Swedish Institute makes up approximately 15% of the total energy consumed for the building. Comparing the total primary cooling energy consumption to the original system it is seen that the VAV system uses 17% less kBtu/yr. This decrease in both heating and cooling lowers the costs spent on electricity annually. Fan energy also decreases dramatically with this alternative with a savings of 73% kBtu used per year.

Energy Consumption Summary					
System		**Elec (kWh)**	**Gas (kBtu)**	**Total(kBtu/yr)**	**% Total**
Primary Heating	Primary Heating	42,171	78,169	222,099	8.2
	Other	3,367	-	11,493	0.4
Primary Cooling	Cooling Compressor	118,309	-	403,788	14.9
	Tower/Cond Fans	305	-	1,041	0.0
	Other	158	-	538	0.0
Auxiliary	Supply Fans	33,790	-	115,325	4.3
	Pumps	65,782		224,515	8.3
Lighting	Lighting	490,330	-	1,673,496	61.6
Receptacle	Receptacles	18,843	-	64,310	2.4
Total		**773,055**	**78,169**	**2,716,604**	**100.0**

Table 6.5: Energy Consumption Summary

Looking at the total percentages for energy consumption in the American Swedish Institute per year it is seen that primary cooling and lighting are the largest totals. These values were compared to a typical public assembly's energy consumption provided by the Department of Energy to verify the accuracy of the results. As shown in Figure 2.1 earlier in the report the typical distribution in a public assembly building is as follows, heating load (44 %) accounts for the largest amount of energy usage in the building followed by cooling (15 %), lighting (10 %), and miscellaneous (9 %) loads.

Comparison of the values calculated by Trace it is seen that the heating load is much lower for the VAV system with a total percentage of 8.6, while the cooling energy consumption is equal to the typical value at 15%. The lighting loads are much larger than the typical values as well. The lower heating consumption can be explained by the use of a geothermal heat pump system instead of boilers as the primary source for heating. Larger lighting loads could be contributed to the amount of lighting used in the gallery spaces where artwork and the architecture are on display. Since museum's account for a small amount of the public assembly sector for commercial buildings the lighting loads could vary greatly to the average value used for this comparison.

Analysis of the electrical peak load for the main mechanical components was completed and can be seen below in Table 6.6. Comparison of the electrical peak load values for the VAV system to the original system it can be seen that the fan equipment decreases by 25% going from the original to the alternative. Electrical peak load for the VAV system is 171.15 kW where the original system uses 194.21 kW which is approximately 12% more than the alternative. Therefore, demonstrating that during peak load the VAV system uses less electricity saving on building costs.

Electrical Peak Load			
System		**Electrical Demand (kW)**	**% Total**
Cooling	Water Source Heat Pump	102.19	59.71
Fan Equip	Existing and Addition	10.84	6.33
Misc.	Lighting	55.97	32.70
	Equipment	2.15	1.26
Total		**171.15**	**100.0**

Table 6.6: Electrical Peak Load Summary

Monthly energy consumption for the American Swedish Institute using the VAV system is shown in Appendix D. The information provided includes the on peak consumption and on peak demand for electricity and gas. Overall building consumption is 42,952 Btu/ (ft^2*year) this is a total building consumption of 2.717x10^9 Btu/year. Building consumption for the year for the VAV system is 15% less than the original systems saving on the annual building operation.

The VAV system's annual cost breakdown for electricity is shown below in Table 6.7*.* As can be seen in the table, electricity is the major expenditure for the American Swedish Institute with a cost of $60,639.45. Overall operational cost for the building operating with a VAV system is $61,545.13. Annual operational costs decrease by 19% if a VAV system was chosen over the original heat pump system.

Annual Utility Breakdown		
Source	**Energy (10^6 Btu/yr)**	**Cost ($/yr)**
Electricity	2,638.4	60,639.45
Gas	78.2	905.68
Total	**2,717**	**61,545.13**

Table 6.7: Annual Utility Breakdown

Monthly costs are shown in Figure 6.1 below. As seen in the graph, the largest utility costs occur in the summer months between May and September with fluctuation in the early spring and fall months as the systems are supplying both heating and cooling. These monthly energy costs are lower than the original system saving the American Swedish Institute on annual energy costs.

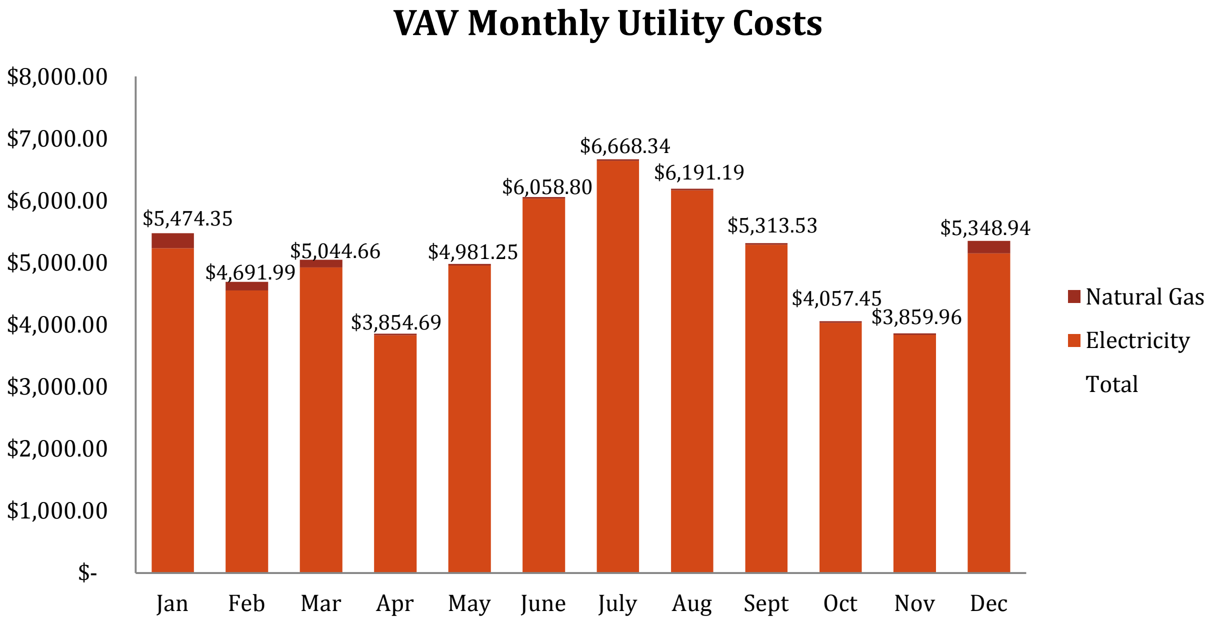

Figure 6.1: Monthly Energy Costs

The annual emissions footprint was reviewed as well for the VAV system to determine if the amount of emissions produced were less than the original system. Emission factors for electricity and natural gas were based on location and selected from the Regional Grid Emission Factors 2007 document. Results for the annual pound of CO_2, NO_x, SO_x, and PM10 produced by electricity and natural gas are shown below in Tables 6.8 and 6.9. Total emissions produced by the VAV system are 579 tons from electricity and 43 tons from natural gas. VAV system electricity emissions are 16% less than the original system's emissions produced. Natural gas emissions for the VAV system are 14% more than the original system's emissions produced which is due to the larger amount of natural gas used to supplement the heating needs of the building.

Electricity Emission Factors				
Pollutant	**lb of pollutant per kWh of electricity**	**Electric kWh per year**	**lb of pollutant**	**tons of pollutant**
CO_2	1.64	773,055	1,267,810	575
NO_x	3.00E-03		2,319	1
SO_x	8.57E-03		6,625	3
PM10	9.26E-05		72	-

Table 6.8: Emission Factors for Electricity

Natural Gas Emission Factors				
Pollutant	**Natural Gas per 1,000 cf**	**Natural Gas cf**	**lb of pollutant**	**tons of pollutant**
CO_2	1.22E+02	782	95,404	43
NO_x	1.11E-01		87	-
SO_x	6.32E-04		-	-
PM10	8.40E-04		7	-

Table 6.9: Emission Factors for Natural Gas

Summarized in Table 6.10 are the areas of the American Swedish Institute that are occupied by the VAV system. The mechanical room in the lower level of the addition and the shaft spaces located on all levels of the mansion and addition are included in this summary. Approximately a 55% increase in space will increase with the VAV system. The increase in mechanical shaft space is limited in the mansion since it is an existing building so expanding shaft sizes and ceiling heights is implausible in many parts of the building.

Section	Area (ft^2)
Addition	1,250
Mansion	150
Total	1400

Table 6.10: Area Occupied by Mechanical Space

Water-to-water heat pumps selected for the VAV system are models WRA 180 from McQuay to handle the heating and cooling loads. 10 heat pumps with an 188,648 Btu/hr capacity were selected to handle the 1,848,000 Btu/hr cooling needs of the American Swedish Institute. 7 of these heat pumps will handle the 1,150,899 Btu/hr heating capacity for the building. The 50 McQuay fan-powered parallel air terminal units, model MQFV15, were selected. VAV air handling model 107 was selected from McQuay with an airflow maximum at 48,400 cfm to supply the building with the required 40,627 cfm of supply air.

Mechanical first costs for the VAV system total $2,459,350 and $54.65 per square foot. This first cost accounts for the geothermal wellfield and piping at a total of $408,000. The 10 water-to-water heat pumps selected from McQuay cost approximately $1,400 per ton and can handle 16 tons per unit having a total cost of $224,000. A packaged VAV rooftop unit at 40,000 cfm costs approximately $240,000 for the unit. The 50 fan-powered VAV boxes selected from McQuay have a total cost of $160,000. All additional system components and the ones listed above the VAV system can be seen in Appendix E broken down by component, basis of estimate, quantity, units, cost per unit, and total cost.

Comparison of the VAV system to the original that costs $2,031,979, it can be seen that the heat pump system costs 17.3% more for the mechanical first costs. The additional $427,371 come from the water-to-water heat pumps, VAV boxes, and VAV rooftop unit selected for the first alternative. This system costs $9.49 per square foot more than the original heat pump system.

The VAV rooftop unit selected for this alternative will controlled with direct digital control (DDC) actuators. On-board controls will be used to provide a constant discharge temperature for all spaces located in the mansion and addition. Amount of outdoor air needed for the zones will depend on the demand needed for the spaces will be supplied through the VAV boxes. The system shall start and stop operation based on an occupancy schedule to provide enough outdoor air to the spaces located throughout the building. An additional water heating coil will be provided for additional heating for the VAV system to maintain an air temperature of 55°F in summer and 62°F in winter.

All VAV boxes located in the building are controlled with DDC to provide the minimum ventilation air of 30% to the spaces. If the building shall become negatively pressurized the DDC system shall open all VAV boxes towards fully open until the building becomes positively pressurized to the outdoors. Refer to Figure 6.2 for a ventilation schematic of the roof-top unit.

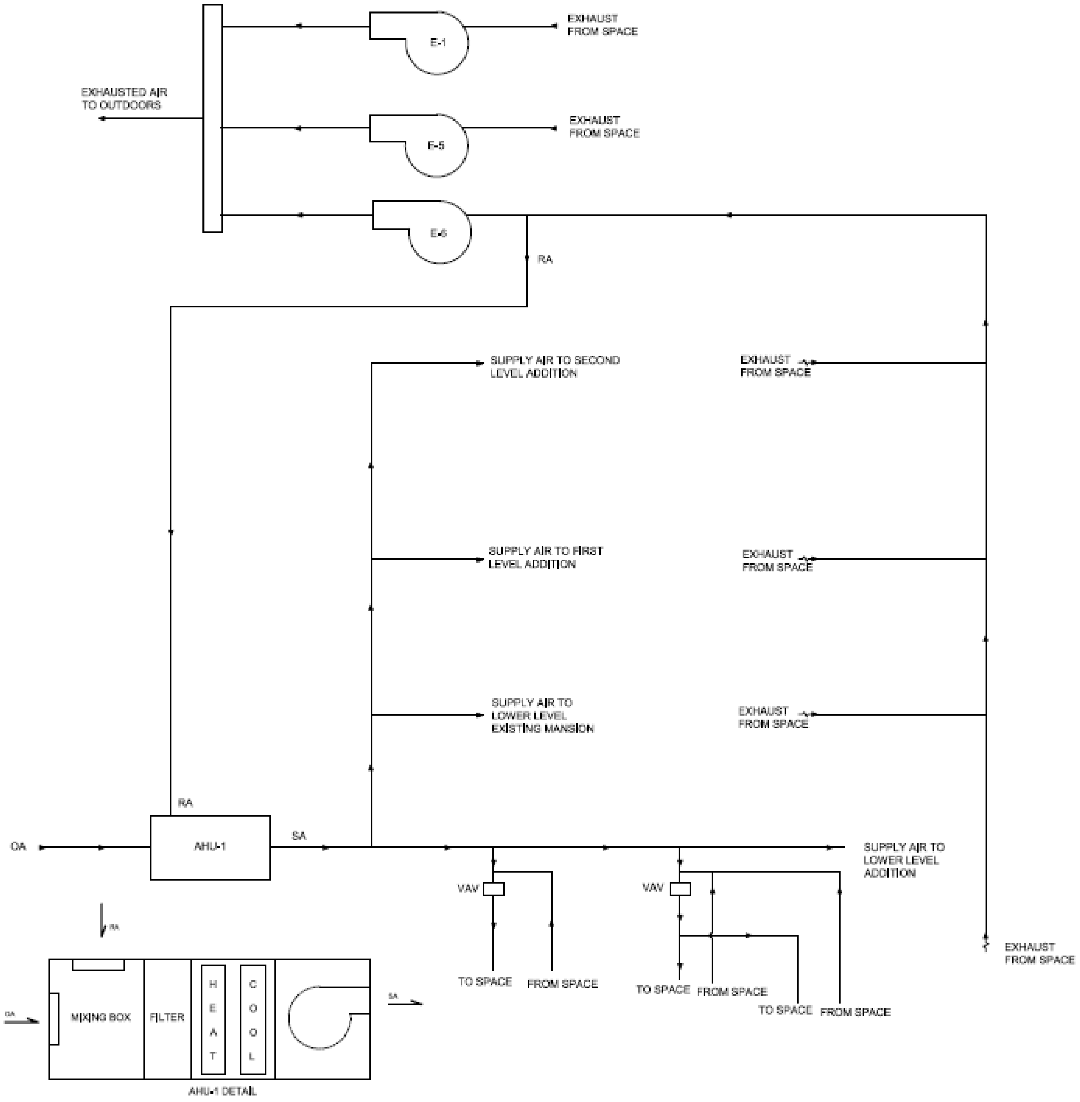

Figure 6.2: Ventilation Schematic for VAV System

Piping shall be routed similar to the geothermal system in the original design for this alternative, which will enter the building through valves and be monitored. Pumps CWP-1 through CWP-4 shall be used to supply water to the mechanical equipment in the building. Sensors shall be interfaced with the DDC system for monitoring of the temperature of the pipes from the geothermal field and the supply and return mains. Refer to Figure 6.3 below for a schematic of the geothermal system.

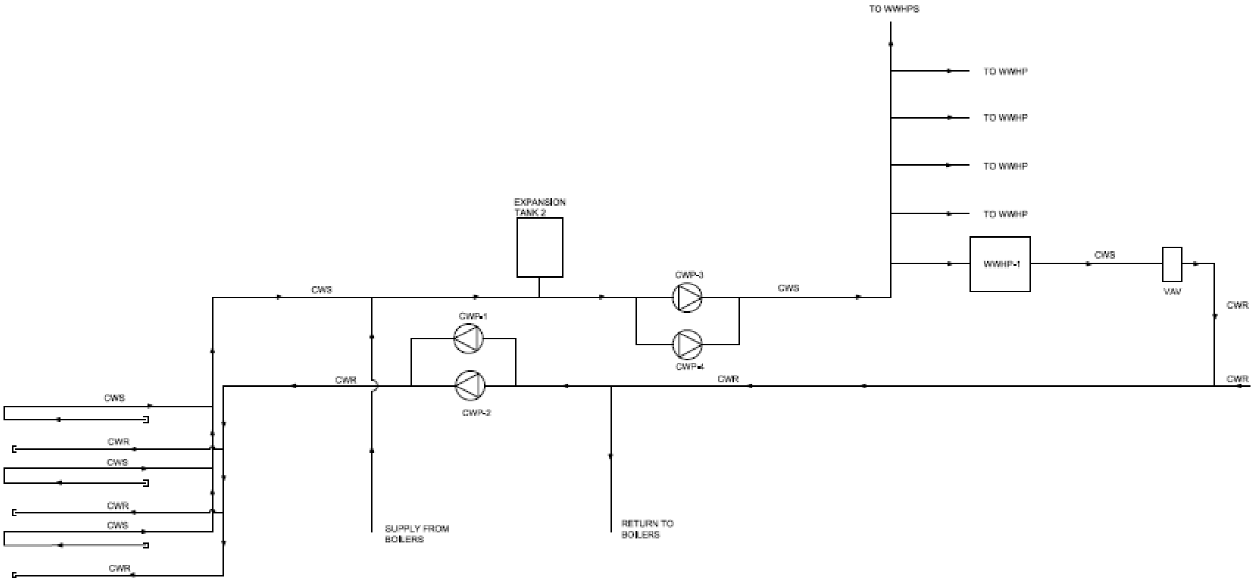

Figure 6.3: Geothermal Schematic for VAV System

For the VAV system, a 30-year life cycle cost analysis was performed to compare the chilled beam and original system to this alternative and can be seen in Table 6.12. Cost escalation factors for natural gas and electricity were taken from the National Institute of Standards and Technology (NIST) *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis -2011*. Natural gas and electricity escalation factors will be used to adjust the costs for electricity and natural gas for an annual basis. Table 6.11 summarizes the initial annual costs including maintenance, electricity and natural gas. Overhaul and capital costs are shown in Table 6.12 below.

Maintenance ($)	Annual Electricity Costs ($)	Annual Natural Gas Cost ($)	OMB Base Discount Rate (%)
44,285.00	60,639.45	905.68	3.0

Table 6.11: Initial Annual Costs

An Excel spreadsheet was created to calculate the total net present value (NPV) for the 30-year life cycle of the VAV system. The assumption of $44,285 per year for maintenance for the VAV system was made and can be seen above in Table 6.11. Total NPV analysis includes the capital investment for the system, overhaul, maintenance, annual electricity, and annual natural gas costs. Table 6.12 shows the values used to determine the total NPV for the life-cycle of the building with a total cost of $5,184,469.43 over a 30-year period.

