Technical Report 3

Evaluation of Existing Mechanical Systems

November 11, 2013

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Executive Summary

Technical Report 3 examines the equipment included in the mechanical design of the Auditorium. It also reports on the systems operation sequence and potential for LEED certification. Finally, the report recaptures the design considerations and requirements previous reported in Technical Reports 1 and 2.

In order to achieve a fully functioning building that met all the needs of the Francis Michael Performing Arts Academy (FMPAA), an $8.5 million budget was allocated for the mechanical system. The current renovated mechanical design adequately meets the required heating, cooling, indoor air quality and comfort standards. Although not the most "green" of facilities, the Auditorium makes strides to be a sustainable building and reduce its impact on the campus.

Utilizing already developed central heating and chilled water plants, the equipment needed for the Auditorium capitalizes on the availability of steam and chilled water. An efficient high pressure flooded heat exchanger provides hot water to the building for heating purposes through many different types of systems including radiant floors, fin-tube radiation and heating coils in the air handling units. On the cooling side, a system of active chilled beams reduces the need for conditioned air down to the require ventilation airflow and also utilizes readily available chilled water. Additionally, energy recovery equipment in one of the four air handling units helps to preheat or precool outdoor air from exhausted room air and reduces the capacity of the heating and cooling coils. Further information regarding the mechanical equipment in the Auditorium and central plants is included in the body of the report.

Prior to the renovation, operational history was not provided to the design team for equipment sizing purposes. Furthermore, construction is scheduled to be complete in April 2014, so current system operational data is also not available yet. However, an update to the annual energy and utilities consumption model was performed with additional information received after Technical Report 2. The updated results yielded an annual operating cost of $ 283,729 ($1.65/SF). The electrical consumption for the year totaled 1,671 MWh and annual heating fuel consumption was 8,171 MMBtu.

Finally, the priorities of the building owner seem to be directed toward restoring the Auditorium to a functional state rather than an extremely high performing building. Therefore, the mechanical design was driven not by LEED certification credits, but by a system approach to bring the Auditorium to current day working conditions. An evaluation of LEED credits pertaining to the mechanical system is included in the LEED Evaluation Section.

Building Overview

The Auditorium is a historic building located on the campus of the Francis Michael Performing Arts Academy (FMPAA). It was built in 1929, and has recently undergone a renovation to revitalize the performance space and allow for greater usage of the ancillary public spaces. After completion of construction the Academy Honors Program will permanently reside in the Auditorium

A pediment entrance way with ionic columns faces the prominent campus mall. The building facade is a 3 wyth historic brick construction with classical ornamentation. The building is approximately 172,000SF, five stories tall and located in the very cold climate of Lemma, Minnesota.

The plan below (Figure 1) shows the expanded performance space (green), audience chamber (maroon), and horseshoe of public spaces and office spaces (orange) surrounding.

