The American Swedish Institute
Minneapolis, MN

Technical Report Three: Mechanical Systems Existing Conditions Evaluation

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Executive Summary

The American Swedish Institute, scheduled to complete construction in late spring 2012, is a 24,600 square feet addition and 27,500 square feet renovation, cultural center and museum project. The building consists of multi-purpose and public spaces for the community to gain knowledge about Swedish culture. A Make-up Air Unit serves fresh air to all the spaces in the addition and existing mansion that is distributed through multiple heat pumps 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.

This report discusses the results and final conclusions made about the American Swedish Institute's mechanical system. Covered in this report are the design objectives, requirements, and conditions. Design ventilation requirements, heating and cooling loads, and energy sources from Technical Reports 1 and 2 are also discussed. New information for this report includes the building's compliance with LEED rating system v2.2, control descriptions and schematics for ventilation, geothermal, hot water, and condenser water; and the mechanical system costs.

LEED Certification for the American Swedish Institute's new construction and renovation was a goal established in the beginning of the project. Owner and project team's goal are to receive a LEED Gold rating. Upon review of LEED documents by the USGBC, the American Swedish Institute has a potential to receive 53 points and earn a LEED Platinum rating. The mechanical system was reviewed for the building under the Energy & Atmosphere and Indoor Environmental Quality categories. 27 of the potential points are obtained in these two categories.

Description of the system operation was completed for the ventilation, geothermal, hot water, and condenser water systems and components for the building. All of these systems are controlled by direct digital controls (DDCs). Included in the control overview are temperature settings, alarms, and information about manual override for the particular systems. Schematics were also drawn for these four systems in the American Swedish Institute. All schematics were simplified to show the key components for the respective systems.

Overall mechanical costs were provided for the building. Total mechanical costs for the system were $2,749,134 and account for 21% of the total building costs; this cost includes all HVAC, plumbing, and fire suppression equipment and accessories. The majority of the mechanical costs come from the plumbing equipment and accessories and total $2,568,000; with HVAC equipment and accessory costs totaling $42,334. Since, the majority of the mechanical costs are plumbing because it is a geothermal system; costs for earthwork were also reviewed. These costs account for 3% of the total project cost or $327,808.

Design Objectives and Requirements

Major design requirements given by the owner included that the addition reflect sustainability 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 healthy environment, and 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 heat loss and infiltration for the building. Another factor would be the 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 vice versa.

Mechanical System Overview

The American Swedish Institute is comprised of a Make-up Air Unit that provides conditioned outside air to all occupied interior spaces in 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 located in the southern part of the site. Heat pumps are used throughout the building and are served conditioned outdoor air from several VAV (Variable Air Volume) boxes, which are served by the Make-up Air Unit. Throughout the building return air from the occupied spaces in the ceiling plenum is recirculated through the heat pumps with the conditioned supply air.

The mechanical system is primarily heated and cooled by the geothermal heat pumps. Any additional heating required for the museum comes from two 20 HP Fulton condensing boilers located in the lower level of the addition. The condensing boiler schedule is shown in Table 1.1 below.

Condensing Boiler Schedule					
Unit No.	**HP**	**Minimum Efficiency**	**Design Pressure (PSI)**	**Flow Rate (GPM)**	**Model**
B-1	20	86%	60	140	Fulton PHW-750
B-2	20	86%	60	140	Fulton PHW-750

Table 1.1: Condensing Boiler Schedule

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 as seen in Table 1.2 below. Throughout the museum VAV boxes are used to supply conditioned air to all the heat pumps in the mansion and addition as shown in Table 1.3 below. 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 spaces, that is then recirculated.

Make-Up Air Unit Schedule		
Unit No.	**CFM**	**Model**
MAU-1	8,000	AADN SA-035

Table 1.2: Make-Up Air Unit Schedule

Air Terminal Unit Schedule			
Terminal Unit No.	**Manufacturer Name**	**Maximum CFM**	**Minimum CFM**
0-A/1	TITUS	150	50
0-A/2	TITUS	750	250
0-A/3	TITUS	170	100
0-A/4	TITUS	130	100
0-T/1	TITUS	1095	600
0-T/2	TITUS	195	100
0-T/3	TITUS	820	400
0-T/4	TITUS	160	160
0-T/5	TITUS	1200	1200
1-A/1	TITUS	240	150
1-A/2	TITUS	110	75
1-A/3	TITUS	130	75
1-A/4	TITUS	700	300
1-A/5	TITUS	1480	250
1-A/6	TITUS	180	100
1-A/7	TITUS	380	200
1-A/8	TITUS	1450	1450
2-A/1	TITUS	690	300
2-A/2	TITUS	90	90
2-A/3	TITUS	450	200
2-A/4	TITUS	250	150

Table 1.3: Air Terminal Unit Schedule

The American Swedish Institute uses heat pumps throughout the addition and existing structure which are coupled with a geothermal system. All 48 heat pumps can be seen below in Table 1.4.