MSYS 2 - VAV									
Year	Capital	Overhaul	Maintenance	Annual Recurring Electric	Annual Recurring Natural Gas	Electric Escalation	Nat Gas Escalation	Base Electric Cost	Base Nat. Gas Cost
1	$ 2,459,350.00	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	1.00	1.00	$ 60,639.45	$ 905.68
2	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.98	0.98	$ 59,426.66	$ 887.57
3	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.98	0.95	$ 59,426.66	$ 860.40
4	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.97	0.92	$ 58,820.27	$ 833.23
5	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.97	0.92	$ 58,820.27	$ 833.23
6	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.97	0.93	$ 58,820.27	$ 842.28
7	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.95	0.94	$ 57,607.48	$ 851.34
8	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.94	0.95	$ 57,001.08	$ 860.40
9	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.94	0.97	$ 57,001.08	$ 878.51
10	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.94	1.00	$ 57,001.08	$ 905.68
11	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.93	1.02	$ 56,394.69	$ 923.79
12	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.93	1.04	$ 56,394.69	$ 941.91
13	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.92	1.06	$ 55,788.29	$ 960.02
14	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.92	1.08	$ 55,788.29	$ 978.13
15	$ -	$ 249,600.00	$ 44,285.00	$ 60,639.45	$ 905.68	0.92	1.10	$ 55,788.29	$ 996.25
16	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.92	1.11	$ 55,788.29	$ 1,005.30
17	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.92	1.13	$ 55,788.29	$ 1,023.42
18	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.92	1.14	$ 55,788.29	$ 1,032.48
19	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.93	1.15	$ 56,394.69	$ 1,041.53
20	$ -	$ 544,100.00	$ 44,285.00	$ 60,639.45	$ 905.68	0.93	1.16	$ 56,394.69	$ 1,050.59
21	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.93	1.17	$ 56,394.69	$ 1,059.65
22	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.93	1.18	$ 56,394.69	$ 1,068.70
23	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.94	1.20	$ 57,001.08	$ 1,086.82
24	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.94	1.22	$ 57,001.08	$ 1,104.93
25	$ -	$ 81,600.00	$ 44,285.00	$ 60,639.45	$ 905.68	0.94	1.25	$ 57,001.08	$ 1,132.10
26	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.95	1.26	$ 57,607.48	$ 1,141.16
27	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.95	1.28	$ 57,607.48	$ 1,159.27
28	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.95	1.30	$ 57,607.48	$ 1,177.38
29	$ -	$ -	$ 44,285.00	$ 60,639.45	$ 905.68	0.95	1.32	$ 57,607.48	$ 1,195.50
30	$ -	$ 489,600.00	$ 44,285.00	$ 60,639.45	$ 905.68	0.95	1.34	$ 57,607.48	$ 1,213.61
NPV	$ 2,459,350.00	$ 702,145.05	$ 868,005.55					$ 1,125,017.99	$ 29,950.84
								Total	**$ 5,184,469.43**

Table 6.12: Life Cycle Cost for VAV System

A simple payback period calculation was completed for the VAV system in comparison to the original heat pump system. The VAV system will pay for itself in approximately 33 years based on the savings in fuel costs and the initial capital investment for the mechanical system.

Conclusion

Energy consumption and usage for a VAV system is more efficient than the original heat pump system. End use for the mechanical system broken down by HVAC options it is determined that the fan and pump energy decreases by approximately 46% when the VAV option was implemented. The cooling and heating energy also decrease by 17% and 31%, respectively. Equipment and lights have the same energy use between the two systems. The annual building consumption for the year is 42,952 Btu/ (ft^2*year) which is 15% less than the original heat pumps used saving on the overall building operation. Electricity for the American Swedish Institute is the major expenditure for the VAV system with a cost of $60,639.45. Total operational cost for the building is $61,545.13 annually which is 19% less than the original mechanical system.

Total first costs for the mechanical VAV system are $2,459,350 at $54.65 per square foot. Included in this first cost is the geothermal wellfield and piping, the 10 water-to-water heat pumps, a packaged rooftop unit and the 50 fan-powered VAV boxes. The additional components used in the VAV system can be seen in Appendix E. This alternative costs $427,371 more than the original heat pump system which costs $2,031,979, increasing first costs by 17.3%.

The life-cycle costs for the American Swedish Institute were completed for the VAV system during a 30-year life-cycle to calculate the total NPV. Included in the total NPV analysis is the capital investment of $2,459,350, overhaul costs occurring every 5 years shown in Appendix F, maintenance at an annual cost of $44,285, annual electricity costs of $60,639.45, and annual natural gas costs at $905.68. Total NPV for the American Swedish Institute implementing a VAV system is $5,184,469.43 over a 30-year period. The approximated payback period for the system is 33 years.

Overall, the VAV system has met the expectations set forth for this analysis based on energy usage, annual costs, and life-cycle costs. Initially the payback period was thought to be less than the 33 years determined based on the energy savings and initial investment. Upon further review the payback period seems realistic for the difference between the capital investment for the VAV system and the original heat pump system. Comparing the original to the VAV alternative the VAV alternative would be a good option for the American Swedish Institute. Due to the lower annual operating costs from the lower energy usage even though the initial investment would be more expensive.

Mechanical Depth 2: Water-to-Water Heat Pumps with Chilled Beams

Background Information

Chilled beams will be applied for this depth to supply the conditioned air to the spaces in the American Swedish Institute. Supply water for the chilled beams will come from water-to-water heat pumps that are connected to the geothermal system located on site. Two different options are available for chilled beams, active and passive, for this thesis active chilled beams shall be implemented in the building. Active chilled beams were selected for this application since they can achieve a larger cooling capacity than passive chilled beams. Working by passing primary air through a series of nozzles, active chilled beams induce air in the room into the chilled beam. This air enters a secondary water coil where the induced air is either cooled or heated to control room temperature. The induced air is mixed with the primary air and discharged into the room. The cooling coil in the chilled beams is supplied water ranging between temperatures of 56°F to 59°F which is close to the temperature of the water leaving the geothermal system which is between 53°F to 55°F.

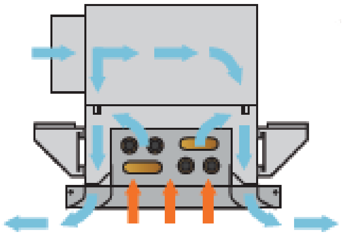

Figure 7.1: Active Chilled Beam[2]

Occupants shall be more comfortable with this system since the air delivery is more evenly distributed decreasing the chances of drafts in the space. Air flow patterns for the chilled beams can also be adjusted to direct the air flow in the direction as needed for the space configuration, compensation for any heat gain through the windows and comfort needs of occupants. Indoor air quality for the spaces using chilled beams will be improved since the minimum outdoor air ventilation rates are maintained with the constant supply of primary air through this system. The low maintenance required for chilled beams shall make it possible for the system to operate more efficiently with little work required by the owners. Chilled beams will need vacuumed once every 2 to 3 years to maintain optimum performance unlike VAV boxes that need maintenance annually.

With implementation of active chilled beams in the American Swedish Institute the primary airflow for spaces shall be reduced by approximately 50-67% of the air required to operate VAVs at peak cooling conditions. This reduction in airflow results in increased fan energy savings decreasing the size of the fan needed in the MAU and cutting costs of electricity supplied to the fan. These reductions in airflow and amount of electricity supplied to fan will be compared to the VAV system to verify that this is correct. Since chilled beams require more stringent controls to monitor temperature and humidity the gallery and storage spaces shall be better controlled.

Floor-to-floor heights in the addition shall be reduced because smaller ductwork and fans are required for the active chilled beam system. Space in the ceiling and mechanical room for the addition will also be maximized do to the smaller mechanical equipment and accessories. Initial cost for this alternative will be more expensive than the original and VAV system but should use the least amount of energy and have a quicker payback period; this will be confirmed from the results.

Procedure

Trane TRACE 700 was used to calculate the loads and energy usage for the American Swedish Institute to determine the monthly and total annual amounts. The tabulated values for the chilled beam system were compared to the original system and typical values for similar building types so an accurate conclusion can be made about the system.

Cooling and heating loads were calculated using Trane for the second mechanical alternative using active chilled beams and a Dedicated Outdoor Air Unit (DOAS). One chilled beam system was created for the American Swedish Institute to calculate the loads. The total cooling and heating loads are shown below in Tables 7.1 and 7.2 which include the %OA, %OA, cfm/ft^2, cfm/ton, ft^2/ton, and occupancy for the entire mechanical system.

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[2] ACBL © Copyright Price Industries Limited 2011

Cooling Loads for Chilled Beams					
	%OA	cfm/ft²	cfm/ton	ft²/ton	Occupancy
Existing and Addition	46.7	0.30	239.23	793.28	831

Table 7.1: Cooling Loads for Chilled Beams

Heating Loads for Chilled Beams		
	%OA	cfm/ft²
Existing and Addition	47.0	0.30

Table 7.2: Heating Loads for Chilled Beams

The %OA for the chilled beam system is outside the range of the %OA for the heat pump system with a value of 47.0% for the cooling and heating loads which can be seen above in Table 7.1. This larger %OA for the chilled beams in comparison to the heat pump system is due to the higher amount of OA required for the chilled beam system to maintain humidity levels in the building. Construction of the mansion could also be associated to the larger amount of %OA used in the system since the building envelope is poor construction in comparison to the newly constructed addition.

Rule of thumb typically used for museums is a cooling load between 250-350 ft²/ton. Comparison of this rule of thumb to the calculated value for the chilled beam system it is seen that the value is far outside the range given above with a total value of 793.29 ft²/ton. There are several reasons for the discrepancy of this value to the typical museum. The schedules had to be created based on the hours of operation found on the American Swedish Institute website from the hours the building was open during the week and weekends. Due to the assumption of building schedule the ft²/ton could be higher than the value would be if the correct schedules were used. The poor construction of the mansion would also affect the cooling load experienced on the building since this portion of the building requires more air to compensate for the loads experienced in these spaces. Cooling load per ft²/ton is in the range for the heat pumps used in the original system which range from 246.31-916.63 ft²/ton. Overall, this cooling load value seems appropriate for the application of the chilled beams in the museum.

Design Cooling		
Plant	**System**	**Peak Load (tons)**
Cooling	Existing and Addition	143.7

Table 7.3: Peak Design Cooling Load

Design Heating		
Plant	**System**	**Peak Load (MBH)**
Heating	Existing and Addition	1,663.8

Table 7.4: Peak Design Heating Load

Peak design cooling load for the American Swedish Institute occurs during the month of August for the chilled beam system based on the computer simulation completed by Trace which can be seen in Table 7.3

above. Comparing the building peak cooling load for the original system to the chilled beams the peak load for the cooling is 6.3% lower for the chilled beams at a value of 143.7 tons. The lower cooling peak load for the chilled beams is contributed to efficiency of the chilled beams which supply the required air for the space in comparison to the heat pumps. For the chilled beam system the peak heating load for the building is 1,663.8 MBH and can be seen above in Table 7.4. This peak heating load is 17% lower than the original system due to the efficiency of the chilled beams in comparison to the heat pumps.

An energy analysis was completed for the chilled beam system to determine the monthly and annual energy consumption and operating costs if the system was implemented in the American Swedish Institute. Rates were determined from the values provided by Xcel Energy in Minnesota for both electricity and natural gas. An electrical rate of $11.19/kW from the months of June to September and $7.79/kW from months October to May were selected. The natural gas rates for the American Swedish Institute are $0.59/therm from April to October and $0.65 from November to March were chosen. Schedules created for the original system were used for the chilled beam system for the most accurate comparison of energy usage; these schedules can be seen in Tables C.1-C.3 in Appendix C.

After the schedules and all information pertaining to the space types were entered in Trace an energy analysis was performed for the chilled beam system. Energy consumption for the whole building is shown below in Table 7.5 below for the annual kWh and kBtu for the building. As can be seen from the information below the utility used for primary heating is electricity since the chilled beams reheat the air before the air enters the space. Chilled beams require 50,873 kWh from electricity and 33,113 kBtu from natural gas for the primary heating which is approximately 35% less electricity and 50% less natural gas per year than the original system. The heating used by the chilled beam system is 31% less kBtu than the original heat pump system. Primary cooling for the chilled beams uses the largest amount of energy consumption per year with a total of 21.9%. Total primary cooling energy consumption for the original system is 21% less than the chilled beam alternative. This increase in the cooling energy used makes up for the heating decrease with chilled beams implementation. Fan energy decreases dramatically with the chilled beam alternative with a total kWh usage of 25,991 compared to the heat pumps which use 125,639 kWh and a decrease of 79%.

Energy Consumption Summary					
System		**Elec (kWh)**	**Gas (kBtu)**	**Total(kBtu/yr)**	**% Total**
Primary Heating	Primary Heating	50,873	33,113	206,741	7.4
	Other	810	-	2,764	0.1
Primary Cooling	Cooling Compressor	178,530	-	609,323	21.8
	Tower/Cond Fans	1,026		3,501	0.1
	Other	170	-	582	0.0
Auxiliary	Supply Fans	25,991	-	88,706	3.2
	Pumps	36,650		125,085	4.5
Lighting	Lighting	490,330	-	1,673,496	59.8
Receptacle	Receptacles	25,851	-	88,229	3.2
Total		**810,230**	**33,113**	**2,798,427**	**100.0**

Table 7.5: Energy Consumption Summary

Upon review of the energy consumption shown in Table 7.5 above, it is seen that the primary cooling and lighting are the largest totals experienced by the American Swedish Institute. The values calculated from Trace were compared to typical values for public assembly's energy consumption provided by the

Department of Energy (DoE) to verify accuracy of the tabulated results. As can be seen in Figure 2.1 located earlier in the report the typical distribution of energy in a public assembly building is 44% heating which accounts for the largest amount of energy usage, 15% cooling, 10% lighting, and 9% miscellaneous.

Comparing the tabulated values from Trace to the typical values from the DoE it was determined that the heating load is much lower for the chilled beam system with a total of 7.5%. Cooling energy consumption for the chilled beams is higher than the typical values with a total of 21.9%. Also the lighting loads are much larger than the typical values for public assembly buildings. With the use of a geothermal heat pump system instead of boilers for the primary heating the lower values for heating energy consumption can be explained. The larger primary cooling value could be due to the fact that chilled beams require a higher temperature to maintain humidity levels in the spaces so dewpoint is not reached which is around the geothermal water temperature; where the DOAS preconditions the air before entering the ducts to the chilled beams. Since two different water temperatures are required for this system more electricity would be used to cool the water down to lower temperatures for the DOAS requiring more energy consumption by the cooling compressor and condenser fans causing the increase in cooling energy. Larger lighting loads can be contributed to the amount of lighting that is used in the gallery spaces. Because museum type buildings account for a small amount of the public assembly sector for the commercial buildings the lighting loads could vary greatly to the average value used for this comparison.

Electrical peak load for the main mechanical components for the chilled beam system were completed and compared to the original mechanical system. Table 7.6 shows the electrical demand used by the water source heat pump for cooling, fan equipment, lighting, and miscellaneous equipment located in the American Swedish Institute. Chilled beam electrical peak load is 163.13 kW which is approximately 5% less than the original heat pump system that uses 171.5 kW. Fan equipment at peak demand for the building decreases significantly by 81% going from the original to the alternative. Overall, it is seen that the peak load for the chilled beams use less electricity during peak operation.

Electrical Peak Load			
System		**Electrical Demand (kW)**	**% Total**
Cooling	Water Source Heat Pump	101.24	62.06
Fan Equip	Existing and Addition	2.97	1.82
Misc.	Lighting	55.97	34.31
	Equipment	2.95	1.81
Total		**163.13**	**100.0**

Table 7.6: Electrical Peak Load Summary

The monthly energy consumption for the American Swedish Institute using the chilled beams is shown in Appendix D. Provided in the monthly energy consumption includes the on peak consumption and on peak demand for electricity and gas for a typical year. The overall building consumption is 44,246 Btu/ (ft^2*year) with a total annual building consumption of $2.798X10^9$ Btu/year. Building consumption for the chilled beams are 13% less per year than the original heat pump, saving on the annual building operation.

Annual Utility Breakdown		
Source	**Energy (10^6 Btu/yr)**	**Cost ($/yr)**
Electricity	2,765.3	64,953.16
Gas	33.1	556.70
Total	**2,798**	**65,509.85**

Table 7.7: Annual Utility Breakdown

Shown in Figure 7.2 below are the monthly costs for the chilled beam system. The largest utility costs for this mechanical system occur in the summer months from May to September similar to the VAV alternative. Fluctuation of costs from high to low can be seen in the early spring and fall months as the system supplies both heating and cooling. Monthly energy costs for the chilled beams are lower than the original saving the American Swedish Institute $9,027.78 on annual energy costs.

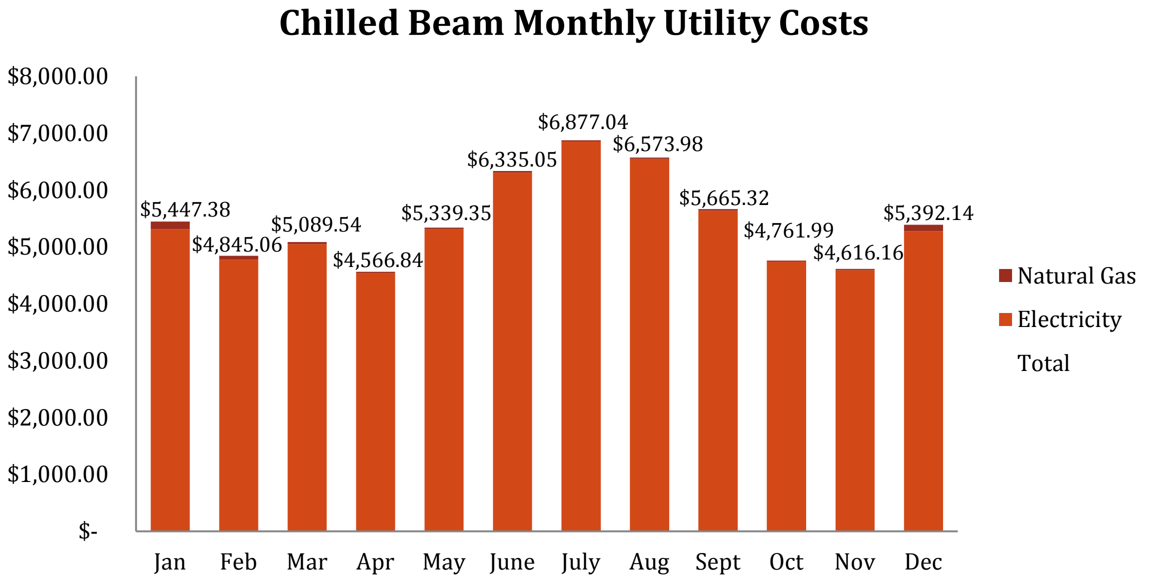

Figure 7.2: Monthly Energy Costs

Annual emissions were calculated for the chilled beam system to verify that the amount of emissions produced from electricity and natural gas use are less than the original heat pump system. The emission factors for electricity and natural gas were based on the location of the building which was selected from the Regional Grid Emission Factors 2007 document. Tables 7.8 and 7.9 below show the results for the annual pounds of CO_2, NO_x, SO_x, and PM10 produced by electricity and natural gas. A total of 607 tons from electricity and 18 tons from natural gas are emitted from the chilled beam system. The chilled beam electricity emissions are 12% less than the original system's emissions. Natural gas emissions for the chilled beam system are 51% less than the original system.