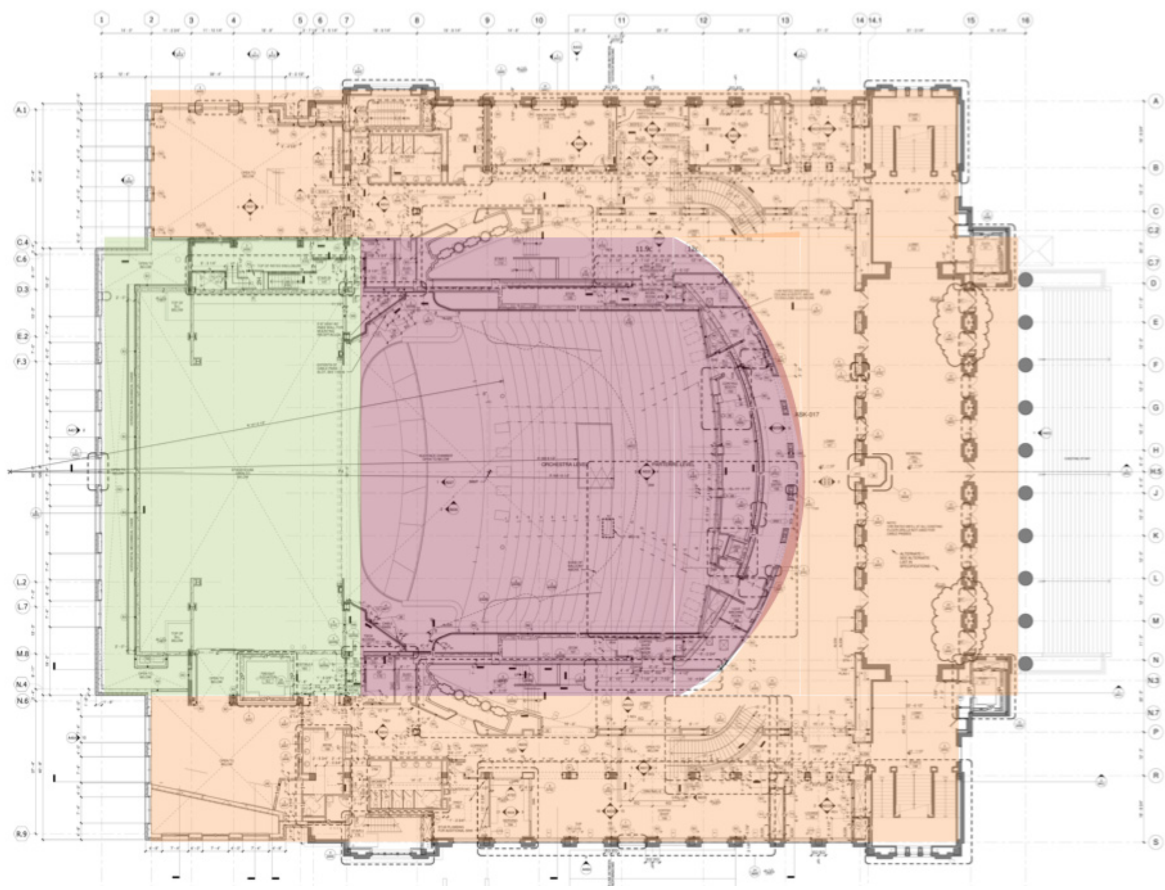


Figure 1 First Floor Level (Source: Architect of Record)

Design Considerations

Objectives

The objective of the renovation of the Auditorium was to restore the building to a functional state for the Academy's use. The performance and audience spaces needed to be redesigned to allow for better performance logistics and acoustical sound, while also providing more office space for the Academy Honors program to reside within the building. The role the mechanical system played in this renovation was to bring the existing system up to current day code regulations and provide a healthy and comfortable environment for the occupants. The major airside systems in the building were completely redesigned and previous systems were removed and replaced with up-to-date technologies. The building is served by campus steam and chilled water plants and their impact drove many design decisions. All standards enforced by the Minnesota State Building Code were complied with and in some cases were exceeded by the design team. Further details on requirements in the redesign of the Auditorium's mechanical system are listed below.

Requirements

Outdoor Design Conditions

The following table (Table 1) contains the outdoor design considerations for Lemma, Minnesota. The Auditorium is located in ASHRAE Zone 6A, which is characterized as cold and moist. Design conditions accommodate 99.6% of the days during the year.

COLDEST MONTH	HEATING DB (99.6%)	HUMIDIFICATION (99.6%)		
		DP	HR	MCWB
JANUARY	-14.9	-25.7	1.4	-14.0

WARMEST MONTH	COOLING (0.4%)		DEHUMIDIFICATION (0.4%)		
	DB	MCWB	DP	HR	MCWB
JULY	91.0 F	73.2	73.3	127.8	83.4

Table 1 Design Conditions (Source: ASHRAE 2005 Handbook of Fundamentals)

Indoor Design Conditions

The indoor design conditions were set to 75°F dry bulb for cooling and 70°F dry bulb for heating. The relative humidity was set for 50% for both heating and cooling. Additionally, thermostat locations were assumed to be in the room.