Heat Pump Schedule			
Terminal Unit No.	**Manufacturer Name**	**CFM**	**GPM**
HP 0-A/1	McQuay Enfinity	1000	7.6
HP 0-A/2	McQuay Enfinity	300	2.1
HP 0-A/3	McQuay Enfinity	630	5.3
HP 0-A/4	McQuay Enfinity	630	5.3
HP 0-A/5	McQuay Enfinity	300	2.1
HP 0-A/6	McQuay Enfinity	1000	7.6
HP 0-A/7	McQuay Enfinity	1000	7.6
HP 0-A/8	McQuay Enfinity	1200	9.0

HP 0-A/9	McQuay Enfinity	1000	7.6
HP 0-A/10	McQuay Enfinity	630	5.3
HP 0-T/12	McQuay Enfinity	1,200	10.3
HP 0-T/13	McQuay Enfinity	1,000	7.3
HP 0-T/14	McQuay Enfinity	1,000	7.3
HP 0-T/15	McQuay Enfinity	1,200	10.3
HP 0-T/17	McQuay Enfinity	400	12.6
HP 0-T/18	McQuay Enfinity	800	13.9
HP 0-T/19	McQuay Enfinity	1,000	7.3
HP 0-T/20	McQuay Enfinity	1,200	10.3
HP 0-T/21	McQuay Enfinity	1,000	7.3
HP 0-T/22	McQuay Enfinity	800	13.9
HP 0-T/23	McQuay Enfinity	800	13.9
HP 0-T/24	McQuay Enfinity	1,400	15.3
HP 0-T/25	McQuay Enfinity	300	8.1
HP 0-T/26	McQuay Enfinity	400	8.1
HP 1-A/1	McQuay Enfinity	1,000	7.3
HP 1-A/2	McQuay Enfinity	400	12.6
HP 1-A/3	McQuay Enfinity	630	10.0
HP 1-A/5	McQuay Enfinity	1,600	20.1
HP 1-A/6	McQuay Enfinity	630	10.0
HP 1-A/7	McQuay Enfinity	400	12.6
HP 1-A/8	McQuay Enfinity	400	12.6
HP 1-A/9	McQuay Enfinity	1,400	15.3
HP 1-A/10	McQuay Enfinity	2,000	22.6
HP 1-A/11	McQuay Enfinity	2,000	22.6
HP 1-A/12	McQuay Enfinity	1,400	15.3
HP 1-A/13	McQuay Enfinity	400	12.6
HP 1-A/14	McQuay Enfinity	2,000	22.6
HP 1-A/15	McQuay Enfinity	1,400	15.3
HP 1-A/16	McQuay Enfinity	1,400	15.3
HP 1-T/17	McQuay Enfinity	1,000	7.3
HP 2-A/1	McQuay Enfinity	630	10.0
HP 2-A/2	McQuay Enfinity	400	8.1
HP 2-A/3	McQuay Enfinity	1,600	20.1
HP 2-A/4	McQuay Enfinity	2,000	22.6
HP 2-A/5	McQuay Enfinity	2,000	22.6
HP 2-A/6	McQuay Enfinity	2,000	22.6
HP 2-A/7	McQuay Enfinity	1,000	7.3
HP 2-A/8	McQuay Enfinity	1,000	7.3

Table 1.4: Heat Pump Schedule

Tables 1.5 and 1.6 show the HVAC pumps and centrifugal fan schedules that are used throughout the building. The majority of the pumps and fans have a high capacity for the large number of heat pumps used in the museum.