Electricity Emission Factors				
Pollutant	**lb of pollutant per kWh of electricity**	**Electric kWh per year**	**lb of pollutant**	**tons of pollutant**
CO_2	1.64	810,230	1,328,777	603
NO_x	3.00E-03		2,431	1
SO_x	8.57E-03		6,944	3
PM10	9.26E-05		75	-

Table 7.8: Emission Factors for Electricity

Natural Gas Emission Factors				
Pollutant	**Natural Gas per 1,000 cf**	**Natural Gas cf**	**lb of pollutant**	**tons of pollutant**
CO_2	1.22E+02	331	40,382	18
NO_x	1.11E-01		37	-
SO_x	6.32E-04		-	-
PM10	8.40E-04		3	-

Table 7.9: Emission Factors for Natural Gas

Table 7.10 summarizes the areas of the American Swedish Institute that are occupied by the chilled beams and DOAS unit. The areas located in this summary include the mechanical room in the lower level of the addition and the shaft spaces located on all levels of the mansion and addition. A 43% decrease in space will occur with the chilled beam system in comparison to the VAV system. Since increasing the mechanical shaft sizes in the mansion are limited because construction in the existing building is restricted to conserve the existing architecture, chilled beams are more applicable for the spaces located in the mansion and the addition.

Section	Area (ft^2)
Addition	725
Mansion	75
Total	800

Table 7.10: Area Occupied by Mechanical Space

An EP Series DOAS unit was selected with a range of 2,000 to 70,000 cfm from SEMCO to handle the 19,073 cfm needed for the system. The DOAS unit has an enthalpy exchanger that recovers both sensible and latent energy selected from SEMCO with a range of 840 to 78,000 cfm. Water-to-water heat pumps selected for the chilled beam system are models WRA 180 from McQuay and will handle the heating and cooling loads required for the building. 10 heat pumps with a capacity of 188,648 Btu/hr shall handle the cooling needs required for the building at 1,728,000 Btu/hr. 9 of the 10 heat pumps shall handle the 1,663,800 Btu/hr heating needs for the American Swedish Institute. 130 active chilled beams with a total linear footage of 546 were required for the mansion and addition. Information pertaining to the chilled beams can be seen in a table located in Appendix G that contains cfm per beam, nozzle size, beam length, Btu/h per beam, number of beams, head per beam, and other defining data. Example calculations for chilled beam sizing are shown below for a typical room in the mansion and the addition.

Mansion chilled beam calculation: (Library)

Taken from Trace: $Q_{T\ (Sensible)} = 6{,}480$ Btu/hr

$Q_{T\ (Latent)}$ = 1,000 Btu/hr
Q_{Total} = 7,480 Btu/hr

Type of room based on ASHRAE Standard 62.1-2007, Table 6.1:
Libraries: R_p = 5 cfm/person
P_z = 500 (ft^2) * 10/1000 (# person/ft^2) = 5 person
R_a = 0.12 cfm/ft^2
A_z = 500 ft^2
E_z = 1

V_r (cfm) = R_p*P_z + R_a*A_z (Equation 6.1)
V_r (cfm) = 5*5 + 0.12*500 = 85 cfm

T_v = 55°F, w_v = 0.0090 lb_w/lb_{DA}
T_{room}= 75°F, w_{room} = 0.0100 lb_w/lb_{DA}

Calculated: $Q_{(Latent)}$ = 4840*cfm*(w_{room} – w_v)
$Q_{(Latent)}$ = 4840*85 cfm*(0.0100-0.0090) lb_w/lb_{DA} = 411 Btu/hr

$Q_{(Sensible)}$ = 1.08*cfm*(T_{room} - T_v) °F
$Q_{(Sensible)}$ = 1.08*85 cfm*(75-55) °F = 1,836 Btu/hr

Need to recalculate V(cfm) because $Q_{T\ (Latent)}$ > $Q_{(Latent)}$ for cooling capacity of air

Recalculated V(cfm): $V(cfm) = \frac{Q_{T\ (Latent)}}{4840*(w_{room} - w_v)}$

$V(cfm) = \frac{1000\ Btu/hr}{4840*(0.0100-0.0090) lb_w/lb_{DA}}$ = 207 cfm

Capacity: $Q_{(sensible)}$ = 1.08*207 cfm*(75-55) °F = 4,463 Btu/hr

Check: $Q_{(sensible)}$ = 6480 Btu/hr – 4,463 Btu/hr = 2,017 Btu/hr

207 cfm required for the room

Selection made from Price manufacturer:
210 cfm per beam
Nozzle diameter of 0.300 inches
Beam Length = 6 ft
7,059 Btu/hr per beam
# of beams needed = 210/207 = 1
(# of beams is based on cfm or Btu/h requirement whichever has a larger number)
4.2 inches of head per beam
6 lf of beams needed

Addition chilled beam calculation: (Gust. Exterior Office)

Taken from Trace: $Q_{T\ (Sensible)}$ = 8,640 Btu/hr
$Q_{T\ (Latent)}$ = 235 Btu/hr
Q_{Total} = 8,875 Btu/hr

Type of room based on ASHRAE Standard 62.1-2007, Table 6.1:

Office Space: R_p = 5 cfm/person
P_z = 235(ft^2) * 5/1000 (# person/ft^2) = 1 person
R_a = 0.06 cfm/ft^2
A_z = 235 ft^2

E_z = 1

V_r (cfm) = R_p*P_z + R_a*A_z (Equation 6.1)
V_r (cfm) = 5*1+ 0.06*235 = 20 cfm

T_v = 55°F, w_v = 0.0090 lb_w/lb_{DA}
T_{room}= 75°F, w_{room} = 0.0100 lb_w/lb_{DA}

Calculated: $Q_{(Latent)}$ = 4840*cfm*(w_{room} – w_v)
$Q_{(Latent)}$ = 4840*20 cfm*(0.0100-0.0090) lb_w/lb_{DA} = 97 Btu/hr

$Q_{(Sensible)}$ = 1.08*cfm*(T_{room} - T_v) °F
$Q_{(Sensible)}$ = 1.08*20 cfm*(75-55) °F = 431 Btu/hr

Need to recalculate V(cfm) because $Q_{T\ (Latent)}$ > $Q_{(Latent)}$ for cooling capacity of air

Recalculated V(cfm): $$V(cfm) = \frac{Q_{T\ (Latent)}}{4840*(w_{room}-w_v)}$$

$$V(cfm) = \frac{235\ Btu/hr}{4840*(0.0100-0.0090) lb_w/lb_{DA}} = 49\ cfm$$

Capacity: $Q_{(sensible)}$ = 1.08*49 cfm*(75-55) °F = 1,049 Btu/hr

Check: $Q_{(sensible)}$ = 8,640 Btu/hr – 1,049 Btu/hr = 7,591 Btu/hr

49 cfm required for the room

Selection made from Price manufacturer:
51 cfm per beam
Nozzle diameter of 0.188 inches
Beam Length = 4 ft
3,823 Btu/hr per beam
# of beams needed = 7,591/3,823 = 1
(# of beams is based on cfm or Btu/h requirement whichever has a larger number)
3.0 inches of head per beam
8 lf of beams needed

Chilled beam first costs for mechanical system total $2,549,100.00 at $56.65 per square foot. Similar to the original heat pump and VAV system included in the first costs are the geothermal wellfield and piping that total $408,000.00. The 10 water-to-water heat pumps with a capacity of 16 tons per unit used for the chilled beams were the same as the ones selected for the VAV system that are from McQuay and cost $1,400 per ton and have a total cost of $224,000. DOAS unit selected from Semco cost approximately $58,000 and includes the cost for the energy recovery wheel in the unit. Costs for the active chilled beams located in the

American Swedish Institute were based on linear footage of beam with a total of 546 with a cost of $325 per linear foot, totaling $177,450. The additional system components used in this analysis can be seen in Appendix E which includes component, basis of estimate, quantity, units, cost per unit, and total cost.

Comparing the chilled beam alternative to the original heat pump system that costs $2,031,979, it was determined that the chilled beam system mechanical first costs are 20% more expensive. Chilled beam system costs $11.49 per square foot more than the original system. The additional $517,121 can be contributed to the 10 water-to-water heat pumps, chilled beams, and DOAS units implemented in the chilled beam alternative.

The DOAS unit selected for the chilled beam alternative will be controlled with direct digital control (DDC) actuators. There will be on-board controls to provide a constant discharge temperature for all the spaces located in the mansion and addition. Fans used in the DOAS unit shall be centrifugal plenum type. The control system used for temperature control shall include four linearised thermistor sensors including proportional, differential, frost prevention, and digital readout. Enthalpy recovery wheel shall have a digital performance display module to confirm the effectiveness of the energy wheel selected based on temperature readings recorded by the sensors and the set points of the controls. The amount of outdoor air required for the zones will depend on the demand of the spaces sensed by the chilled beams via thermostats located in the space. System shall start and stop operation based on the occupancy schedule to provide enough ventilation air during operating hours. All chilled beams located in the mansion and addition are controlled by DDC to provide the necessary air for the space to meet the demands of occupants. Refer to Figure 7.3 for a ventilation schematic of the DOAS unit.

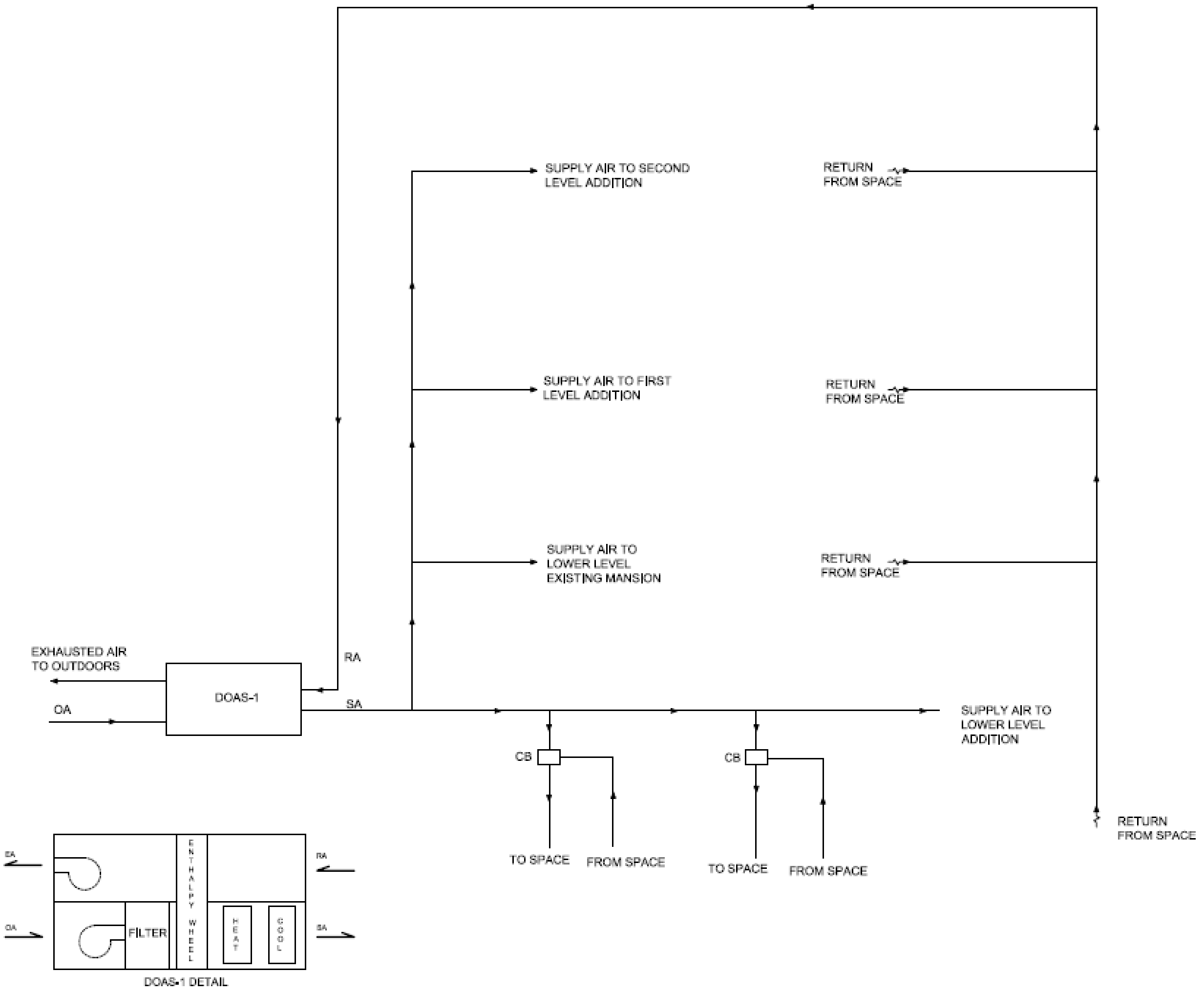

Figure 7.3: Ventilation Schematic for Chilled Beam System

All piping for the geothermal system shall be routed similar to the original system for the chilled beams located in the building. Water shall enter the building through valves and be monitored to verify accurate gpm and pressure values in the piping. Pumps CWP-1 and CWP-4 shall be used to supply the water from the geothermal wellfield to the mechanical equipment located in the building. There shall be sensors that are interfaced with a DDC system to monitor the temperature of the water in the pipes from the geothermal field to the supply and return mains located in the building. Refer to Figure 7.4 below for a schematic of the geothermal system.

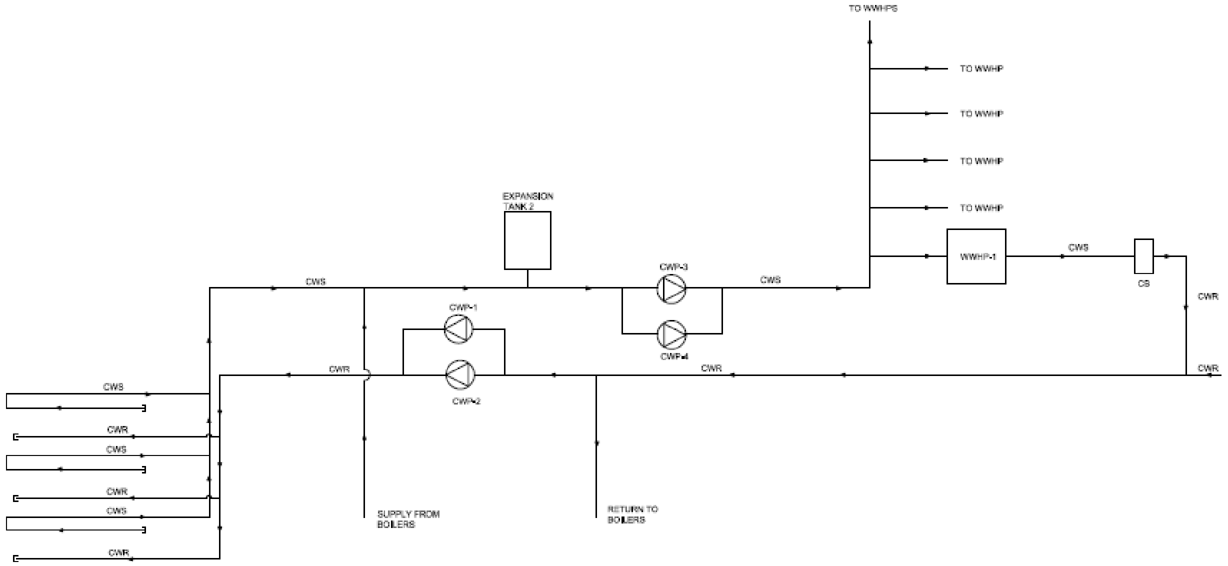

Figure 7.4: Geothermal Schematic for Chilled Beam System

A 30-year life-cycle cost analysis was completed for the chilled beam system to compare to the original heat pump system and VAV alternative. The 30-year life-cycle costs for the American Swedish Institute using chilled beams can be seen in Table 7.12 shown below which includes the capital investment, maintenance, overhaul, and energy costs for electricity and natural gas. Cost escalation factors were taken from the NIST *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis-2011* for natural gas and electricity. Natural gas and electricity escalation factors taken from NIST will be used to adjust the expected annual costs of electricity and natural gas through the 30 year life-cycle. Table 7.11 below summarizes the annual costs for maintenance, electricity, and natural gas initially. The overhaul and capital investment are shown in Table 6.12 for the 30 year period.

Maintenance ($)	Annual Electricity Costs ($)	Annual Natural Gas Cost ($)	OMB Base Discount Rate (%)
36,470.00	63,951.48	524.13	3.0

Table 7.11: Initial Annual Costs

Excel was used to create a spreadsheet to calculate the total net present value (NPV) for the chilled beam 30 year life-cycle costs. An assumption of $36,470 for maintenance costs per year was made for the chilled beam system which is shown above in Table 7.11. As stated above the total NPV analysis completed for the chilled beam system includes the first cost for the system, overhaul, maintenance, annual electricity and natural gas costs. The total NPV for the 30 year life-cycle of the building is $5,678,296.01 which is shown in Table 7.12 below.