Ventilation Requirements

Adequate ventilation air is supplied to all the space in the Auditorium through four air handling units (AHU). The Public Spaces, Audience Chamber and Performance Spaces are each served by a variable air volume AHU. The percentage of outdoor air for these units are 26%, 21% and 33% respectively. The Performance Support Spaces are supplied the minimum ventilation air required by ASHRAE 62.1-2010 and the loads are accommodated through and active chilled beam system. All ventilation air flows comply with ASHRAE 62.1-2010 and below is a summary of the airflows for each air handling unit (Table 2).

System Name	Total Supply CFM	Total OA	AHU Ventilation Efficiency	AHU OA Required	Exhaust CFM	Total OA/Makeup Air Required	AHU OA %
AHU-1 : Public Spaces	74,370	15,475	0.8	19,343	3,359	19,343	26%
AHU-2 : Audience Chamber	60,545	11,649	0.9	12,943	0	12,943	21%
AHU-3 : Performance Spaces	26,990	7,083	0.8	8,854	0	8,854	33%
AHU-5: Performance Support Spaces	5,360	3,123	0.8	3,904	2,738	3,904	73%

Table 2 Ventilation Calculation

Heating & Cooling Requirements

The heating and cooling loads were calculated on an initial basis using Trane Trace 700 software. The discrepancies in design heating and cooling loads listed in Table 3 are most likely due to the designer using relying on his previous experience to determine more appropriate load values after using the airflows to determine a basis for the loads. The model loads have been updated from the previous Technical 2 Report using more information regarding load approximations and system characteristics. See more information on annual energy consumption in sections below.

UPDATED 11/9/13	System Name	Total Supply [CFM]	Total OA [CFM]	HEATING [MBh]	COOLING [Ton]	FINAL SIZE [CFM]
MODEL	AHU-1 : Public Spaces	74,370	15,475	4,967	330.6	- -
	AHU-2 : Audience Chamber	60,545	11,649	3,200	223.5	- -
	AHU-3 : Performance Spaces	26,990	7,083	500	48.2	- -
	AHU-5: Performance Support Spaces	5,360	3,123	760	47.3	- -
TOTALS		167,265	37,330	9,426	262	SF/Ton
DESIGN	AHU-1 : Public Spaces	69,909	15,839	2,964	195.3	70,000
	AHU-2 : Audience Chamber	61,500	12,371	5,140	135.3	61,000
	AHU-3 : Performance Spaces	28,655	7,771	2,744	36.7	31,000
	AHU-5: Performance Support Spaces	7,990	3,010	803	99.4	10,000
TOTALS		168,054	38,991	11,651	364	SF/Ton

Table 3 Heating and Cooling Load Comparison

Energy Sources

Based on additional modeling information received after the submission of Technical Report 2, the annual consumption of energy by the Auditorium has been updated as follows:

Fuel Type

The Auditorium is feed by a steam plant and chilled water plant. The fuel sources that these plants use are electricity for the chilled water plant and a variety of heating fuel types including coal, oat hulls, fuel oil and natural gas. Depending on the economics of fuels, the central plant can operate to maximize efficiency and keep heating costs low.

Rates

The Auditorium is supplied electricity from Xcel Energy Inc. The agreement that the FMPAA holds with Xcel Energy is summarized below in Table 4. Using a general time of day rate structure, The Auditorium is charged based on its consumption at different times of day and year.

Xcel Energy General Time of Day Rate Structure			
Fixed Monthly Charge	$ 25.00	per month	
Total Demand Charge - Summer	$ 10.71	per kW	June - September
Total Demand Charge - Winter	$ 7.37	per kW	October - May
Total On Peak Energy Charge	$0.064619	per kWh	9 am - 9 pm (weekdays)
Total Off Peak Energy Charge	$0.039929	per kWh	All other times

Table 4 Xcel Energy Rate Structure (Source: Xcel Energy)

The FMPAA estimates that its steam heating costs are $8.182/MMBTU. This figure takes into account fuel, operation, and maintenance costs for a given year. Additionally, using the electricity rate structures and the efficiency of the chilled water plant, FMPAA approximates that it costs $0.09/ton-hr of chilled water.