HVAC Pump Schedule							
Pump No.	**Pump Type**	**Capacity (GPM)**	**Head (FT)**	**Efficiency (%)**	**HP**	**RPM**	**Model**
CWP-1	End-Suct	300	92	68.4	20	1750	B&G 1510 3E
CWP-2	End-Suct	300	92	68.4	20	1750	B&G 1510 3E
CWP-3	End-Suct	450	98	72.7	25	1750	B&G 1510 4E
CWP-4	End-Suct	450	98	72.7	25	1750	B&G 1510 4E
HWP-1	End-Suct	180	65	69.4	7.5	1750	B&G 1510 2BC
HWP-2	End-Suct	180	65	69.4	7.5	1750	B&G 1510 2BC
HWP-3	In-Line	18.7	47	40.1	1	1750	B&G 90 1-1/2A

Table 1.5: HVAC Pump Schedule

Centrifugal Fan Schedule					
Fan No.	**Capacity (GPM)**	**Static Pressure ("WG)**	**HP**	**Fan (RPM)**	**Model**
E-1	2,120	1.7	1 1/2	2,421	Greenheck BSQ-120-15
E-2	280	0.2	1/4	575	Greenheck SBE
E-3	1,300	1.6	1	2,229	Greenheck BSQ-130HP-10
E-4	140	-	-	-	Skutt Envirovent 2
E-5	400	1.0	1/4	1,801	Greenheck BSQ-80-4
E-6	1,100	1.0	1	2,360	Greenheck BSQ-90-7
E-7	400	0.3	1/4	1,233	Greenheck BSQ-80-4

Table 1.6: Centrifugal Fan Schedule

System Operation

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 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 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 2.1 for a schematic of MAU-1.

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 2.2 for a schematic of the geothermal system.

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 closed once supply water temperature reach 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 2.3 for a schematic of B-1 and B-2.

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 2.4 for a schematic of the condenser water system.

Schematic Drawings

Ventilation

Figure 2.1 shows the ventilation schematic for a portion of the zones served by MAU-1. The MAU serves all zones in the existing mansion and addition through VAV boxes located throughout the building.