MSYS 3 - Chilled beams									
Year	Capital	Overhaul	Maintenance	Annual Recurring Electric	Annual Recurring Natural Gas	Electric Escalation	Nat Gas Escalation	Base Electric Cost	Base Nat. Gas Cost
1	$ 2,549,100.00	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	1.00	1.00	$ 63,951.48	$ 524.13
2	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.98	0.98	$ 62,672.45	$ 513.65
3	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.98	0.95	$ 62,672.45	$ 497.92
4	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.97	0.92	$ 62,032.94	$ 482.20
5	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.97	0.92	$ 62,032.94	$ 482.20
6	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.97	0.93	$ 62,032.94	$ 487.44
7	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.95	0.94	$ 60,753.91	$ 492.68
8	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.94	0.95	$ 60,114.39	$ 497.92
9	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.94	0.97	$ 60,114.39	$ 508.41
10	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.94	1.00	$ 60,114.39	$ 524.13
11	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.93	1.02	$ 59,474.88	$ 534.61
12	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.93	1.04	$ 59,474.88	$ 545.10
13	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.92	1.06	$ 58,835.36	$ 555.58
14	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.92	1.08	$ 58,835.36	$ 566.06
15	$ -	$ 89,600.00	$ 36,470.00	$ 63,951.48	$ 524.13	0.92	1.10	$ 58,835.36	$ 576.54
16	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.92	1.11	$ 58,835.36	$ 581.78
17	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.92	1.13	$ 58,835.36	$ 592.27
18	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.92	1.14	$ 58,835.36	$ 597.51
19	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.93	1.15	$ 59,474.88	$ 602.75
20	$ -	$ 622,250.00	$ 36,470.00	$ 63,951.48	$ 524.13	0.93	1.16	$ 59,474.88	$ 607.99
21	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.93	1.17	$ 59,474.88	$ 613.23
22	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.93	1.18	$ 59,474.88	$ 618.47
23	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.94	1.20	$ 60,114.39	$ 628.96
24	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.94	1.22	$ 60,114.39	$ 639.44
25	$ -	$ 259,050.00	$ 36,470.00	$ 63,951.48	$ 524.13	0.94	1.25	$ 60,114.39	$ 655.16
26	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.95	1.26	$ 60,753.91	$ 660.40
27	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.95	1.28	$ 60,753.91	$ 670.89
28	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.95	1.30	$ 60,753.91	$ 681.37
29	$ -	$ -	$ 36,470.00	$ 63,951.48	$ 524.13	0.95	1.32	$ 60,753.91	$ 691.85
30	$ -	$ 147,600.00	$ 36,470.00	$ 63,951.48	$ 524.13	0.95	1.34	$ 60,753.91	$ 702.33
NPV	$ 2, 549,100.00	$ 586,568.54	$ 714,828.10					$ 1,810,466.40	$ 17,332.98
								Total	**$ 5,678,296.01**

Table 7.12: Life Cycle Cost for Chilled Beam System

Upon completion of the capital cost and energy savings for the building with the implementation of a chilled beam system and the original costs and energy savings for the heat pump system a simple payback calculation was done. Over a total of approximately 52 years the chilled beam system will pay for itself in energy savings per year and the initial capital investment.

Conclusion

After review of the results of the energy consumption and usage for the chilled beam system it was determined that the chilled beam system is more efficient than the original heat pump system. The end use for the mechanical system broken down by equipment, lights, fan and pumps, cooling, and heating it was determined that overall the chilled beam system uses 13% less kBtu/sf than the original system. With implementation of the chilled beams the end use fan and pump energy decreases by 66%, saving significantly on annual utility cost for electricity to run the fans and pumps used in the building. However, cooling energy for the building increases with chilled beams by 20% due to the larger requirement for cool preconditioned air to avoid condensation on the beams. Heating decreases by 39% with the chilled beam alternative saving on natural gas and electricity used for the equipment. Annual building consumption for the American Swedish Institute is 44,246 Btu/ (ft^2*year) which is 13% less than the original heat pumps saving on overall building operation every year. With a chilled beam system, electricity is still the major expenditure for the building with $64,953.16 spent every year to run the mechanical equipment using electricity. The total operational costs for the building are $65,509.85 annually which is 12% less than the original mechanical system utility costs.

The total first costs for the mechanical system are $2,549,100.00 at $56.65 per square foot. First costs included are the geothermal well field and piping, the 10 water-to-water heat pumps, a DOAS unit and the 546 linear feet of active chilled beams. Additional components used in the chilled beam cost analysis are shown in Appendix E. Overal the alternative costs $517,122 more than the original heat pump system which costs $2,031,979, increasing first costs by 20% for this alternative.

A life-cycle cost analysis was completed for the American Swedish Institute if a chilled beam system was implemented for a 30 year period to calculate the total NPV. Included in this NPV calculation are the capital investment of $2,549,100, overhaul costs occurring every 5 years that are shown in Appendix F for breakdown, maintenance at an annual cost of $36,470, annual electricity cost of $64,953.16, and annual natural gas cost of $556.70. The total NPV for the chilled beam system is $5,678,296.01 over a 30-year period. An approximated payback period of 52 years for the system was calculated from the energy savings between the chilled beam and original system and the capital investments for both.

Overall, the chilled beam system for the most part has met the expectations set forth by this analysis from the energy usage, annual costs, and life-cycle costs determined. The discrepancy that was found for this alternative to the original and first alternative was the increase in cooling needed to meet the loads for the building. A possible reason for this is due to the requirement of the air being provided to the chilled beams to be conditioned enough so dewpoint does not occur on the chilled beams. Additionally, the receptacle loads for the building increased with this alternative since the implementation of chilled beams get added to the receptacle loads for the building due to the way they are connected in the mechanical system. The payback period is much higher for the chilled beam alternative than the VAV system but could still be a feasible option for the American Swedish Institute because the building has been in existence since 1905. Comparison of the original heat pumps to the chilled beam alternative, the chilled beam system would be an option that could be offered to the owners although the payback period could be a deterrent for this selection.

Breadth 1: Architectural

Background Information

A green roof was explored for this breadth for the social, aesthetic and environmental benefits associated with this technology. By adding a green roof to this walkway, occupants in the upper stories of the American Swedish Institute will no longer see asphalt but instead plants that reflect the landscaping in the central courtyard. For this breadth the green roof will be added onto the walkway connecting the mansion and addition. The two options of green roofs looked at for the walkway, were extensive and intensive. Additionally, by having a green roof on the walkway Swedish ideals of sustainability will be reflected in this area.

Procedure

Green roofs that were selected for this breadth are from the LiveRoof Hybrid Green Roof System manufacturer website. LiveRoof green roofs were chosen since they are easier to transport and install due to their modular design. The two green roofs selected from the manufacturer were the LiveRoof Lite and LiveRoof Maxx systems. LiveRoof Lite green roof was selected for the extensive system which has approximately 2 ½" soil depth and is ideal for applications with load limitations which is shown in Figure 8.1 below. This option has many different plant selections ranging from ground covers, water conserving accent plants, and spring blooming bulbs. The intensive green roof selected for the other option is the LiveRoof Maxx system which has approximately 8" soil depth that is used to optimize biodiversity this can be seen in Figure 8.2. Plant selections range from ground covers to drought tolerant native and perennials as well as non-native adapted perennials, grasses and vegetables.

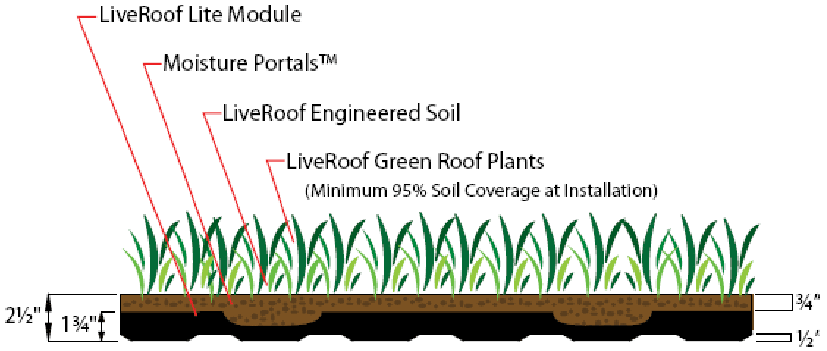

Figure 8.1: LiveRoof Lite Green Roof [3]

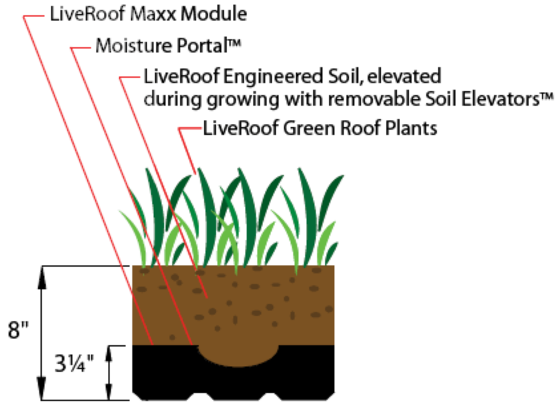

Figure 8.2: LiveRoof Maxx Green Roof [4]

The LiveRoof Lite and Maxx green roofs were modeled as sections in AutoCAD to compare the difference in layers and thicknesses to the original roof design. The results of these sections can be seen below in Figures

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[3] © LiveRoof Hybrid Green Roof System manufacturer
[4] © LiveRoof Hybrid Green Roof System manufacturer

8.3-8.5. As can be seen below in Figure 8.4, the LiveRoof Lite green roof has more layers of insulation in comparison to the original roof and the LiveRoof Maxx seen in Figures 8.3 and 8.5, respectively.

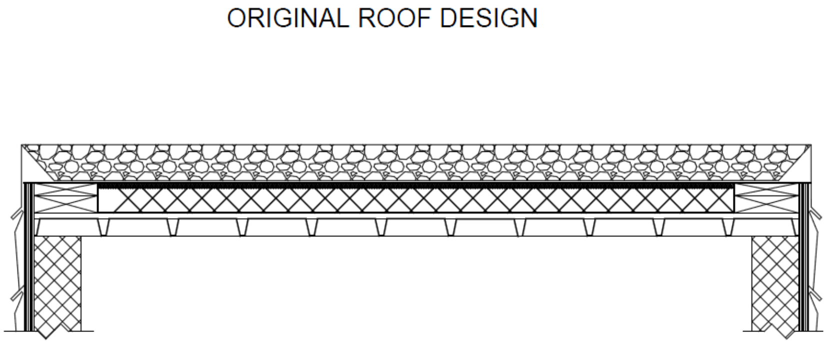


Figure 8.3: Original Roof Section

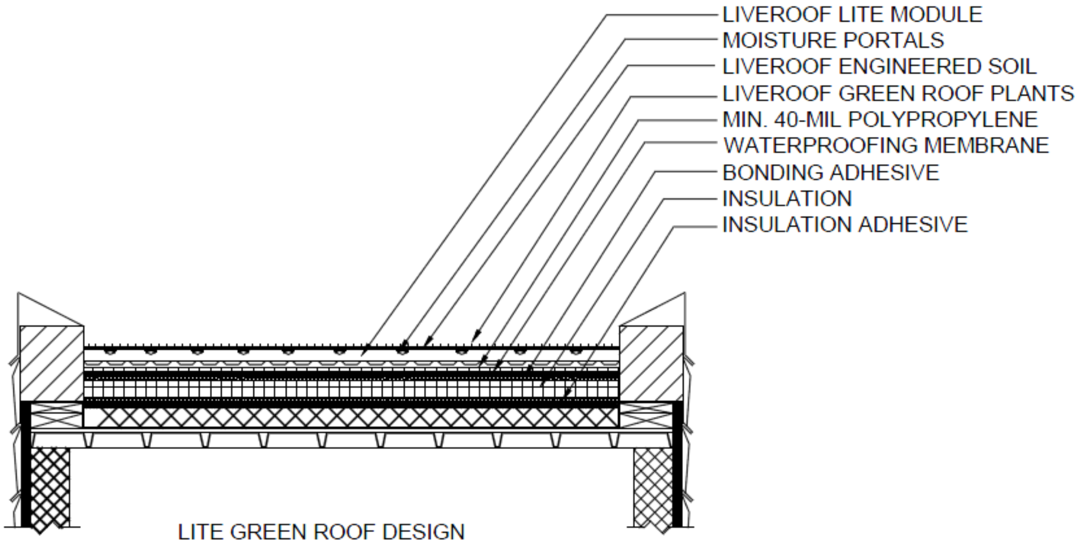


Figure 8.4: LiveRoof Lite Green Roof Section

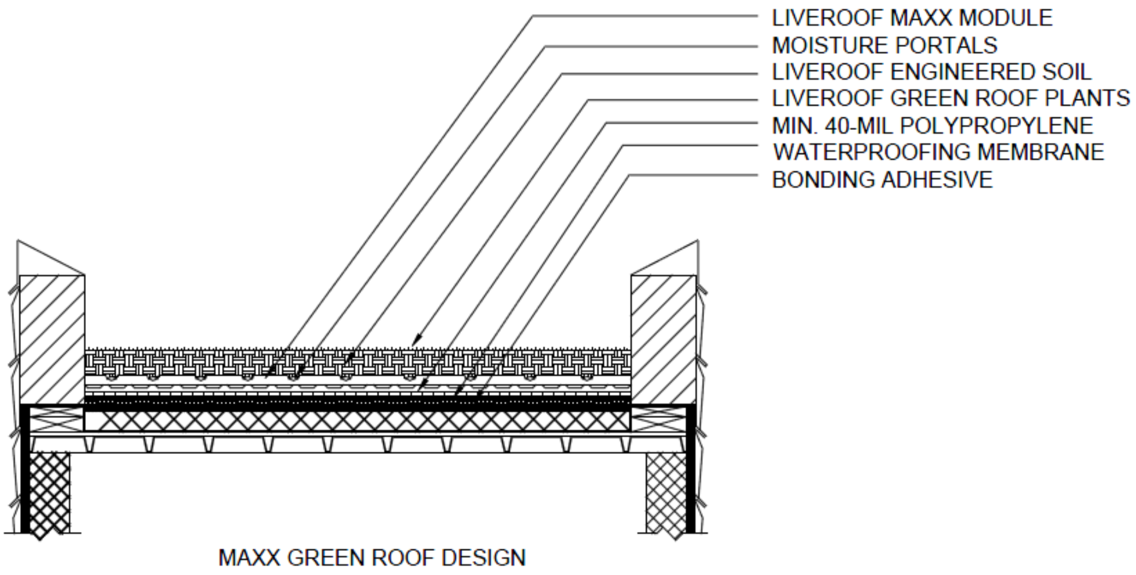


Figure 8.5: LiveRoof Maxx Green Roof Section

A 3-D model was created to help visualize how the addition of a green roof would look on the walkway. Google Sketchup was used to create this model, Figure 8.6 shown below, represents how the green roof would look on the walkway connecting the addition and mansion.

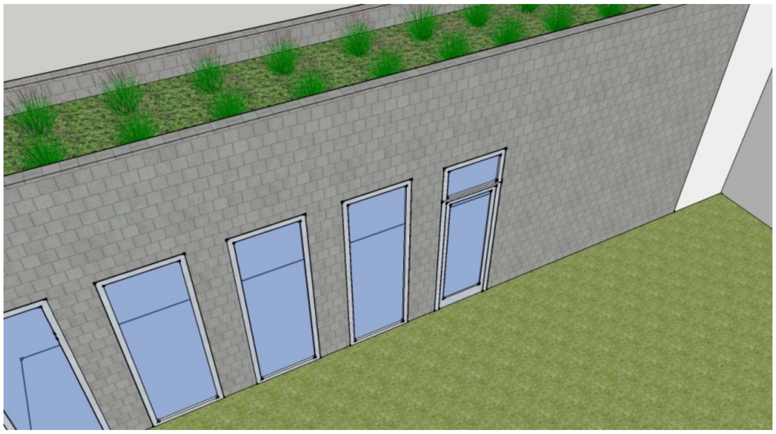


Figure 8.6: 3-D Model of Green Roof on Walkway

Conclusion

Both options are inexpensive due to lower maintenance and installation costs for the life of the green roof selected from LiveRoof. The cost for the LiveRoof Maxx (intensive) is approximately $19/sf and LiveRoof Lite (extensive) is approximately $12/sf. Since the American Swedish Institute already has two extensive green roofs located on the second story roof of the addition an extensive green roof was implemented for this breadth. The major reason for this decision is to keep consistency with the green roof design on the addition. Economically the extensive green roof is a cheaper alternative to the intensive green roof which requires more dirt. Even though the intensive green roof does not have additional insulation since it was assumed that the 8 inches of soil would account for the necessary insulation required for the walkway, as can be seen above in Figure 8.5. Although an extensive green roof was decided for this breadth, the structural breadth shall look at both options before a final conclusion is made.

Breadth 2: Structural

Background Information

For the proposed breadth of a green roof on the walkway connecting the mansion and addition, structural calculations were completed to see the effect of load changes on roof decking. Two different types of green roofs were analyzed for the walkway, extensive and intensive. The weights for the extensive and intensive green roofs were taken from the LiveRoof Hybrid Green Roof System manufacturer website. This manufacturer was selected because it provides modules for easy installation for an instant green roof and has options of wide plant diversity. Saturated weight values used for the structural calculations for the LiveRoof Lite and LiveRoof Maxx system are 17 psf and 65 psf, respectively.

Procedure

Structural calculations for the original roof system were completed first for this breadth and can be seen below; all calculations for the green roof systems selected are shown in Appendix H. For all roof and composite deck calculations dead load were determined based on weights of metal deck, rigid insulation, built up roof, fenestration system, saturated green roof, slab weight and miscellaneous dead load depending on the case. The flat roof snow load for Minneapolis, MN was used for all calculations. Depending on the type of roof whether it was the existing, extensive or intensive green roof two different roof live loads were used either a 20 psf for a typical roof or a 100 psf load for an accessible roof garden. Total loads were calculated based on the factored load equation, R_u. All decking selected for the roofs were taken from Vulcraft Steel Roof and Floor Deck catalog 2008.

Since the intensive green roof has larger dead and live loads associated with it three different options were completed; the first and second option will just use composite deck in different gauge sizes and the third option will use composite deck in combination with steel joists. The last option was done because smaller deck can be used for composite deck when steel joists are used in combination with this decking. All concrete used for composite deck calculations was lightweight concrete.