The Auditorium has a 6" water line connection and an 8" sanitary sewer line connection. Based on monthly meter readings the FMPAA is charged based on the following rate structure in Table 5.

Municipal Water Utility Rates			
Fixed Annual Charge	$ 100.00	per year	6" Water Line connection
Water Demand Charge	$ 3.29	per unit	1 water unit = 100 ft^3 (748 gal)
Fixed Annual Charge	$ 240.00	per year	8" Sanitary Sewer line connection
Sewer Demand Charge	$ 3.14	per unit	1 water unit = 100 ft^3 (748 gal)

Table 5 Water Utility Rates (Source: Municipal Water Utility)

Annual Energy Use

The updated monthly breakdown of electricity demand is shown in Figure 2. Additionally, each month broken down by system type. As expected the demand for electricity increases during the summer months due to the increased usage of the chilled water plant. Larger images of the graphs presented can be found in Appendix A.

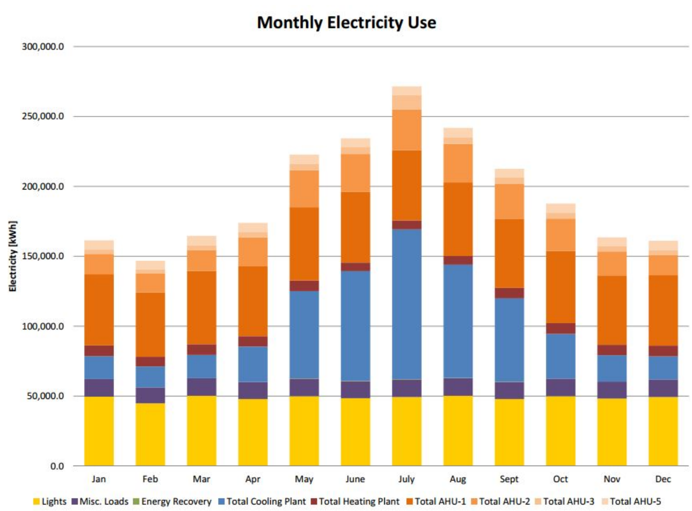


Figure 2 Monthly Electricity Use

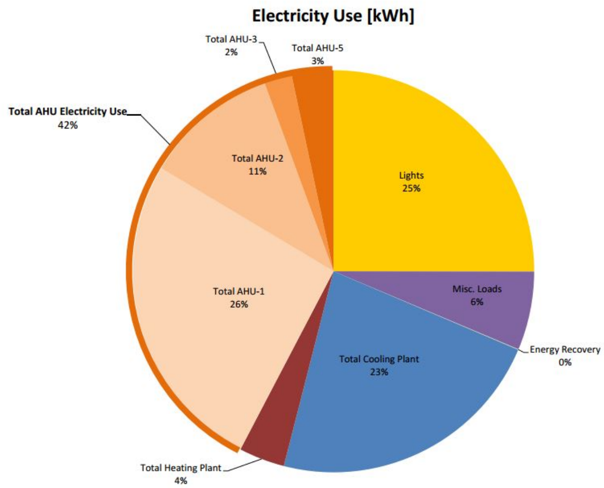
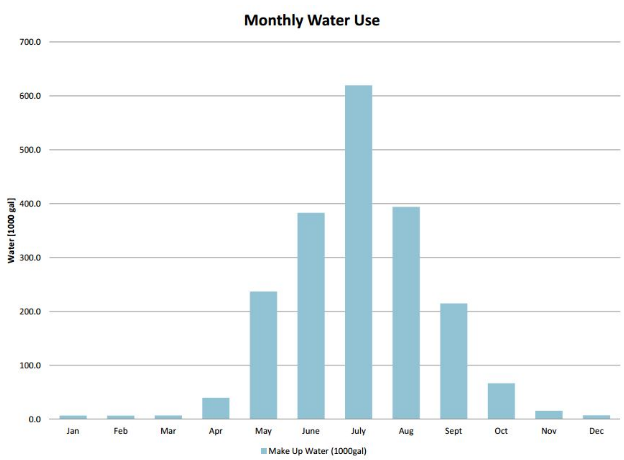