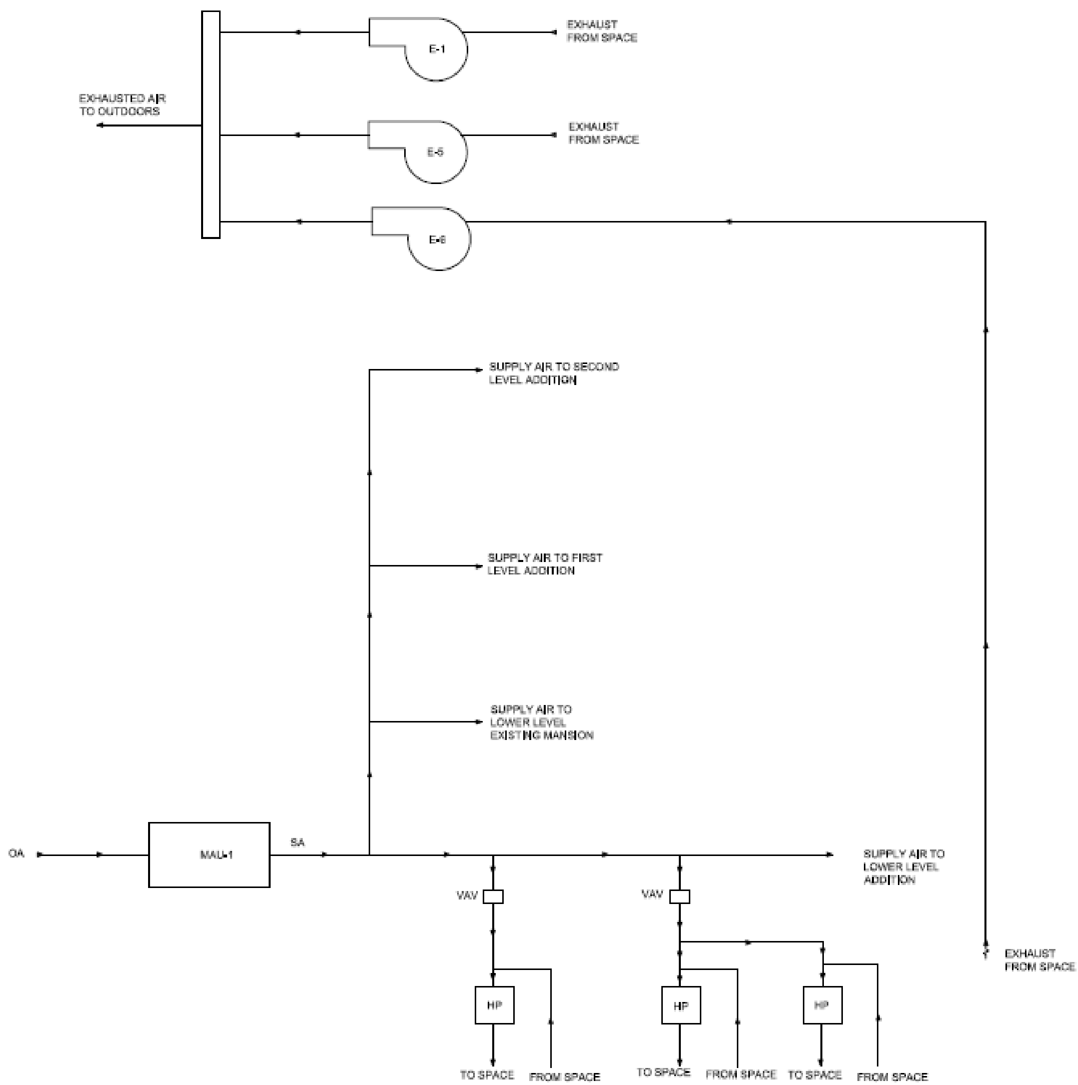

Figure 2.1: Ventilation Schematic

Geothermal

Figure 2.2 shows the geothermal schematic from the geothermal well field to the building. Connection of the geothermal to the hot water system can be seen below.

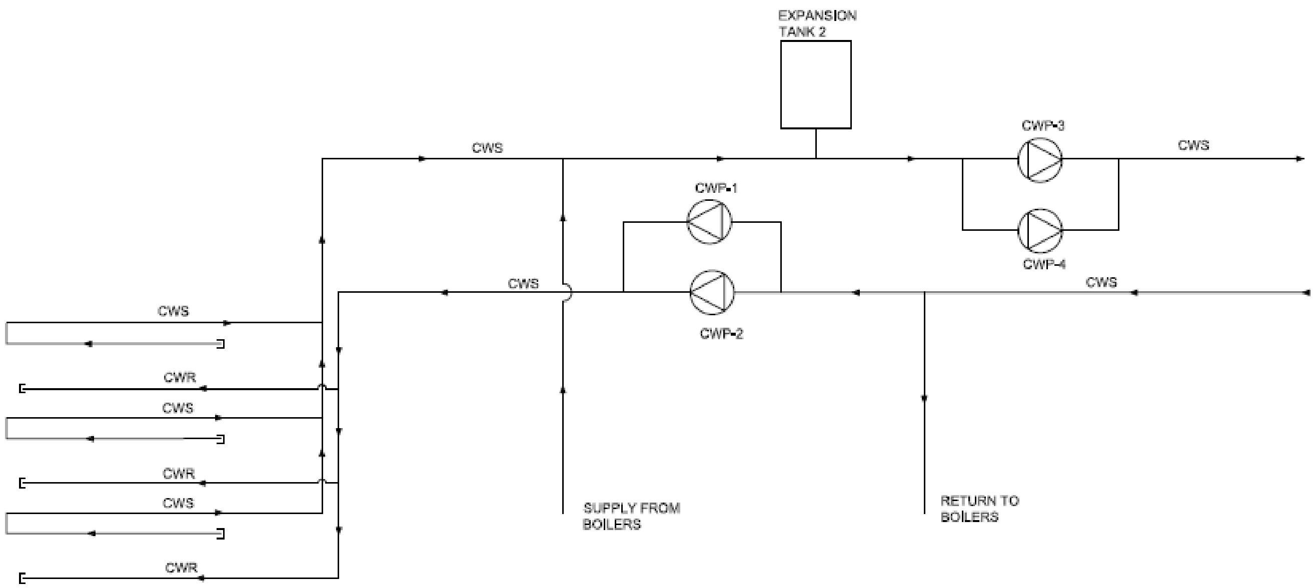

Figure 2.2: Geothermal Schematic

Hot Water

Figure 2.3 shows the hot water schematic from where the geothermal pipes enter the building and connect with piping from B-1 and B-2. As seen in the schematic hot water from the boilers connects to the condenser water from the geothermal wells. Hot and condenser water piping continues to the heat pumps throughout the building.