Original Roof Deck Calculation

Dead Load: D = 25 psf
    Metal Deck: 2 psf
    Rigid Insulation: 2 psf
    Built up Roof: 16 psf
    Misc. Dead Load: 5 psf   (includes ceiling, sprinklers, mechanical and plumbing)

Snow Load: p_g = 50 psf   (from Figure 7-1 for Minneapolis, MN)
    Calculating:
    Flat Roof Snow Loads, p_f (From ASCE-07, Section 7.3)

    $p_f = 0.7C_eC_tIp_g$ [psf]   (From ASCE-07, Equation 7-1)

From Section 7.3.4 p_f cannot be less than the following minimum values for low slope roofs where p_g exceeds 20 lb/ft^2:

$P_f = 20(I)$ [psf]

C_e (Exposure factor) = 1.0 (From ASCE-07, From Table 7.2)
C_t (Thermal factor) = 1.0 (From ASCE-07, From Table 7.3)
I (Importance factor) = 1.0 (From ASCE-07, From Table 7.4; Category 2)

$p_f = 0.7(1.0)(1.0)(1.0)(50) = 35$ psf

Use $p_f = 35$ psf for flat roof snow load; S = 35 psf

Roof Live Load: $L_r = 20$ psf

Factored Loads: (Use equation 3 from ASCE 7-10 Section 2.3)

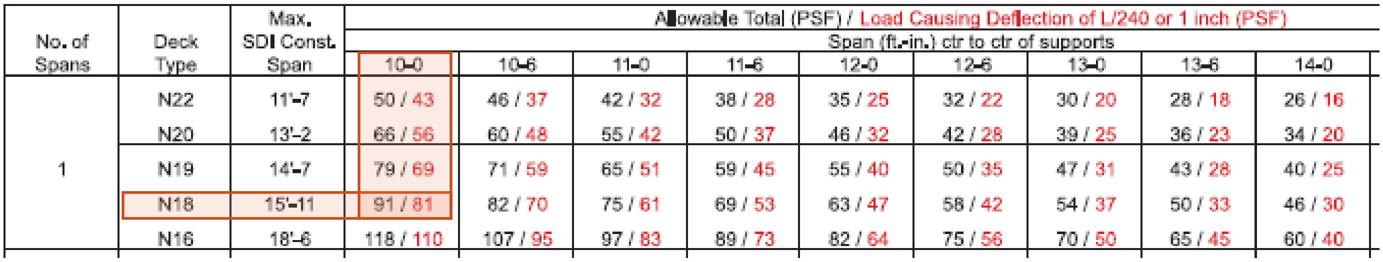
$R_u = 1.2D + 1.6(S \text{ or } L_r) + L$ (L=0)
Use S controls in equation since $S > L_r$

Therefore,
$R_u = 1.2D + 1.6S$

$R_u = 1.2(25) + 1.6\ (35) = 86$ psf

From Vulcraft Steel Roof and Floor Deck catalog 2008 shown in Figure 9.1 below.

Use 3N with number of spans of 1, 8’-4”
Use deck type N18
Max. SDI Construction Span = 15’-11” > 8’-4” check
For 10’-0” Total Load = 91 psf >86 psf
Checking with the addition of actual roof deck weight:
Dead Load metal deck weight for N18 is 3.56 psf
Total Dead Load: 29 psf
$R_u = 1.2(29) + 1.6(35) = 91$ psf which is equals the 91 psf maximum therefore, still works.



No. of Spans	Deck Type	Max. SDI Const. Span	Allowable Total (PSF) / Load Causing Deflection of L/240 or 1 inch (PSF)								
			Span (ft.-in.) ctr to ctr of supports								
			10-0	10-6	11-0	11-6	12-0	12-6	13-0	13-6	14-0
1	N22	11’-7	50 / 43	46 / 37	42 / 32	38 / 28	35 / 25	32 / 22	30 / 20	28 / 18	26 / 16
	N20	13’-2	66 / 56	60 / 48	55 / 42	50 / 37	46 / 32	42 / 28	39 / 25	36 / 23	34 / 20
	N19	14’-7	79 / 69	71 / 59	65 / 51	59 / 45	55 / 40	50 / 35	47 / 31	43 / 28	40 / 25
	N18	15’-11	91 / 81	82 / 70	75 / 61	69 / 53	63 / 47	58 / 42	54 / 37	50 / 33	46 / 30
	N16	18’-6	118 / 110	107 / 95	97 / 83	89 / 73	82 / 64	75 / 56	70 / 50	65 / 45	60 / 40

Figure 9.1: 3N Roof Decking from Vulcraft Steel Roof and Floor Deck Catalog 2008, page 10

Conclusion

After calculation of the three systems, the original thermoplastic single ply roofing and two green roofs, five different decking types were selected for the walkway. A summarized table of all loads and decking used for each system can be seen below in Table 9.1. The original roof uses a 3 inch 18 gauge decking that spans from East to West. 3 inch 16 gauge roof decking was selected for the extensive green roof since the loads only increased by 6 psf when going from the original roofing to the LiveRoof Lite green roof.

Due to the dramatic increase of dead and live load weight for the LiveRoof Maxx green roof three different options were examined; all calculations can be seen in Appendix H. Composite decking was used for all of these options since the factored load, R_u, exceeded the maximum roof decking load. Option 1 for the intensive green roof used a 2VLI16 deck with a total slab depth of 5 ½" for the specified conditions. The system was analyzed a second time and used 3VLI16 with a total slab depth of 6". With the larger weights for the intensive green roof a third option was evaluated that incorporated composite decking with steel joists. For option 3, 1.5VLI18 decking was used with a total slab depth of 4" and used 18KCS3 open web steel joists. Although for this calculation 1.5VLI19 decking would work for this application 1.5VLI18 was selected since 18 gauge is common for most steel deck applications and was used throughout the American Swedish Institute. With the third option a smaller deck can be selected decreasing costs for the concrete and steel deck.

If this was a real life situation whichever option was selected for the roofing, masonry and foundation calculations would need to be completed to verify the structure can handle the additional load. This type of calculation is outside of the scope of this proposal and was not completed for this breadth.

Loads and Decking								
	Dead Load (deck real weight)	**Roof Live Load**	**Snow Load**	**R_u (control S or L_r)**	**Span**	**Roof (R) or Composite (Co)**	**Slab Depth**	**Steel Joists**
3N18	29	20	35	91 (S)	8'-4"	(R)	-	-
3N16	34	20	35	97 (S)	8'-4"	(R)	-	-
2VLI16	119	100	35	303 (L_r)	8'-4"	(Co)	5 ½"	-
3VLI16	119	100	35	303 (L_r)	8'-4"	(Co)	6"	-
1.5VLI18	105	100	35	286 (L_r)	6'-0"	(Co)	4"	18KCS3

Table 9.1: Loads and Decking

Below is a roof plan (Figure 9.2) showing the span for the roof deck for the original and LiveRoof Lite system, this plan also represents the roofing plan for the LiveRoof Maxx system options 1 and 2. Option 3 for the LiveRoof Maxx system can be seen in Figure 9.3 below which shows the direction of the decking and joists used for this case.

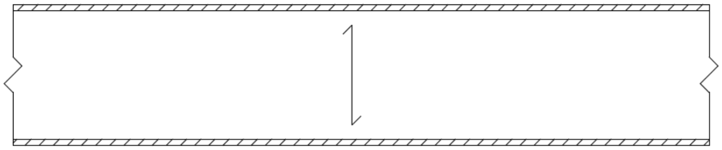


Figure 9.2: Roof Plan (Original, LiveRoof Lite and LiveRoof Maxx Options 1 and 2)

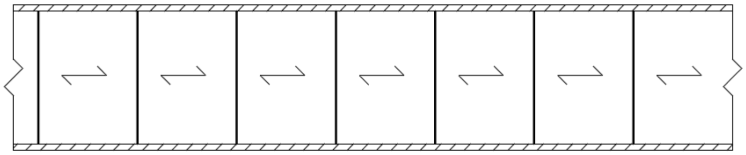


Figure 9.3: Roof Plan (LiveRoof Maxx Option 3)

Conclusion

Mechanical Depth

The analysis of the VAV system versus the chilled beam system proves that the VAV alternative is the better option. There are several reasons why the VAV alternative would be selected over the chilled beam option. Comparing the results of the annual energy use for the HVAC option based on end use operation it can be seen in Figure 10.1 below, that the VAV system uses 43.11 kBtu/sf. Although the chilled beam alternative fan and pump energy use decreases significantly from the original and VAV alternative by 68% and 41%, respectively. However there is a considerable increase in cooling energy use causing the chilled beams to use more energy than the VAV system by 35%. A possible reason for this additional cooling being used by the building could come from the requirement that the supply air entering the chilled beams be below dewpoint so condensation does not occur. Since the air has to be below dewpoint the air would be preconditioned to a cooler temperature so condensation does not happen increasing the cooling energy use. Overall, the VAV system uses 15% less energy than the original system and 3% less than the chilled beam system. Since there is such a small difference in the energy usage between the VAV and chilled beam alternative either system could actually be implemented by the American Swedish Institute. The energy costs for the VAV system are $61,545.13 per year this is shown below in Figure 10.2. Included in this graph are the total energy costs for the original heat pump and chilled beam system. The majority of the costs for the VAV system is electricity that has a total of $60,639.45 spent annually. Annual costs spent on electricity and natural gas for the VAV alternative are 17% less than the original system and 6% less than the chilled beam alternative.

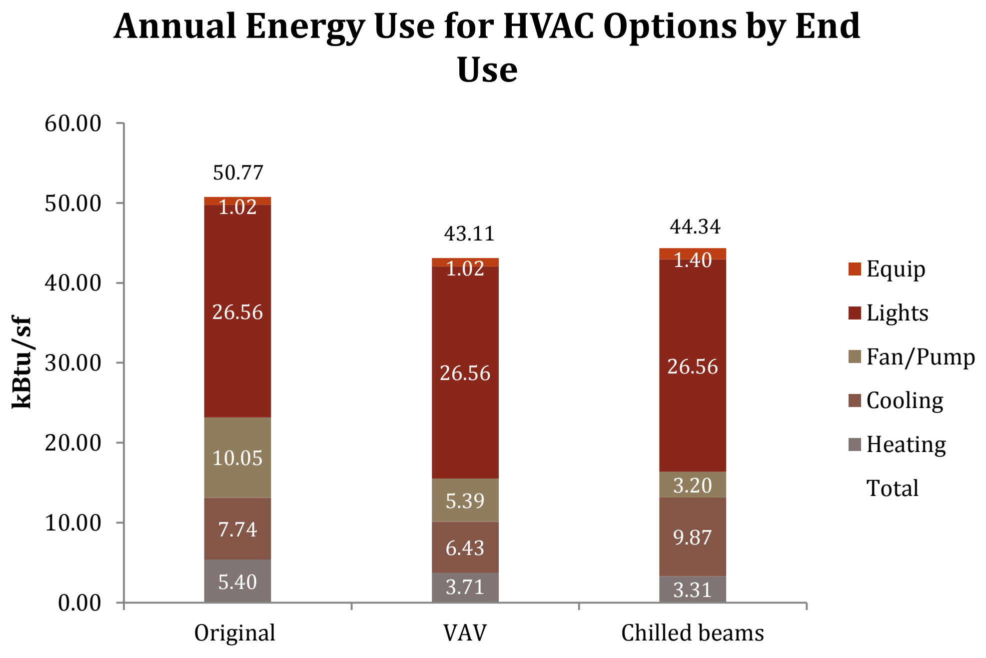


Figure 10.1: Annual Energy Use for HVAC Options by End Use

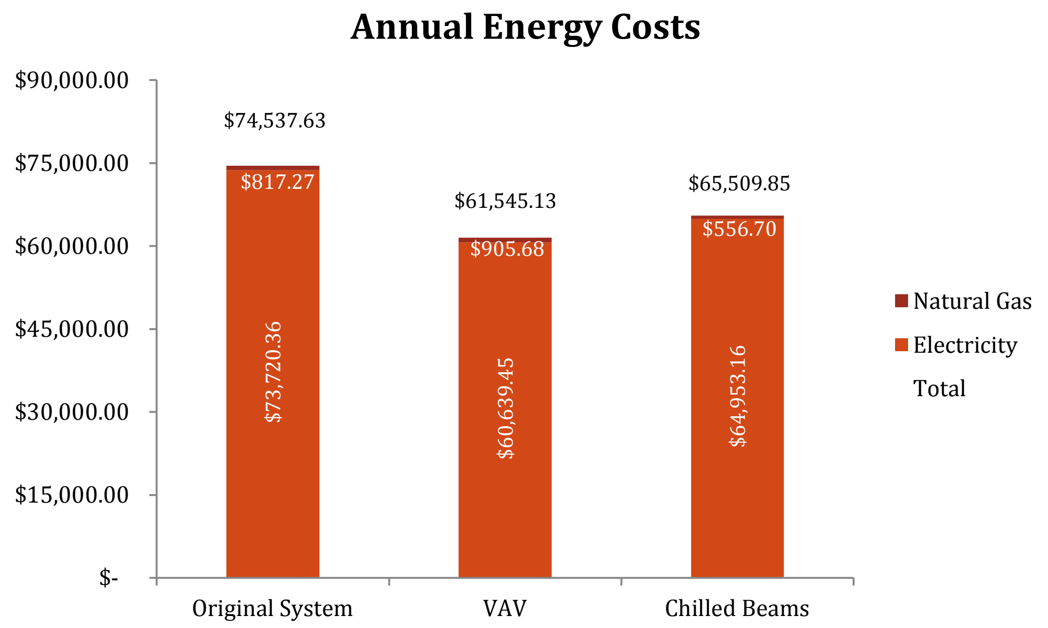


Figure 10.2: Annual Energy Costs

Total annual Carbon emissions produced from electricity for the three systems are shown below in Figure 10.3. As can be seen from the figure the Carbon emissions produced from the VAV system are the lowest out of the three systems with a total of 575 tons per year. The emissions from the VAV system are 16% less than the original heat pump system and the 5% less than the chilled beam alternative.

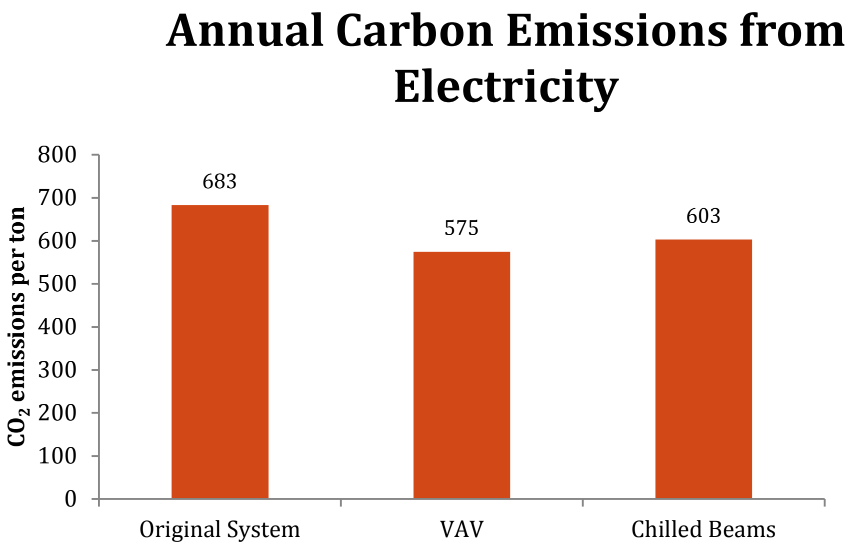


Figure 10.3: Annual Carbon Emissions from Electricity

First costs, annual maintenance, overhaul, annual electric and natural gas costs and life-cycle information is shown below in Table 10.1. With respect to first cost, the VAV system is $427,371 cheaper in mechanical equipment and labor than the original heat pump system. Estimated maintenance costs decrease between the three systems as efficiency increases where the chilled beams require the least amount of maintenance annually decreasing the costs spent on personnel and equipment. Overall the VAV system costs 17% more than original heat pumps and 4% less than the chilled beam alternative. Comparing the life-cycle costs between the three systems, shown in Figure 10.4 below, the chilled beam alternative is the most expensive option. The VAV system costs 9% less than the chilled beams and costs 4% more than the heat pumps. Although the VAV system has a higher life-cycle cost over the 30 year period, the annual energy savings from this system compared to the heat pumps and chilled beams make this investment worthwhile. Approximated payback for the VAV system is 33 years which is less than the chilled beams with a payback of 52 years.

Life-cycle Costs Input Table			
LCC Duration		30	years
Discount Rate		3.0%	Based on NIST from published year 2011
Fuel Escalation Rates		Average values	
	Electricity	0.94	Based on 30 – year projections by the DOE
	Natural Gas	1.10	Based on 30 – year projections by the DOE
	Water	0	

System		MSYS1	MSYS2	MSYS3
Description		Original	VAV	Chilled Beams
HVAC System First Cost		$ 2,031,979.00	$ 2,459,350.00	$ 2,549,100.00
Estimated Utility Incentive		$ -	$ -	$ -
Total First Cost		$ 2,031,979.00	$ 2,459,350.00	$ 2,549,100.00
Annual Maintenance Cost		$ 52,100.00	$ 44,285.00	$ 36,470.00
Replacement costs thru year:				
	5	$ -	$ -	$ -
	10	$ -	$ -	$ -
	15	$ 275,500.00	$ 89,600.00	$ 89,600.00
	20	$ 372,479.00	$ 544,100.00	$ 622,250.00
	25	$ 81,600.00	$ 81,600.00	$ 259,050.00
	30	$ 275,500.00	$ 489,600.00	$ 147,600.00
Annual Recurring Electric		$ 73,720.36	$ 60,639.45	$ 63,951.48
Annual Recurring Natural Gas		$ 817.27	$ 905.68	$ 524.13
Annual Recurring Water		$ -	$ -	$ -
Total Energy Cost		$ 74,537.63	$ 61,545.13	$ 64,475.61

Table 10.1: Total Costs for Systems

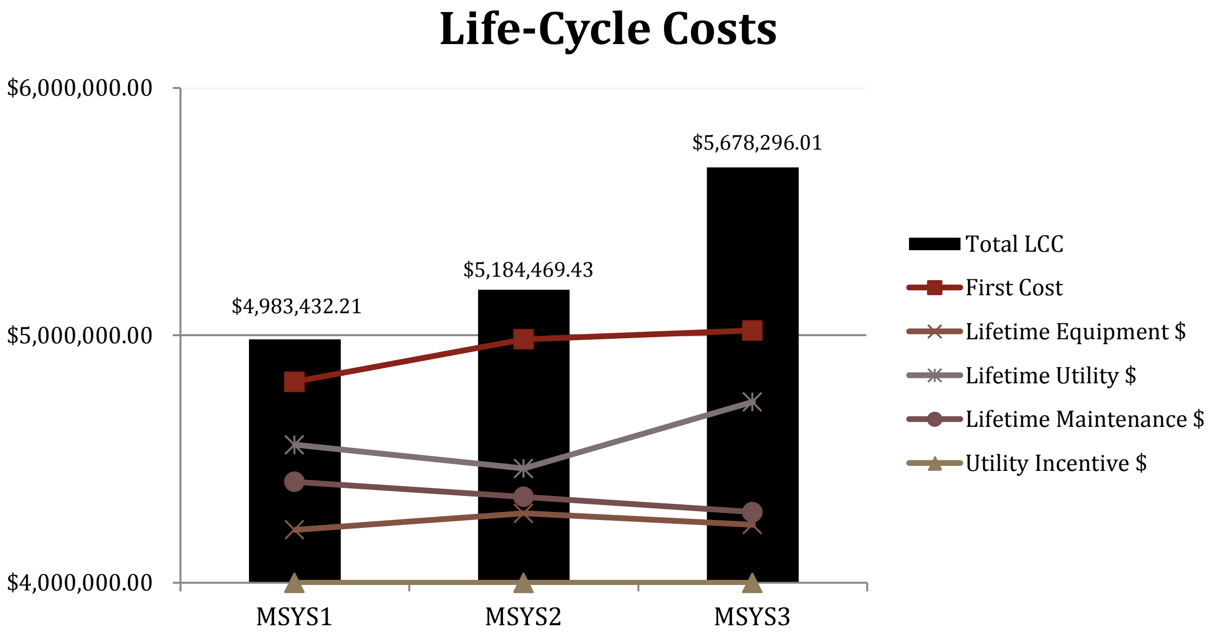


Figure 10.4: Life-Cycle Costs

Therefore, after the analysis of the VAV and chilled beam system, it is recommended that the VAV system be implemented in the American Swedish Institute. Even though, the VAV boxes use more space than the chilled beams the space used by the VAV boxes would be almost equivalent to the heat pumps currently in place. The efficiency of the VAV system for the type of spaces in the building make the investment worthwhile for the life of building especially since payback would occur after 33 years and the building would still be occupied past that time.