Figure 3 shows the percentage of electricity used by each system compared to the annual consumption. The annual demand for electricity is 1,672 MWh. Note that a majority of electricity consumed is by the air handling units at 42%, which is due to the fan power required.

Figure 3 Annual Electricity Consumption

Furthermore the demand for heating fuel shows the expected trend of a heating dominated climate from October through May (Figure 5). In terms of water usage, the Auditorium requires almost 2 million gallons of make-up water each year to operate the chilled water plant for the Auditorium alone. Figure 4 shows the monthly breakdown of make-up water required. Note that the water demand peaks in July with almost 620,000 gallons required. A full breakdown of the equipment energy and water consumption can be found in Appendix A.



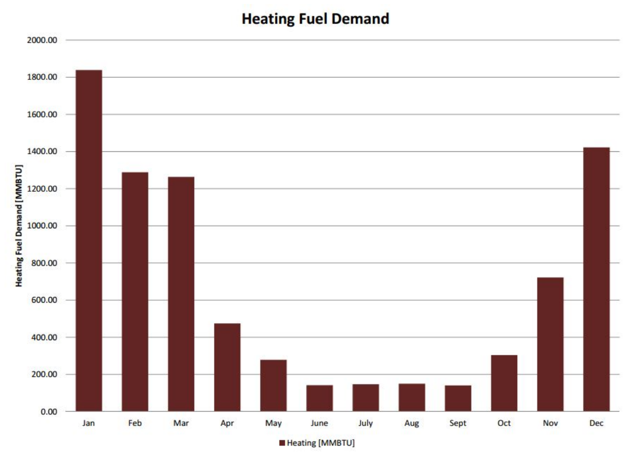


Figure 4 Monthly Make-up Water Demand

Figure 5 Heating Fuel Demand

Annual Utility Costs

The Auditorium's annual utility costs are approximately $283,729. This includes electricity based on the Xcel Energy Rate Structure shown in Table 4, Heating fuel cost from the campus steam plant approximated at $8.182/MMBTU and water demand based on the utility rates shown in Table 5. It can be seen that electricity is a primary cost category at 73% of the total annual cost (Table 6).

ANNUAL UTILITY COST			
ELECTRICITY	**$**	**207,985.79**	**73%**
Fixed Montly Charge	*$*	*300.00*	*0.1%*
Lights	*$*	*52,979.55*	*25.5%*
Misc	*$*	*11,294.57*	*5.4%*
Energy Recovery	*$*	*97.37*	*0.0%*
Cooling Plant	*$*	*47,817.22*	*23.0%*
Heating Plant	*$*	*6,643.53*	*3.2%*
AHU	*$*	*88,853.55*	*42.7%*
HEATING FUEL	**$**	**66,856.03**	**24%**
WATER	**$**	**8,887.95**	**3%**
Total	**$**	**283,729.77**	**100%**

Table 6 Annual Utility Cost

The monthly utility cost distribution shown in Figure 6 is of particular interest. Over a typical year the utilities costs peak in January, July and December forming a tri-modal distribution. Milder months in the spring and fall greatly reduce heating and cooling costs for the Auditorium. Peak utility costs occur in July at approximately $29,660.