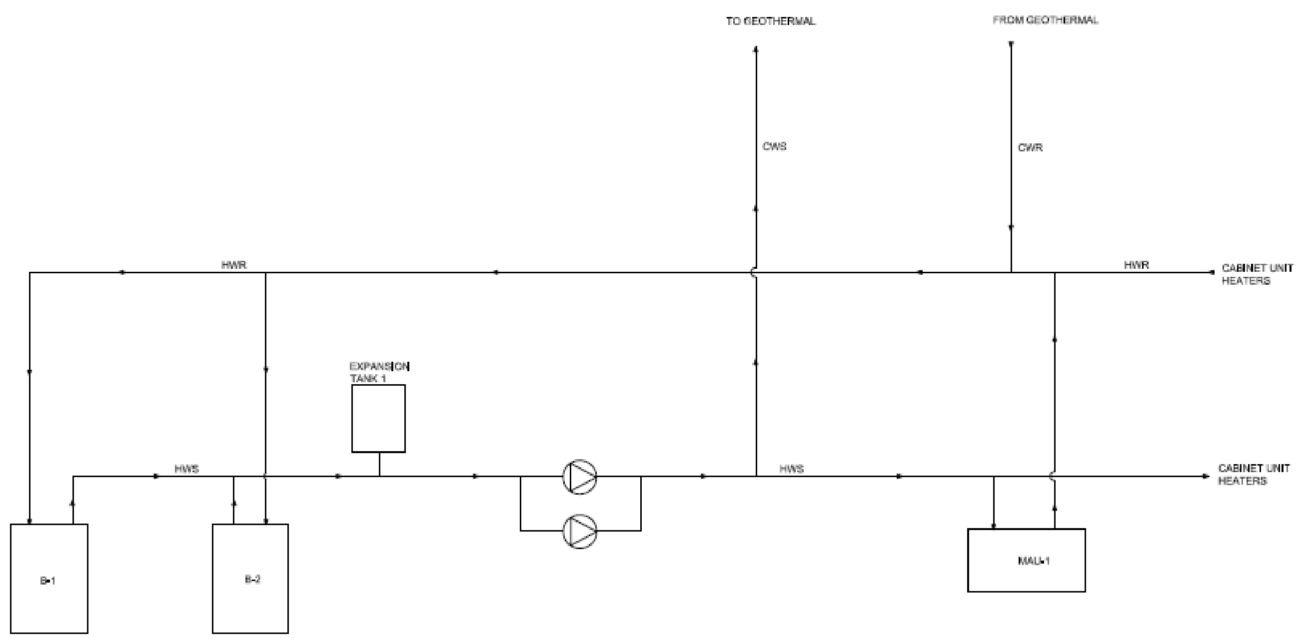

Figure 2.3: Hot Water Schematic

Condenser Water

Figure 2.4 shows the condenser schematic from the mechanical room to a portion of the heat pumps located in the building.

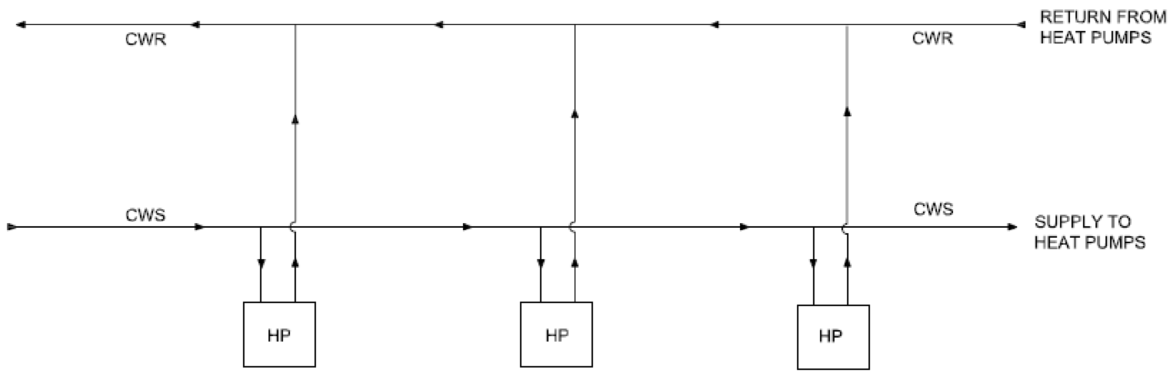

Figure 2.4: Condenser Water Schematic

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 A.

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 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 the spaces.

Design Heating and Cooling Loads

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 3.1-3.7 was analyzed using Trane TRACE 700 based on %OA, cfm/ft², cfm/ton, ft²/ton, and occupancy.