Architectural

Architectural changes to the walkway connecting the mansion and addition were done to increase the aesthetic appeal of the building when looking at the exterior of the building from an upper level. Plants that will be used on the green roof will reflect the inner courtyard. Since extensive green roofs are already implemented on the second story roof of the addition the selection of an extensive green roof was made for replacing the existing roof adding to the Swedish influence in both landscape and sustainability. Additionally, with the selection of an extensive green roof over an intensive green roof the additional cost in material makes the change a reasonable option for the American Swedish Institute with the extensive green roof costing $7/sf less than the alternative. In the structural breadth the final conclusion for roof type will be made upon review of calculations.

Structural

Upon review of the structural calculations to determine the correct roof deck to handle the additional loads from an extensive or intensive green roof, an extensive green roof was chosen. Selection for an extensive green roof was based on thickness of decking and additional weight to the structure in comparison to the existing roofing. With implementation of an extensive green roof, the total loads experienced increase by 6 psf therefore not comprising the structural integrity of the walkway roof and load bearing walls. The roof deck selected for the walkway was 3 inch 16 gauge which can handle a maximum load of 118 psf and is well above the total load experienced on the roof.

References

ANSI/ASHRAE Standard 62.1-2007, *Ventilation for Acceptable Indoor Air Quality*. Atlanta Georgia: American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

ANSI/ASHRAE Standard 90.1-2007, *Energy Standard for Buildings Except Low-Rise Residential Buildings*. Atlanta, Georgia: American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

"Chilled Beam & Pinnacle Application Guide." *Semcohvac.com*. Semco. 2010. Web. 04 Dec. 2011.

DADANCO – Active Chilled Beam Air Conditioning. DADANCO, n.d. Web. 14 Mar. 2012

Daikin McQuay. McQuay, 2012. Web. 16 Mar. 2012

"Greenroofs101." *Green roofs.com*. Green roofs. 2011. Web. 07 Dec. 2011.

HGA Architects and Engineer. Architectural Construction Documents. HGA Architects and Engineers, Minneapolis, MN.

HGA Architects and Engineer. Mechanical Construction Documents. HGA Architects and Engineers, Minneapolis, MN.

Kavanaugh, Steve. "Ground Source Heat Pumps for Commerical Buildings." *Hpac.com*. HPAC Engineering. 1 Sept. 2008. Web. 08 Dec. 2011.

Lippiatt, Barbara C., Joshua D. Kneifel, Amy S. Rushing. "Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2011." *Annual Supplement to NIST Handbook 135 Special.* Publication 709 (2011). Print.

Peters, George. "Geothermal Retrofitting at Commercial Facilities." *Billgladstone.com.* Bill Gladstone Group of NAI CIR. 2011-2012. Web. 08 Dec. 2011.

Sackrison, Chris. "Why Water Source Heat Pump Systems are so Efficient." *Engineering System Solutions*. McQuay., Oct. 2002. Web. 08 Dec. 2011.

"Section H – Radiant Heating and Cooling Systems." *Price.* Price, 2012. Web. 09 Mar. 2012.

U.S. Green Building Council. LEED – NC: Green Building Rating for New Construction & Major Renovations v2.2. U.S. Green Building Council. 2005.

"Variable Air Volume Systems." *Highperformancehvac.com*. High Performance HVAC. 23 Aug. 2011. Web. 08 Dec. 2011.

Vastyan, John. "Chilled-Beam Basics." *HPAC Engineering* July 2011: 26-28, 42. Print

Appendix A – Utility Costs

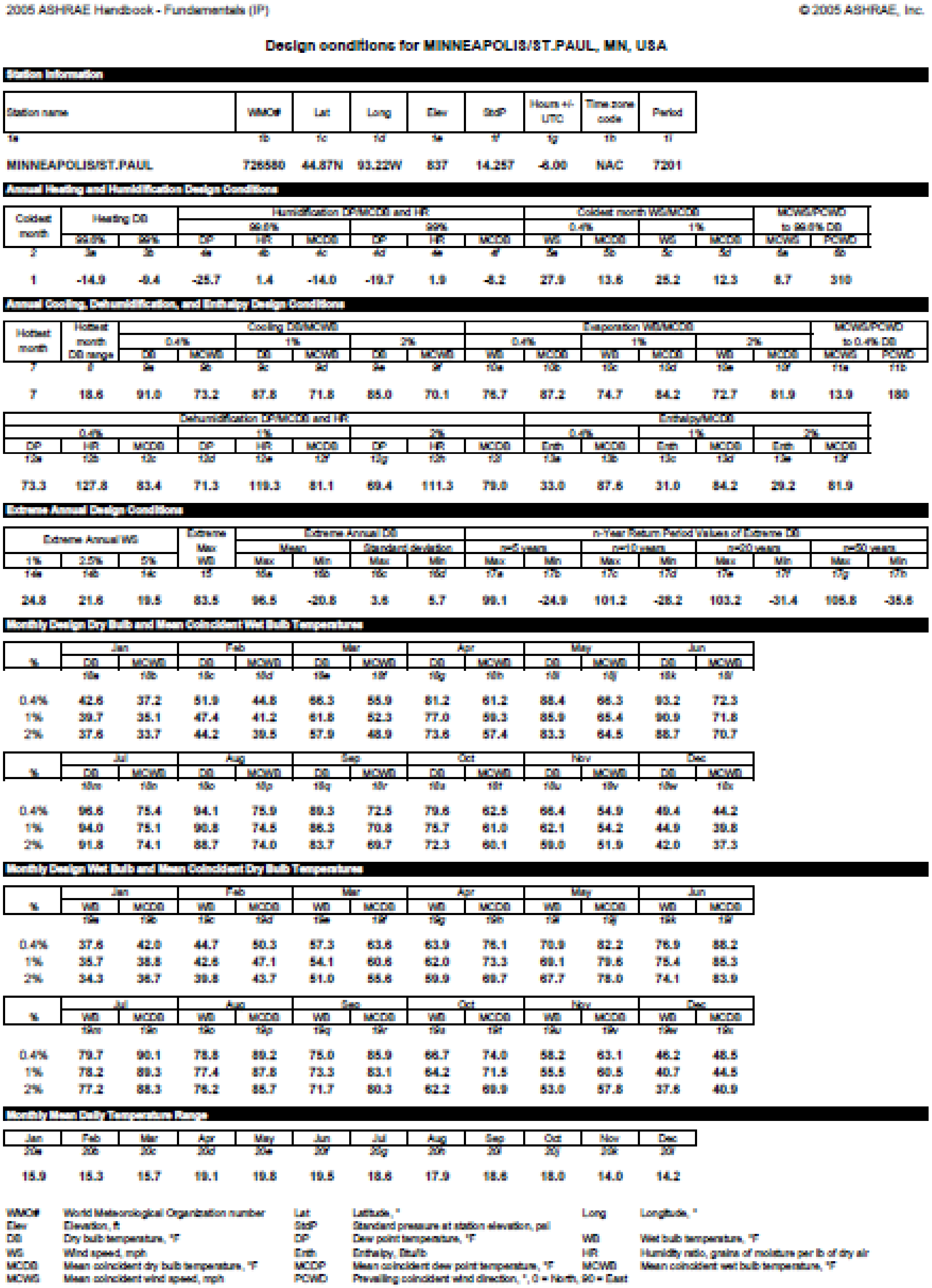
Electricity Utility Costs			
Type	**June-Sept**	**Oct-May**	**Year**
Electricity consumption/kW	$11.19	$7.79	
Electricity demand per month/kW	-	-	$0.059765
Metered per month	-	-	$8.65

Table A.1: Electricity Utility Costs

Natural Gas Utility Costs			
Type	**April-Oct**	**Nov-March**	**Year**
Gas distribution/therm	-	-	$0.12331
Base of gas/therm	$0.59440	$0.65221	-
Metered per month	-	-	$25.00

Table A.2: Natural Gas Utility Costs

Appendix B – Weather Data for Minneapolis, MN



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Design conditions for MINNEAPOLIS/ST.PAUL, MN, USA

Station Information

Station name	WMO#	Lat	Long	Elev	StdP	Hours +/- UTC	Time zone code	Period
1a	1b	1c	1d	1e	1f	1g	1h	1i
MINNEAPOLIS/ST.PAUL	726580	44.87N	93.22W	837	14.257	-6.00	NAC	7201

Annual Heating and Humidification Design Conditions

Coldest month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
2	3a	3b	4a	4b	4c	4d	4e	4f	5a	5b	5c	5d	6a	6b
1	-14.9	-9.4	-25.7	1.4	-14.0	-19.7	1.9	-8.2	27.9	13.6	25.2	12.3	8.7	310

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest month	Hottest month DB range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	8	9a	9b	9c	9d	9e	9f	10a	10b	10c	10d	10e	10f	11a	11b
7	18.6	91.0	73.2	87.8	71.8	85.0	70.1	76.7	87.2	74.7	84.2	72.7	81.9	13.9	180

Dehumidification DP/MCDB and HR									Enthalpy/MCDB					
0.4%			1%			2%			0.4%		1%		2%	
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB
12a	12b	12c	12d	12e	12f	12g	12h	12i	13a	13b	13c	13d	13e	13f
73.3	127.8	83.4	71.3	119.3	81.1	69.4	111.3	79.0	33.0	87.6	31.0	84.2	29.2	81.9

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
14a	14b	14c	15	16a	16b	16c	16d	17a	17b	17c	17d	17e	17f	17g	17h
24.8	21.6	19.5	83.5	96.5	-20.8	3.6	5.7	99.1	-24.9	101.2	-28.2	103.2	-31.4	105.8	-35.6

Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18a	18b	18c	18d	18e	18f	18g	18h	18i	18j	18k	18l
0.4%	42.6	37.2	51.9	44.8	66.3	55.9	81.2	61.2	88.4	66.3	93.2	72.3
1%	39.7	35.1	47.4	41.2	61.8	52.3	77.0	59.3	85.9	65.4	90.9	71.8
2%	37.6	33.7	44.2	39.5	57.9	48.9	73.6	57.4	83.3	64.5	88.7	70.7

%	Jul		Aug		Sep		Oct		Nov		Dec	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18m	18n	18o	18p	18q	18r	18s	18t	18u	18v	18w	18x
0.4%	96.6	75.4	94.1	75.9	89.3	72.5	79.6	62.5	66.4	54.9	49.4	44.2
1%	94.0	75.1	90.8	74.5	86.3	70.8	75.7	61.0	62.1	54.2	44.9	39.8
2%	91.8	74.1	88.7	74.0	83.7	69.7	72.3	60.1	59.0	51.9	42.0	37.3

Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19a	19b	19c	19d	19e	19f	19g	19h	19i	19j	19k	19l
0.4%	37.6	42.0	44.7	50.3	57.3	63.6	63.9	76.1	70.9	82.2	76.9	88.2
1%	35.7	38.8	42.6	47.1	54.1	60.6	62.0	73.3	69.1	79.6	75.4	85.3
2%	34.3	36.7	39.8	43.7	51.0	55.6	59.9	69.7	67.7	78.0	74.1	83.9

%	Jul		Aug		Sep		Oct		Nov		Dec	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19m	19n	19o	19p	19q	19r	19s	19t	19u	19v	19w	19x
0.4%	79.7	90.1	78.8	89.2	75.0	85.9	66.7	74.0	58.2	63.1	46.2	48.5
1%	78.2	89.3	77.4	87.8	73.3	83.1	64.2	71.5	55.5	60.5	40.7	44.5
2%	77.2	88.3	76.2	85.7	71.7	80.3	62.2	69.9	53.0	57.8	37.6	40.9

Monthly Mean Daily Temperature Range

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20a	20b	20c	20d	20e	20f	20g	20h	20i	20j	20k	20l
15.9	15.3	15.7	19.1	19.8	19.5	18.6	17.9	18.6	18.0	14.0	14.2

WMO#	World Meteorological Organization number	Lat	Latitude, °	Long	Longitude, °
Elev	Elevation, ft	StdP	Standard pressure at station elevation, psi		
DB	Dry bulb temperature, °F	DP	Dew point temperature, °F	WB	Wet bulb temperature, °F
WS	Wind speed, mph	Enth	Enthalpy, Btu/lb	HR	Humidity ratio, grains of moisture per lb of dry air
MCDB	Mean coincident dry bulb temperature, °F	MCDP	Mean coincident dew point temperature, °F	MCWB	Mean coincident wet bulb temperature, °F
MCWS	Mean coincident wind speed, mph	PCWD	Prevailing coincident wind direction, °, 0 = North, 90 = East		

Appendix C – Occupancy Schedule

Cooling Design Weekday Schedule		
Start Time	**End Time**	**Percentage**
Midnight	5 a.m.	30
5 a.m.	6 a.m.	60
6 a.m.	7 a.m.	90
7 a.m.	8 p.m.	100
8 p.m.	9 p.m.	90
9 p.m.	10 p.m.	60
10 p.m.	Midnight	30

Table C.1: Cooling Design Weekday Schedule

Heating Design Schedule		
Start Time	**End Time**	**Percentage**
Midnight	Midnight	100

Table C.2: Heating Design Schedule

Saturday and Sunday Schedule		
Start Time	**End Time**	**Percentage**
Midnight	5 a.m.	30
5 a.m.	7 a.m.	60
7 a.m.	9 a.m.	90
9 a.m.	6 p.m.	100
6 p.m.	8 p.m.	90
8 p.m.	9 p.m.	60
9 p.m.	Midnight	30

Table C.3: Saturday and Sunday Schedule

Appendix D – Monthly Energy Consumption

Monthly Energy Consumption														
Utility		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Total**
Electric	On-Peak Cons (kWh)	90,663	74,205	78,669	62,854	74,433	79,275	87,969	81,470	69,101	65,942	66,115	87,095	**917,790**
	On-Peak Demand (kW)	194	188	185	157	152	174	186	181	162	160	172	191	**194**
Gas	On-Peak Cons (therms)	300	115	64	0	0	0	0	0	0	0	1	187	**667**
	On-Peak Demand (therms/yr)	2	2	2	0	0	0	0	0	0	0	0	2	**2**

Table D.1: Monthly Energy Consumption for Original System

Monthly Energy Consumption														
Utility		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Total**
Electric	On-Peak Cons (kWh)	72,399	61,673	67,755	50,900	64,145	69,546	78,996	71,574	59,510	53,641	51,640	71,275	**773,055**
	On-Peak Demand (kW)	115	110	111	100	143	167	171	168	154	105	95	113	**171**
Gas	On-Peak Cons (therms)	281	149	125	0	0	0	0	0	0	0	0	226	**782**
	On-Peak Demand (therms/yr)	1	1	1	0	0	0	0	0	0	0	0	1	**1**

Table D.2: Monthly Energy Consumption for VAV System

Monthly Energy Consumption														
Utility		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Total**
Electric	On-Peak Cons (kWh)	67,482	58,702	63,234	56,820	71,310	77,164	83,986	79,664	66,707	59,955	57,906	67,299	**810,230**
	On-Peak Demand (kW)	163	162	162	146	134	151	163	159	147	147	144	160	**163**
Gas	On-Peak Cons (therms)	143	53	19	0	0	0	0	0	0	0	0	116	**331**
	On-Peak Demand (therms/yr)	2	1	1	0	0	0	0	0	0	0	0	1	**2**

Table D.3: Monthly Energy Consumption for Chilled Beam System

Appendix E – Mechanical System First Cost

MSYS1 **Heat Pumps**

System Components	Basis of Estimate	Quantity	Units	$/Unit	Total
Geothermal wellfield & piping	Vertical, 96 bores @ 250' + pipe manifolding to bldg	96	each	$ 4,250.00	$ 408,000.00
Water-to-air heat pump-all	Small units, 1 ton	16	each	$ 2,100.00	$ 33,600.00
Water-to-air heat pump-all	Small units, 2 ton	9	each	$ 2,475.00	$ 22,275.00
Water-to-air heat pump-all	Small units, 3 ton	4	each	$ 2,915.00	$ 11,660.00
Water-to-air heat pump-all	Small units, 4 ton	9	each	$ 3,145.00	$ 28,305.00
Water-to-air heat pump-all	Small units, 5 ton	4	each	$ 3,715.00	$ 14,860.00
Water-to-air heat pump-all	Small units, 10 ton	5	each	$ 10,100.00	$ 50,500.00
Water-to-air heat pump-all	Small units, 25 ton	1	each	$ 24,700.00	$ 24,700.00
Gas-Fired Hot Water Boiler	750 MBH, 86% eff., incl. accessories	2	each	$ 40,800.00	$ 81,600.00
Natural gas piping	Piping to boilers	2	lsum	$ 7,500.00	$ 15,000.00
Condenser water piping	Complete system for CW to heat pumps	52,100	sq.ft.	$ 4.00	$ 208,400.00
Condenser pumps and accessories	(1) 140 GPM per boiler +boiler connection to CW	2	each	$ 15,675.00	$ 31,350.00
Makeup Air Unit	8,000 cfm	1	each	$ 57,100.00	$ 57,100.00
Gas-fired Makeup Air Unit	4,400 cfm & 415 CFH	1	each	$ 31,225.00	$ 31,225.00
Air Distribution System @ HPs	Small/minimal ductwork	52,100	sq.ft.	$ 10.00	$ 521,000.00
Air Distribution System @ Ventilation Air Loop	Ductwork mains connected to heat pumps	1	lsum	$ 150,000.00	$ 150,000.00
Exhaust Systems	Typical, localized	52,100	sq.ft.	$ 1.00	$ 52,100.00
Misc. CUH, FCU	Typical, localized	5	loc	$ 7,500.00	$ 37,500.00
HVAC Controls System	Packaged heat pump controls, simple boiler + pumps	52,100	sq.ft.	$ 4.50	$ 234,450.00
VAV boxes	Sizes ranging from 90-1480	21	each	$ 874.00	$ 18,354.00
Total HVAC System Cost					**$ 2,031,979.00**