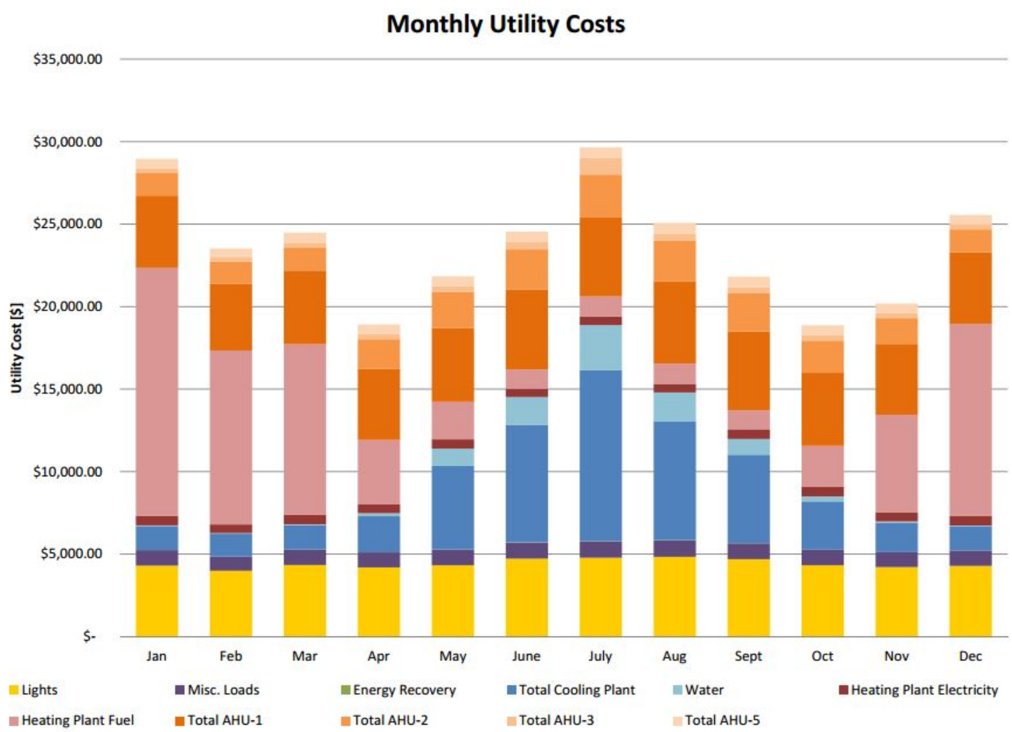


Figure 6 Monthly Utility Cost

Rebates

The design team contracted an independent consultant to perform an energy study and life cycle cost analysis for different variations of the proposed mechanical system. Another task the consultant performed was an analysis on the estimated utility incentive the build could receive. Based on extensive computer modeling, the consultant approximated that the Auditorium could receive a rebate incentive of $13,000 - $14,000 to offset the first cost of the equipment.

Existing Mechanical System

The Auditorium's mechanical system is split into several different types of arrangements. The following sections describe the equipment, system schematics and operation. Additionally analysis on the space requirements, renovation first cost and LEED evaluation are included.

Equipment

Heating

Steam Plant

The campus steam plant includes 3 boilers; two natural gas and fuel oil boilers and a third circulating fluidized boiler. The circulating fluidized boiler burns coal, oat hulls and has the capacity to burn a blended version of fuel. Steam is produced and distributed to all campus buildings for heating and humidification purposes.

Heat Exchanger

When steam is delivered to the building, it enters at high pressure into a flooded heat exchanger (SHE-1). The heat exchanger is rated to accommodate 500 °F and 250 psi steam to heat water up to a maximum temperature of 200 °F. Valves control the amount of water held in the tank based on the load capacity needs. This heat exchanger has a capacity of 12,000 lbs/hr .