Lower Level Addition Heat Pump		
	Cooling	**Heating**
% OA	7.7	7.7
cfm/ft²	0.50	0.50
cfm/ton	432.09	-
ft²/ton	870.07	-
Occupancy	18	-

Table 3.1: Heat Pump for Lower Level Addition

First Level Addition Heat Pump		
	Cooling	**Heating**
% OA	19.7	25.4
cfm/ft²	0.97	0.97
cfm/ton	299.31	-
ft²/ton	307.37	-
Occupancy	280	-

Table 3.2: Heat Pump for First Level Addition

Second Level Addition Heat Pump		
	Cooling	**Heating**
% OA	16.2	16.2
cfm/ft²	1.38	1.38
cfm/ton	341.10	-
ft²/ton	246.64	-
Occupancy	220	-

Table 3.3: Heat Pump for Second Level Addition

Lower Level Existing Heat Pump		
	Cooling	**Heating**
% OA	31.6	31.6
cfm/ft²	0.58	0.58
cfm/ton	259.03	-
ft²/ton	447.36	-
Occupancy	228	-

Table 3.4: Heat Pump for Lower Level Existing Mansion

First Level Existing Heat Pump		
	Cooling	Heating
% OA	11.7	11.7
cfm/ft²	0.72	0.72
cfm/ton	377.71	-
ft²/ton	521.21	-
Occupancy	34	-

Table 3.5: Heat Pump for First Level Existing Mansion

Second Level Existing Heat Pump		
	Cooling	Heating
% OA	7.4	7.4
cfm/ft²	1.16	1.16
cfm/ton	412.40	-
ft²/ton	357.05	-
Occupancy	29	

Table 3.6: Heat Pump for Second Level Existing Mansion

Third Level Existing Heat Pump		
	Cooling	Heating
% OA	12.4	12.4
cfm/ft²	0.69	0.69
cfm/ton	372.95	-
ft²/ton	543.37	-
Occupancy	22	-

Table 3.7: Heat Pump for Third Level Existing Mansion

The %OA for the seven heat pump systems range from 7.4% - 31.6% this can be seen in Tables 3.1-3.7 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 in Tables 3.4 and 3.2, respectively. 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. 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 (Table 3.1) has the largest amount of ft^2/ton at 870.07. 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. All the systems serving the mansion have large ft^2/ton values ranging from 357.05 – 543.37; these can be seen in Tables 3.4-3.7. These systems are larger due to the amount of gallery spaces and art work storage in this portion of the building. Overall, the systems with large ft^2/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**	**Main Coil (Tons)**
Cooling	A-Lower HP	7.9
	A-First HP	26.6
	A-Second HP	23
	T-Lower HP	18.7
	T-First HP	16.3
	T-Second HP	21.7
	T-Third HP	10.2
Total		124.4

Table 3.8: Peak Design Cooling Load

Design Heating		
Plant	**System**	**Main Coil (MBH)**
Heating	A-Lower HP	38
	A-First HP	195.4
	A-Second HP	148.8
	T-Lower HP	156.6
	T-First HP	282.4
	T-Second HP	339.7
	T-Third HP	174.8
Total		1335.7

Table 3.9: Peak Design Heating Load

The peak design heating and cooling loads for the American Swedish Institute occur in July, this can be seen in Table 3.8 and 3.9 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. This is accurate since the construction of the mansion is older and considered to be poor in comparison to the addition. It can also be seen that the lower levels in the 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 and second 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.

Rates and Energy Sources

All electric and gas rates were based off of the values provided by Xcel Energy for the state of Minnesota. $3.03/kW is used for the electric rate and the average rate of $0.62/Therm was used for natural gas.

Overall energy consumption for the building annually is shown in Table 4.1 below. 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 extra heating if the system calls for more heat in 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.

Energy Consumption Summary					
System		**Elec (KWH)**	**Gas (KBTU)**	**Total (KBTU/Yr)**	**% Total**
	Primary Heating	77,858	71,188	336,919	11.6
	Other	4,480	-	15,291	0.5
Primary Cooling	Cooling Compressor	118,538	-	404,569	13.9
	Other	132	-	451	0.0
Auxiliary	Supply Fans	122,891	-	419,428	14.4
Lighting	Lighting	490,330	-	1,673,496	57.4
Receptacle	Receptacles	18,843	-	64,310	2.2
Total		**833,072**	**71,188**	**2,914,464**	**100.0**

Table 4.1: Energy Consumption Summary

Mechanical System Cost

Although the costs for each piece of equipment were not available the costs for each section of the total mechanical costs 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 to 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 Space Requirements

Summarized in Table 5.1 are the areas of the American Swedish Institute that are occupied by mechanical system. Included in this summary 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 5.1: Area Occupied by Mechanical Space

LEED Mechanical System Assessment

The Leadership in Energy and Environmental Design (LEED) certification system is broken into six different sections. Only two sections are analyzed in this report; 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. 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.