MSYS2 **VAV**

System Components	Basis of Estimate	Quantity	Units	$/Unit	Total
Geothermal wellfield & piping	Vertical, 96 bores @ 250' + pipe manifolding to bldg	96	each	$ 4,250.00	$ 408,000.00
Water-to-water heat pumps	10 @ 188,648 Btu/hr (16 tons)	160	ton	$ 1,400.00	$ 224,000.00
Packaged VAV Rooftop Unit	Multizone, 40,000 cfm, HW heat +Cooling	40,000	cfm	$ 6.00	$ 240,000.00
VAV boxes w/ Reheat	Typical, hw re-heat	50	each	$ 3,200.00	$ 160,000.00
Gas-fired Hot Water Boiler	750 MBH, 86% eff., incl. accessories	2	each	$ 40,800.00	$ 81,600.00
Natural Gas Piping	Piping to boilers	2	lsum	$ 7,500.00	$ 15,000.00
HW & CW Water piping	Complete system for HW + CW to units	52,100	sq.ft.	$ 4.50	$ 234,450.00
HW & CW Pumps & Accessories	(1) 140 GPM per boiler +boiler connection to CW	2	each	$ 3,750.00	$ 7,500.00
Air Distribution System @ Single Zones	Typical ductwork	24,500	sq.ft.	$ 10.00	$ 245,000.00
Air Distribution System @ VAV Zones	Typical ductwork	27,600	sq.ft.	$ 16.00	$ 441,600.00
Exhaust Systems	Typical, localized	52,100	sq.ft.	$ 1.00	$ 52,100.00
Misc. CUH, FCU	Typical, localized	5	loc	$ 7,500.00	$ 37,500.00
HVAC Controls System	BAS	52,100	sq.ft.	$ 6.00	$ 312,600.00
Total HVAC System Cost					**$ 2,459,350.00**

MSYS3 **Chilled Beams**

System Components	Basis of Estimate	Quantity	Units	$/Unit	Total
Geothermal wellfield & piping	Vertical, 96 bores 2 250' + pipe manifolding to bldg	96	each	$ 4,250.00	$ 408,000.00
Water-to-water heat pumps	10 @ 188,648 Btu/hr (16 tons)	160	ton	$ 1,400.00	$ 224,000.00
DOAS unit	20,000 cfm with energy recovery wheel	1	each	$ 58,000.00	$ 58,000.00
Chilled beams	546 LF of chilled beams required	546	LF	$ 325.00	$ 177,450.00
Gas-fired Hot Water Boiler	750 MBH, 86% eff., incl. accessories	2	each	$ 40,800.00	$ 81,600.00
Natural Gas Piping	Typical ductwork	2	lsum	$ 7,500.00	$ 15,000.00
HW & CW Water piping	Complete system for HW + CW to units	52,100	sq.ft.	$ 6.00	$ 312,600.00
HW & CW Pumps & Accessories	(1) 140 GPM per boiler +boiler connection to CW	2	each	$ 3,750.00	$ 7,500.00
Air Distribution System @ Single Zones	Typical ductwork	24,500	sq.ft.	$ 14.00	$ 343,000.00
Air Distribution System @ Chilled Beams	Typical ductwork	27,600	sq.ft.	$ 16.00	$ 441,600.00
Exhaust Systems	Typical, localized	52,100	sq.ft.	$ 1.00	$ 52,100.00
Misc. CUH, FCU	Typical, localized	5	loc	$ 7,500.00	$ 37,500.00
HVAC Controls System	BAS	52,100	sq.ft.	$ 7.50	$ 390,750.00
Total HVAC System Cost					**$ 2,549,100.00**

Appendix F – System Cost Details

MSYS1 **Individual ground source heat pumps - Original**

Total System First Cost	$ 2,031,979.00
Annual Maintenance Costs	$ 52,100.00
Annual Water Costs	$ -

System Components	Component Costs	Component Life in Years
Geothermal wellfield & piping	$ 408,000.00	50
Water-to-air heat pumps	$ 185,900.00	15
(2) Gas-fired boiler (back-up boiler)	$ 81,600.00	25
Ventilation makeup air unit	$ 88,325.00	20
Pumps	$ 31,350.00	20
Valving	$ 45,000.00	40
Exhaust Fans	$ 52,100.00	15
Unit heaters & misc.	$ 37,500.00	15
Air distribution	$ 671,000.00	50
Hydronic piping	$ 223,400.00	50
Controls	$ 234,450.00	20
VAV Boxes	$ 18,354.00	20

MSYS2 **Water-to-Water HPs and VAV**

Total System First Cost	$ 2,459,350.00
Annual Maintenance Costs	$ 44,285.00
Annual Water Costs	$ -

System Components	Component Costs	Component Life in Years
Geothermal wellfield & piping	$ 408,000.00	50
Water-to-water heat pumps	$ 224,000.00	20
Air handling units	$ 240,000.00	30
VAV boxes	$ 160,000.00	15
Gas-fired boiler (back up boiler)	$ 81,600.00	25
Pumps	$ 7,500.00	20
Valving	$ 50,000.00	40
Exhaust Fans	$ 52,100.00	15
Unit heaters & misc.	$ 37,500.00	15
Air distribution	$ 686,600.00	50
Hydronic piping	$ 249,450.00	50
Controls	$ 312,600.00	20

MSYS3	**Chilled Beams**		
	Total System First Cost	$ 2,549,100.00	
	Annual Maintenance Costs	$ 36,470.00	
	Annual Water Costs	$ -	
	System Components	Component Costs	Component Life in Years
	Geothermal wellfield & piping	$ 408,000.00	50
	Water-to-water heat pumps	$ 224,000.00	20
	DOAS	$ 58,000.00	30
	Chilled Beams	$ 177,450.00	25
	Gas-fired boiler (back up boiler)	$ 81,600.00	25
	Pumps	$ 7,500.00	20
	Valving	$ 50,000.00	40
	Exhaust Fans	$ 52,100.00	15
	Unit heaters & misc.	$ 37,500.00	15
	Air distribution	$ 784,600.00	50
	Hydronic piping	$ 327,600.00	50
	Controls	$ 390,750.00	20

Appendix G – Chilled Beam Calculations

#	Room	CFM for Room	CFM per beam	Nozzle size (in dia.)	Beam Length (ft)	1 or 2 - way	Btu/h per beam	Total	#	gpm per beam	head	Total gpm for space	Area of CB (sq ft)	Area of Room	LF of beams
0A-1	Electrical /Telecom	24	28	0.160	4	2-way	3014	21,600	7	1.00	3.0	7.17	57	400	29
0A-2	Mechanical	34	36	0.160	4	2-way	3465	6,480	2	1.00	3.0	1.87	15	565	7
0A-3	Elev Equip Room	6	28	0.125	4	2-way	3014	13,608	5	1.00	3.0	4.51	36	50	18
0A-4	Quarantine & Table/Chair, Kitchen Storage and Corridor	19	21	0.125	4	2-way	2651	13,608	5	1.00	3.0	5.13	41	320	21
0A-5	Building Engineer	31	39	0.188	4	2-way	3180	5,811	2	1.00	3.0	1.83	15	150	7
0A-6	Elev Equip Room	12	21	0.125	4	2-way	2651	21,600	8	1.00	3.0	8.15	65	100	33
0A-7	Storage, Maint Storage, & Maint Shop	41	51	0.188	4	2-way	3823	21,600	6	1.00	3.0	5.65	45	685	23
0A-8	Collection Storage	144	146	0.350	4	2-way	5659	25,920	5	1.00	3.0	4.58	37	2,400	18
0A-9	Corridor, Work & Material Storage	142	146	0.350	4	2-way	5659	18,543	3	1.00	3.0	3.28	26	685	13
0A-10	Retail Work Storage	61	65	0.250	4	2-way	3919	13,608	3	1.00	3.0	3.47	28	1,020	14
1A-2	Gust Exterior Office	49	51	0.188	4	2-way	3823	7,591	2	1.00	3.0	1.99	16	235	8
1A-3	Waiting/Conference/Reception/ Printer	91	93	0.250	4	2-way	4378	11,644	3	1.00	3.0	2.66	21	440	11
1A-4	Hallways	52	65	0.250	4	2-way	3919	34,560	9	1.00	3.0	8.82	71	860	35
1A-5	Hallways, Restrooms	55	65	0.250	4	2-way	3920	13,608	3	1.00	3.0	3.47	28	920	14
1A-6	Multi-purpose, Hallway	148	190	0.350	4	2-way	6566	5,449	1	1.00	3.0	0.83	7	715	3
1A-7	Catering Suport, Shipping & Receiving	61	65	0.250	4	2-way	3919	7,323	2	1.00	3.0	1.87	15	295	7
1A-12	Reception, Storage, Office	81	93	0.250	4	2-way	4378	6,900	2	1.00	3.0	1.58	13	390	6
1A-13	Gift Shop	527	292	0.350	6	2-way	9410	31,820	3	1.00	4.2	3.38	41	850	20
2A-1	Coat, Storage, Restrooms	55	65	0.250	4	2-way	3919	13,608	3	1.00	3.0	3.47	28	920	14
2A-2	Hallways	28	28	0.160	4	2-way	3014	8,640	3	1.00	3.0	2.87	23	460	11
2A-3	Prefunction	1,587	292	0.350	6	2-way	9410	286	5	1.00	4.2	5.43	65	1,280	33
0T-7	Hallways, Storage, Restrooms	78	93	0.250	4	2-way	4378	21,600	5	1.00	3.0	4.93	39	1,300	20
0T-8	Elev Equip	12	28	0.160	4	2-way	3014	25,920	9	1.00	3.0	8.60	69	100	34
0T-9	Links	24	28	0.160	4	2-way	3014	21,600	7	1.00	3.0	7.17	57	395	29
0T-10	Links	19	21	0.125	4	2-way	2651	17,280	7	1.00	3.0	6.52	52	320	26
0T-11	Archive, Storage	71	72	0.250	4	2-way	3893	17,280	4	1.00	3.0	4.44	36	1,190	18
0T-13	Library	207	210	0.300	6	2-way	7059	2,017	1	1.00	4.2	0.98	12	500	6
OT-14	Storage	21	21	0.125	4	2-way	2651	8,640	3	1.00	3.0	3.26	26	280	13
1T-1	Work Room	21	21	0.125	4	2-way	2652	21,600	8	1.00	3.0	8.14	65	280	33
														Total LF	546

Appendix H – Roof Deck Calculations

Extensive green roof

Dead Load: D = 31 psf
    Metal Deck: 2 psf
    Rigid Insulation: 2 psf
    Fenestration system: 5 psf
    Green roof (Lite) saturated: 17 psf
    Misc. Dead Load: 5 psf (includes ceiling, sprinklers, mechanical and plumbing)

Snow Load: S = 35 psf (from above calculation)

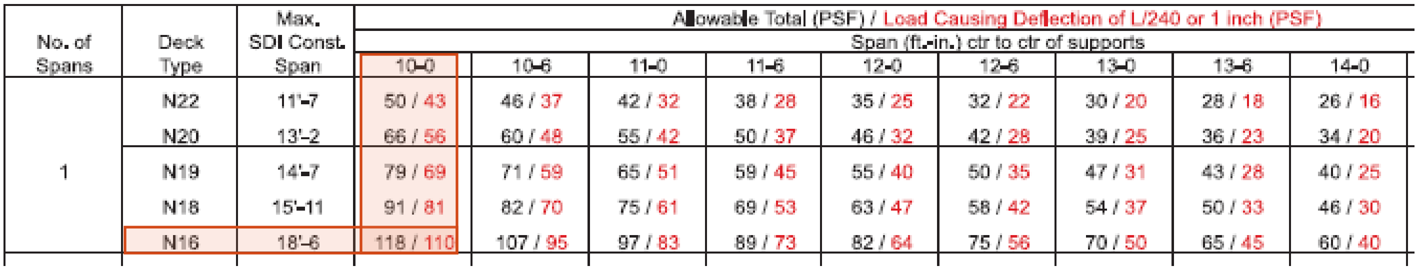
Roof Live Load: L_r = 20 psf

Factored Loads: (Use equation 3 from ASCE 7-10 Section 2.3)
    $R_u = 1.2D + 1.6(S \text{ or } L_r) + L$ (L=0)
    Use S controls in equation since $S > L_r$

    Therefore,
    $R_u = 1.2D + 1.6S$

    $R_u = 1.2(31) + 1.6(35) = 94$ psf

From Vulcraft Steel Roof and Floor Deck catalog 2008
    Use 3N with number of spans of 1, 8'-4"
    Use deck type N16
        Max. SDI Construction Span = 18'-6" > 8'-4" check
        For 10'-0" Total Load = 118 psf >86 psf
        Checking with the addition of actual roof deck weight:
            Dead Load metal deck weight for N16 is 4.46 psf
            Total Dead Load: 34 psf
            $R_u = 1.2(34) + 1.6(35) = 97$ psf which is still below the 118 psf maximum therefore, still works.



No. of Spans	Deck Type	Max. SDI Const. Span	Allowable Total (PSF) / Load Causing Deflection of L/240 or 1 inch (PSF)								
			Span (ft.-in.) ctr to ctr of supports								
			10-0	10-6	11-0	11-6	12-0	12-6	13-0	13-6	14-0
1	N22	11'-7	50 / 43	46 / 37	42 / 32	38 / 28	35 / 25	32 / 22	30 / 20	28 / 18	26 / 16
	N20	13'-2	66 / 56	60 / 48	55 / 42	50 / 37	46 / 32	42 / 28	39 / 25	36 / 23	34 / 20
	N19	14'-7	79 / 69	71 / 59	65 / 51	59 / 45	55 / 40	50 / 35	47 / 31	43 / 28	40 / 25
	N18	15'-11	91 / 81	82 / 70	75 / 61	69 / 53	63 / 47	58 / 42	54 / 37	50 / 33	46 / 30
	N16	18'-6	118 / 110	107 / 95	97 / 83	89 / 73	82 / 64	75 / 56	70 / 50	65 / 45	60 / 40

Figure H.1: 3N Roof Decking from Vulcraft Steel Roof and Floor Deck Catalog 2008, page 10

Intensive green roof

Dead Load: D = 77 psf
    Metal Deck: 2 psf

Fenestration system: 5 psf
Green roof (Maxx) saturated: 65 psf (Assume that soil is thick enough to account for insulation)
Misc. Dead Load: 5 psf (includes ceiling, sprinklers, mechanical and plumbing)

Snow Load: S = 35 psf (From above calculation)

Roof Live Load: L_r = 100 psf (Roof garden)

Factored Loads: (Use equation 3 from ASCE 7-10 Section 2.3)

$R_u = 1.2D + 1.6(S \text{ or } L_r) + L$ (L=0)
Use L_r controls in equation since $L_r > S$

Therefore,
$R_u = 1.2D + 1.6L_r$

$R_u = 1.2(77) + 1.6\,(100) = 253$ psf

Roof decking maximum weight is 154 psf and the load calculated above exceeds this value by ~100 psf. Therefore, must use composite deck for this alternative.

This system shall look into three options for design; the first and second option will just use composite deck in different gauge sizes and the third option will use composite deck in combination with steel joists.

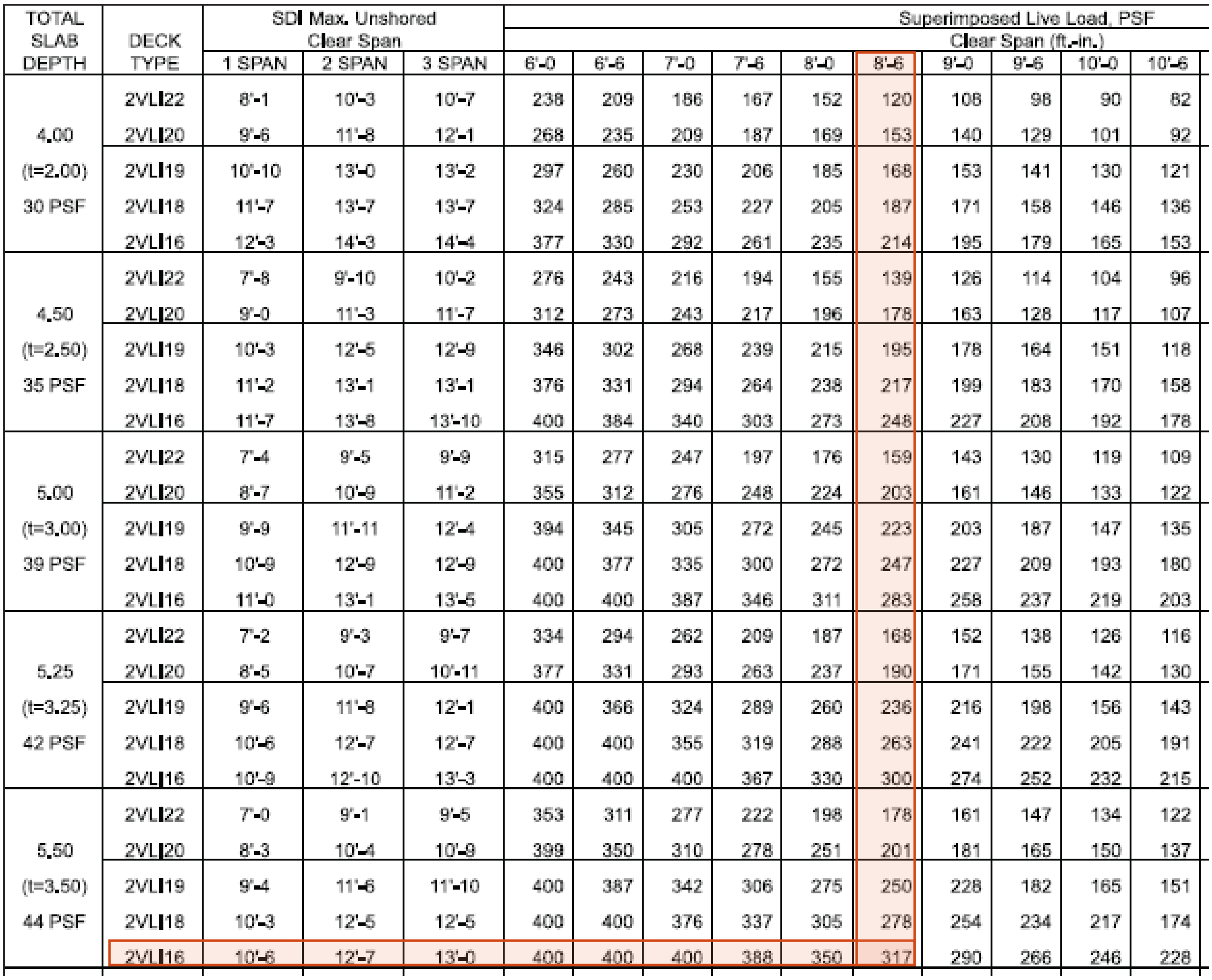
Note: All concrete used for composite deck calculations was considered lightweight concrete.