EA Prerequisite 1: Fundamental Commissioning of the Building Energy Systems

Prerequisite 1 is intended to verify that all of the building's energy related systems were installed, calibrated and perform according to the initial design. A commissioning team shall perform all commissioning for the building and be documented by a Commissioning Authority (CxA). The work to be commissioned includes the verification of the installation and performance of all energy-related systems. As well as having a qualified personnel to report all results and recommendations to the owner.

Prerequisite 2: Minimum Energy Performance

Prerequisite 2 is meant to establish minimum levels of energy efficiency for all systems in the building and the building itself. A consultant was contracted to determine the American Swedish Institute's compliance with the mandatory and prescriptive provisions of Standard 90.1 with use of a computer simulation model. The results show a 44.2% energy cost savings for the building.

Prerequisite 3: Fundamental Refrigerant Management

Prerequisite 3 is intended to reduce the building's contribution of ozone depletion with zero use of CFC-based refrigerants. The American Swedish Institute does not use any CFC-based refrigerants, therefore in compliance with this prerequisite.

EA Credit 1: Optimize Energy Performance – 10 points

Credit 1 is intended to achieve increasing levels of energy performance above the baseline requirements in Prerequisite 2. The design engineers chose Option 1 to verify compliance for the whole building energy simulation. From the calculations it was determined that the American Swedish Institute's energy cost savings were 44.2%.

EA Credit 3: Enhanced Commissioning – 1 point

Credit 3 is designed to begin the commissioning process early in the design. The American Swedish Institute has contracted a commissioning agent for Prerequisite 1 and has extended the contract for the additional requirements for Credit 3 to earn an additional point.

EA Credit 4: Enhanced Refrigerant Management – 1 point

The purpose of Credit 4 is to reduce ozone depletion and support compliance with the Montreal Protocol. Option 1 was used for this credit since no refrigerants are used in the mechanical systems for the American Swedish Institute.

EA Credit 6: Green Power – 1 point

Credit 6 is designed to encourage the development and use of grid-source, renewable energy technologies. The American Swedish Institute intends to purchase electricity from WindSource/Xcel for 35% of the total electrical use per year.

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.

EQ Prerequisite 1: Minimum IAQ Performance

Prerequisite 1 is intended to establish the minimum indoor air quality of the building. This section requires that minimum requirements in Sections 4 through 7 are met in ASHRAE 62.1-2004 for mechanically ventilated buildings. The American Swedish Institute meets Prerequisite 1 requirements since the building is in compliance with ASHRAE 62.1-2007 and the Minnesota Code.

EQ Prerequisite 2: Environmental Tobacco Smoke (ETS) Control

The purpose of Prerequisite 2 is to minimize exposure of building occupants, indoor surfaces, and ventilation air to Environmental Tobacco Smoke. The Owner has specified that all smoking areas are at least 25 feet away from all entries, air intakes and operable windows. Therefore, the American Swedish Institute is in compliance with this prerequisite.

EQ Credit 1: Outdoor Air Delivery – 1 point

Credit 1 is designed to provide capacity for ventilation system monitoring to assist in sustaining occupant comfort and well-being. Monitoring systems have been installed to monitor ventilation rates to ensure that ventilation is maintained at design minimum flows. In all densely occupied spaces CO_2 sensors have been installed to monitor carbon dioxide concentrations. With all other spaces, minimum outdoor air rates will be monitored by control systems.

EQ Credit 3.1: Construction IAQ Management Plan: During Construction – 1 point

Credit 3.1 intends to reduce the indoor air quality problems that result from the construction/renovation process. Typical contractor procedures and plans have been included in the construction /renovation of the American Swedish Institute to comply with this credit.

EQ Credit 3.2: Construction IAQ Management Plan: Before Occupancy – 1 point

The purpose of Credit 3.2 is to reduce indoor air qualities that occur from the construction/renovation process. Option 1 was decided for this credit, which requires the building to be flushed out after construction ends prior to occupancy. Full flush-out will occur after coordination with the Contractor and Owner schedules.

EQ Credit 4.1: Low-Emitting Materials: Adhesives & Sealants – 1 point

Credit 4.1is designed to reduce the quantity of indoor air contaminants that are odorous, irritating, or harmful to the installers and occupants. The VOC limits under SCAQMD Rule #1168 have been accepted under HGA Architects and Engineers' specifications. Therefore the American Swedish Institute is in compliance with this section.

EQ Credit 4.2: Low-Emitting Materials: Paints & Coatings – 1 point

Credit 4.2 intends to reduce the quantity of indoor contaminants that are harmful to the installers and occupants. The paints and coatings used in the building have been accepted under HGA Architects and Engineers' specifications and are used on the American Swedish Institute.

EQ Credit 4.3: Low-Emitting Materials: Carpet Systems – 1 point

The purpose of Credit 4.3 is to reduce the amount of indoor air contaminants that are harmful to the installers and occupants. HGA Architects and Engineers' specifications require that all carpet, carpet cushions, and carpet adhesives are installed to the requirements of this credit.

EQ Credit 4.4: Low-Emitting Materials: Composite Wood & Agrifiber Products – 1 point

Credit 4.4 is designed to reduce the amount of indoor air contaminants that are odorous, irritating or harmful to the occupants and installers. All composite wood and agrifiber products used on the interior of the American Swedish Institute meet the specifications of HGA Architects and Engineers, which require the selection of all products in this section to meet this credit.

EQ Credit 5: Indoor Chemical & Pollutant Source Control – 1 point

Credit 5 intends to minimize the exposure of building occupants to potentially hazardous particulates and chemical pollutants. The American Swedish Institute is in compliance with this section with all entryways designed to proper dimensions. Proper exhaust is provided in all areas that are potentially exposed to hazardous gases or chemicals such as the loading dock on the lower level of the addition. MERV 13 filters have been installed to process all outdoor air to be delivered as supply air to the building.

EQ Credit 6.1: Controllability of Systems: Lighting – 1 point

The purpose of Credit 6.1 is to provide a high level of lighting system control for individual occupants and multi-occupant spaces. More than 90% of the building is provided with individual lighting controls as well as controllability for the multi-purpose rooms located on the second level of the addition and throughout the mansion.

EQ Credit 6.2: Controllability of Systems: Thermal Comfort – 1 point

Credit 6.2 is designed to provide a high level of thermal comfort system control for individual occupants and multi-occupant spaces. Over 50% of the American Swedish Institute has individual controls for offices and smaller task areas to maintain occupant comfort for the specific heat pumps for those zones. As well as, all multi-occupant spaces in the building have thermostats to maintain comfort for the group.

EQ Credit 7.1: Thermal Comfort: Design – 1 point

Credit 7.1 intends to provide a comfortable thermal environment to support the productivity and well-being of the building occupants. All HVAC systems and the building envelope have been designed to meet the requirements of ASHRAE Standard 55-2004, therefore in compliance with this credit.

EQ Credit 7.2: Thermal Comfort: Verification – 1 point

The purpose of Credit 7.2 is to provide assessment of the building's thermal comfort over time. The American Swedish Institute shall provide a survey, using HGA Architects and Engineers' template, to all building occupants to assess satisfaction with thermal comfort.

EQ Credit 8.1: Daylight & Views: Daylight 75% of Spaces – 1 point

Credit 8.1 is designed to provide the building occupants a connection between indoor spaces and the outdoors through views and daylighting into regularly occupied areas of the building. The compliance for this credit must be reviewed by USGBC; with exclusion of the renovation of the mansion the American Swedish Institute shall receive an additional point.

EQ Credit 8.2: Daylight & Views: Views of 90% of Spaces – 1 point

Credit 8.2 intends to provide the building occupants with a connection between the indoor spaces with the outdoors. An additional point will be received upon interpretation by the USGBC, with exclusion of the renovation of the mansion.

Final 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 considered 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 is 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 Standards 62.1 and 90.1. Results from Technical Report 2 were compared to average values and provided realistic results for a building of this type. Comparison of the energy usage and performance, 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 being supplied to the heat pumps. This would need further research to verify that this method is a possible chance for 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 $2,545,853 to operate. This cost seems high for a geothermal system that does not rely heavily on boilers to heat the building. Annual cost could be further reduced with the appropriate schedules and occupancy rates to get a more accurate utility cost.

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 cost for plumbing and earthwork could be reduced with changing the mechanical system to a cooling tower; therefore, eliminating excavation and piping run in the ground for the geothermal system. This method would also need researched and verified.

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 possibilities for other design options to decrease costs and energy usage in other areas of the building with different methods.

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.

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

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

Appendix A – Weather Data for Minneapolis, MN

2005 ASHRAE Handbook - Fundamentals (IP)

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	86.3
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	86.7	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