Option 1: Composite deck with smaller gauge

From Vulcraft Steel Roof and Floor Deck catalog 2008
Use 2VLI with number of spans of 1, 8'-4"
Use deck type 2VLI16 with a total slab depth of 5 ½"

Total Dead Load: 44 + 5 + 65 + 5 = 119 psf (Where 44 psf is the slab weight)
$R_u = 1.2(119) + 1.6\,(100) = 303$ psf

Max. SDI Unshored Clear Span = 10'-6" > 8'-4" check
For 8'-6" Total Load = 317 psf > 303 psf check



TOTAL SLAB DEPTH	DECK TYPE	SDI Max. Unshored Clear Span			Superimposed Live Load, PSF Clear Span (ft.-in.)									
		1 SPAN	2 SPAN	3 SPAN	6'-0	6'-6	7'-0	7'-6	8'-0	8'-6	9'-0	9'-6	10'-0	10'-6
4.00 (t=2.00) 30 PSF	2VLI22	8'-1	10'-3	10'-7	238	209	186	167	152	120	108	98	90	82
	2VLI20	9'-6	11'-8	12'-1	268	235	209	187	169	153	140	129	101	92
	2VLI19	10'-10	13'-0	13'-2	297	260	230	206	185	168	153	141	130	121
	2VLI18	11'-7	13'-7	13'-7	324	285	253	227	205	187	171	158	146	136
	2VLI16	12'-3	14'-3	14'-4	377	330	292	261	235	214	195	179	165	153
4.50 (t=2.50) 35 PSF	2VLI22	7'-8	9'-10	10'-2	276	243	216	194	155	139	126	114	104	96
	2VLI20	9'-0	11'-3	11'-7	312	273	243	217	196	178	163	128	117	107
	2VLI19	10'-3	12'-5	12'-9	346	302	268	239	215	195	178	164	151	118
	2VLI18	11'-2	13'-1	13'-1	376	331	294	264	238	217	199	183	170	158
	2VLI16	11'-7	13'-8	13'-10	400	384	340	303	273	248	227	208	192	178
5.00 (t=3.00) 39 PSF	2VLI22	7'-4	9'-5	9'-9	315	277	247	197	176	159	143	130	119	109
	2VLI20	8'-7	10'-9	11'-2	355	312	276	248	224	203	161	146	133	122
	2VLI19	9'-9	11'-11	12'-4	394	345	305	272	245	223	203	187	147	135
	2VLI18	10'-9	12'-9	12'-9	400	377	335	300	272	247	227	209	193	180
	2VLI16	11'-0	13'-1	13'-5	400	400	387	346	311	283	258	237	219	203
5.25 (t=3.25) 42 PSF	2VLI22	7'-2	9'-3	9'-7	334	294	262	209	187	168	152	138	126	116
	2VLI20	8'-5	10'-7	10'-11	377	331	293	263	237	190	171	155	142	130
	2VLI19	9'-6	11'-8	12'-1	400	366	324	289	260	236	216	198	156	143
	2VLI18	10'-6	12'-7	12'-7	400	400	355	319	288	263	241	222	205	191
	2VLI16	10'-9	12'-10	13'-3	400	400	400	367	330	300	274	252	232	215
5.50 (t=3.50) 44 PSF	2VLI22	7'-0	9'-1	9'-5	353	311	277	222	198	178	161	147	134	122
	2VLI20	8'-3	10'-4	10'-9	399	350	310	278	251	201	181	165	150	137
	2VLI19	9'-4	11'-6	11'-10	400	387	342	306	275	250	228	182	165	151
	2VLI18	10'-3	12'-5	12'-5	400	400	376	337	305	278	254	234	217	174
	2VLI16	10'-6	12'-7	13'-0	400	400	400	388	350	317	290	266	246	228

Figure H.2: 2VLI Roof Decking from Vulcraft Steel Roof and Floor Deck Catalog 2008, page 53

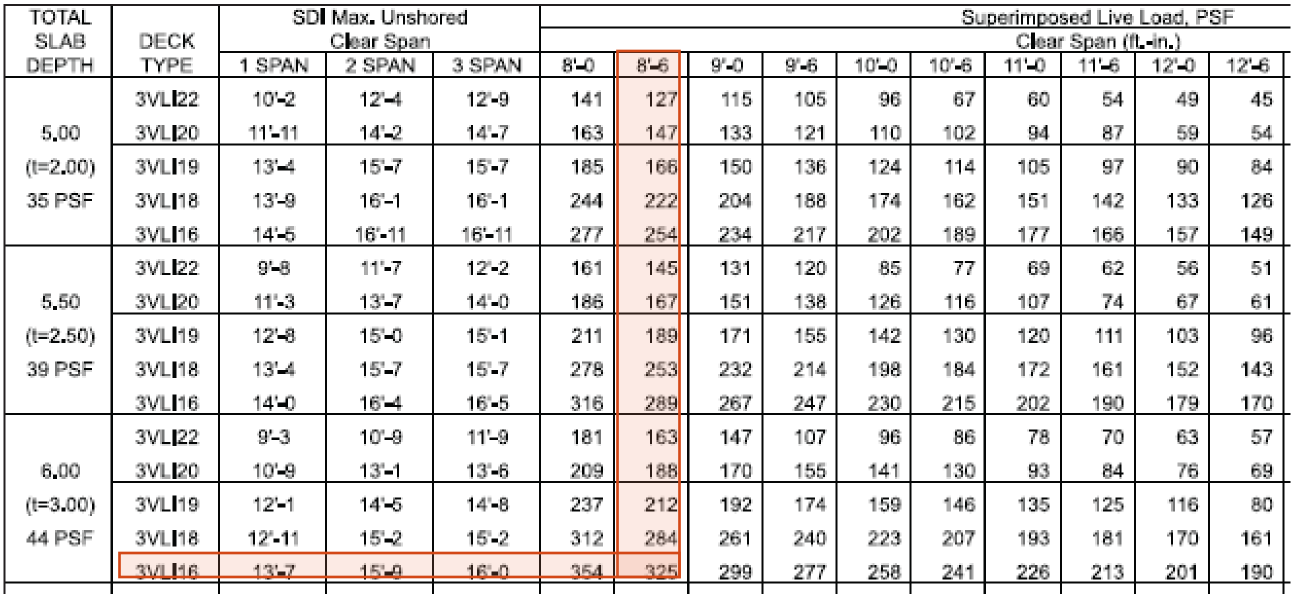
Option 2: Composite deck with larger gauge

Roof Live Load: 100 psf
Snow Load 35 psf

From Vulcraft Steel Roof and Floor Deck catalog 2008
Use 3VLI with number of spans of 1, 8'-4"
Use deck type 3VLI16 with a total slab depth of 6"

Total Dead Load: 44 + 5 + 65 + 5 = 119 psf (Where 44 psf is the slab weight)
R_u = 1.2(119) + 1.6 (100) = 303 psf

Max. SDI Unshored Clear Span = 13'-7" > 8'-4" check
For 8'-6" Total Load = 325 psf > 303 psf check



TOTAL SLAB DEPTH	DECK TYPE	SDI Max. Unshored Clear Span			Superimposed Live Load, PSF Clear Span (ft.-in.)									
		1 SPAN	2 SPAN	3 SPAN	8'-0	8'-6	9'-0	9'-6	10'-0	10'-6	11'-0	11'-6	12'-0	12'-6
5.00 (t=2.00) 35 PSF	3VLI22	10'-2	12'-4	12'-9	141	127	115	105	96	67	60	54	49	45
	3VLI20	11'-11	14'-2	14'-7	163	147	133	121	110	102	94	87	59	54
	3VLI19	13'-4	15'-7	15'-7	185	166	150	136	124	114	105	97	90	84
	3VLI18	13'-9	16'-1	16'-1	244	222	204	188	174	162	151	142	133	126
	3VLI16	14'-5	16'-11	16'-11	277	254	234	217	202	189	177	166	157	149
5.50 (t=2.50) 39 PSF	3VLI22	9'-8	11'-7	12'-2	161	145	131	120	85	77	69	62	56	51
	3VLI20	11'-3	13'-7	14'-0	186	167	151	138	126	116	107	74	67	61
	3VLI19	12'-8	15'-0	15'-1	211	189	171	155	142	130	120	111	103	96
	3VLI18	13'-4	15'-7	15'-7	278	253	232	214	198	184	172	161	152	143
	3VLI16	14'-0	16'-4	16'-5	316	289	267	247	230	215	202	190	179	170
6.00 (t=3.00) 44 PSF	3VLI22	9'-3	10'-9	11'-9	181	163	147	107	96	86	78	70	63	57
	3VLI20	10'-9	13'-1	13'-6	209	188	170	155	141	130	93	84	76	69
	3VLI19	12'-1	14'-5	14'-8	237	212	192	174	159	146	135	125	116	80
	3VLI18	12'-11	15'-2	15'-2	312	284	261	240	223	207	193	181	170	161
	3VLI16	13'-7	15'-9	16'-0	354	325	299	277	258	241	226	213	201	190

Figure H.3: 3VLI Roof Decking from Vulcraft Steel Roof and Floor Deck Catalog 2008, page 55

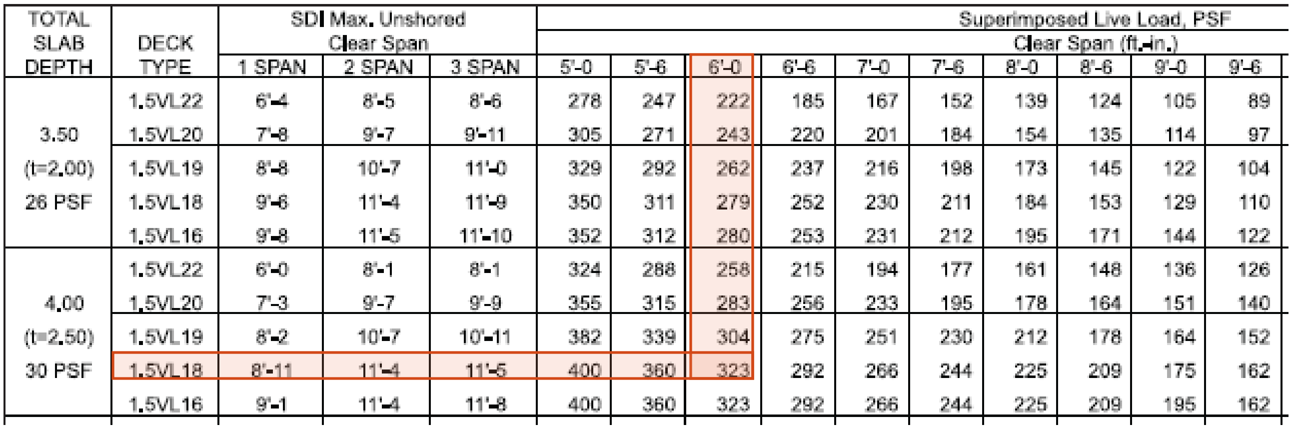
Option 3: Composite deck with steel joists

Roof Live Load: 100 psf
Snow Load 35 psf

From Vulcraft Steel Roof and Floor Deck catalog 2008
Use 1.5VLI with number of spans of 3, 6'-0"
Use deck type 1.5VLI18 with a total slab depth of 4"

Total Dead Load: 30 + 5 + 65 + 5 = 105 psf (Where 30 psf is the slab weight)
R_u = 1.2(105) + 1.6 (100) = 286 psf

Max. SDI Unshored Clear Span = 11'-5" > 6'-0" check
For 6'-0" Total Load = 323 psf > 286 psf check



TOTAL SLAB DEPTH	DECK TYPE	SDI Max. Unshored Clear Span			Superimposed Live Load, PSF Clear Span (ft.-in.)									
		1 SPAN	2 SPAN	3 SPAN	5'-0	5'-6	6'-0	6'-6	7'-0	7'-6	8'-0	8'-6	9'-0	9'-6
3.50 (t=2.00) 26 PSF	1.5VL22	6'-4	8'-5	8'-6	278	247	222	185	167	152	139	124	105	89
	1.5VL20	7'-8	9'-7	9'-11	305	271	243	220	201	184	154	135	114	97
	1.5VL19	8'-8	10'-7	11'-0	329	292	262	237	216	198	173	145	122	104
	1.5VL18	9'-6	11'-4	11'-9	350	311	279	252	230	211	184	153	129	110
	1.5VL16	9'-8	11'-5	11'-10	352	312	280	253	231	212	195	171	144	122
4.00 (t=2.50) 30 PSF	1.5VL22	6'-0	8'-1	8'-1	324	288	258	215	194	177	161	148	136	126
	1.5VL20	7'-3	9'-7	9'-9	355	315	283	256	233	195	178	164	151	140
	1.5VL19	8'-2	10'-7	10'-11	382	339	304	275	251	230	212	178	164	152
	1.5VL18	8'-11	11'-4	11'-5	400	360	323	292	266	244	225	209	175	162
	1.5VL16	9'-1	11'-4	11'-8	400	360	323	292	266	244	225	209	195	162

Figure H.4: 1.5VLI Roof Decking from Vulcraft Steel Roof and Floor Deck Catalog 2008, page 49

From Vulcraft Steel Joists and Joist Girders Catalog 2007

Total Load:

$D + L_r$ (Since L_r controls over the S)

105 + 100 = 205 psf

205 psf *6'-0" = 1230 plf

L_r: 100 psf * 6'-0" = 600 plf

$$M = \left(\frac{\omega l^2}{8}\right)$$

Where $\omega = 1230$ plf

l = 8'-4" = 8.33'

$$M = \left(\frac{(1230)(8.33)^2}{8}\right) = 10677.1\,\frac{lbs}{ft} * \frac{1\ kip}{1000\ lbs} * \frac{12\ inches}{1\ ft}$$

M = 128.13 inch*kips

$$V = \left(\frac{\omega l}{2}\right) = \frac{(1230)(8.33)}{2} = 5123\ \text{lbs}$$

Use 18KCS3 Open Web Steel Joists

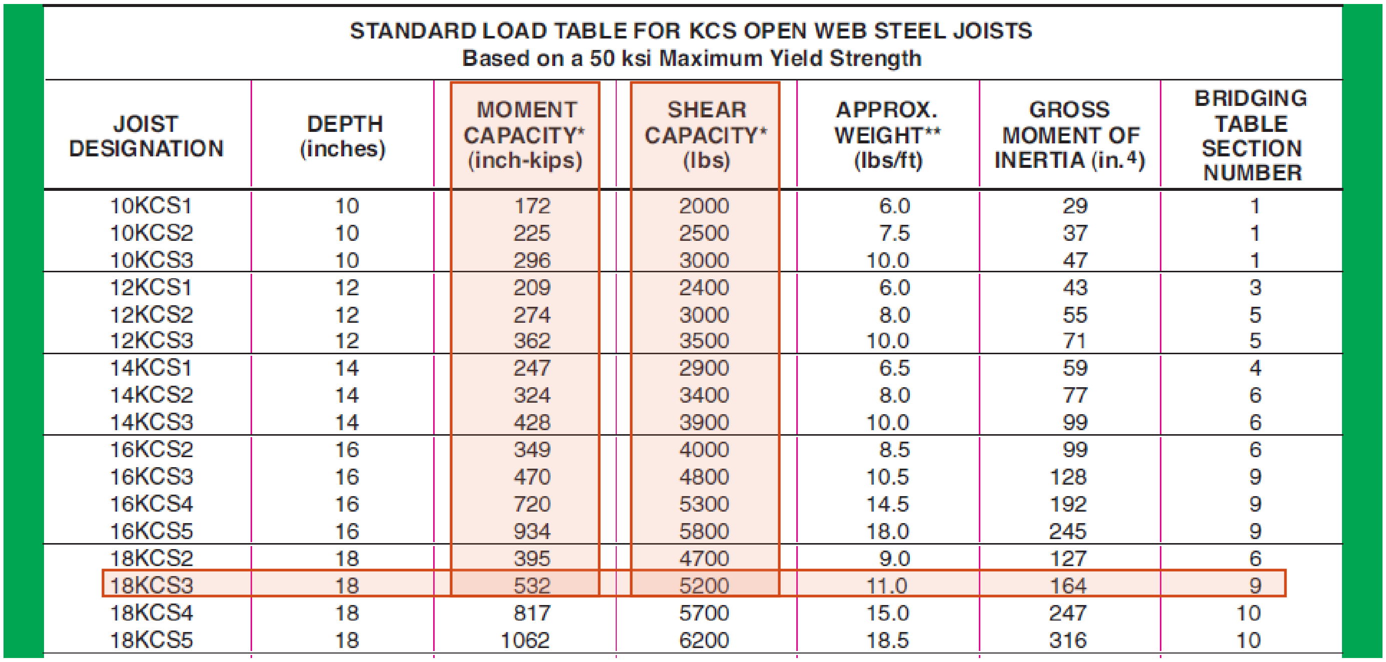
Depth of 18"

Weight: 11 psf

Maximum Moment (inch*kips) = 532 > 128.13 check

Maximum Shear Capacity (lbs) = 5200 > 5123 check

Although 16KCS4 would work for the joist and have a smaller depth it weighs 14.5 psf in comparison to 18KCS3 which weighs 11 psf with an 18 inch depth. Therefore, use 18 KCS3.



STANDARD LOAD TABLE FOR KCS OPEN WEB STEEL JOISTS
Based on a 50 ksi Maximum Yield Strength

JOIST DESIGNATION	DEPTH (inches)	MOMENT CAPACITY* (inch-kips)	SHEAR CAPACITY* (lbs)	APPROX. WEIGHT** (lbs/ft)	GROSS MOMENT OF INERTIA (in.⁴)	BRIDGING TABLE SECTION NUMBER
10KCS1	10	172	2000	6.0	29	1
10KCS2	10	225	2500	7.5	37	1
10KCS3	10	296	3000	10.0	47	1
12KCS1	12	209	2400	6.0	43	3
12KCS2	12	274	3000	8.0	55	5
12KCS3	12	362	3500	10.0	71	5
14KCS1	14	247	2900	6.5	59	4
14KCS2	14	324	3400	8.0	77	6
14KCS3	14	428	3900	10.0	99	6
16KCS2	16	349	4000	8.5	99	6
16KCS3	16	470	4800	10.5	128	9
16KCS4	16	720	5300	14.5	192	9
16KCS5	16	934	5800	18.0	245	9
18KCS2	18	395	4700	9.0	127	6
18KCS3	18	532	5200	11.0	164	9
18KCS4	18	817	5700	15.0	247	10
18KCS5	18	1062	6200	18.5	316	10

Figure H.5: KCS Open Web Steel Joists from Vulcraft Steel Joists and Joist Girders Catalog 2008, page 33