Heating Equipment

Several types of fin tube radiation are used in the Auditorium based on their location and needed capacity. The number of rows range from three to a single row and the capacity also varies greatly. The basis for each fin tube design is on 180 °F entering water temperature (EWT), 150 °F leaving water temperature (LWT) and 65 °F entering air temperature (EAT). The system of fin tube radiators, in conjunction with hot water heating coils in 107 of the VAV boxes and a radiant floor slab above the load dock, keep the Auditorium warm during the heating season of Lemma, Minnesota.

Domestic Hot Water Heater

The domestic water is heated from the heating water from the flooded heat exchanger in a brazed plate heat exchanger. This water to water process uses the superheated steam condensate to raise the domestic water from 40 °F to 115 °F to supply the building. The heat plate heat exchanger is rated at 150,000 BTUh output.

Cooling

Chilled Water Plant

The chilled water plant supplies chilled water to all campus buildings for space cooling purposes. The plant, located in the basement of the Auditorium, includes two 1000 ton centrifugal chillers and a third 800 centrifugal chiller, all manufactured by Trane. They use refrigerant R-123, a commonly used chlorofluorocarbon. The system is designed as primary/secondary with a front-end decoupling pipe with control valve. The pumping arrangement is centralized and includes a set of three primary pumps in parallel and three distribution pumps in parallel with variable speed drives.

Airside

Air Handling Units

There are four air handling units (AHU) serving the Auditorium. AHU-1, AHU-2, and AHU-3 are variable air volume units that serve the public spaces, auditorium chamber and performance spaces correspondingly. They all use a fan wall system and have rated filters of MERV 7 and MERV 14. AHU-1 is designed for 70,000 cfm and serves 130 VAV boxes. AHU-2 serves a 61,000 cfm underfloor air distribution systems located in the audience chamber. The performance spaces are served by AHU-3 directly, and it is designed for 31,000cfm.

AHU-5 uses a dual energy recovery wheel. One wheel is for heat recovery (HRW) to preheat the incoming outdoor air. The other is a passive dehumidification wheel (PDW) to control humidity. AHU-5 is a 10,000 cfm variable air volume unit that serves 16 active chilled beams in the performance support spaces. It also has filters rated at MERV 8 and MERV 14. Note, AHU-4 was not used and does not exist in the final construction documentation.

Chilled Beams

Active chilled beams are supplied with the minimum amount of air required by code standards for adequate amount of air required by code standards for adequate ventilation. They, in turn, cool the spaces by recirculating the room air and passing the warm air over a series of cooling coils located in the unit. The inlet water temperature supplied to the cooling coil in the chilled beam is 60°F. Figure 7 to the right shows how the circulation process works. The cooling fluid is supplied by the chilled

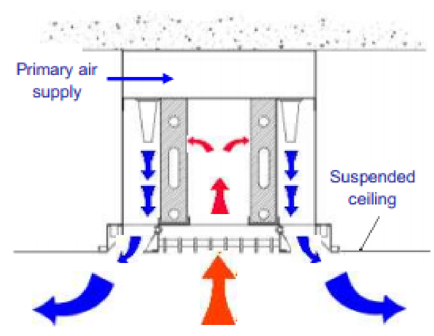


Figure 7 (Source: Trox Chilled Beam Design Guide)

water plant and returned to the plant after it has cooled the air in the space. With these units, as stated before, only minimum outdoor airflow is needed which can significantly reduce energy costs.

Air Terminal Units

The air handling units supply cooled air to the 130 VAV boxes that serve the public spaces. The boxes include a heating coil to reheat the air to the desired control based on space conditions. Of the 130 boxes, 23 serve spaces that cannot be accommodated with a water heating coil and therefore have electric reheat instead (i.e. electrical rooms). Air terminal unit supply temperature is controlled by thermostats located in the space served.

Pumps

Hot Water Pumps

Hot water is pumped to both the air handling units heating coils and distributed to the VAV boxes located throughout the building. There are two end suction pumps serving the building and have a flow rate of 740 gpm each. Additionally, the hot water pumps serving the AHUs are inline and range in flow rate from 132 gpm (AHU-1) to 18.8 gpm (AHU-5) to recirculate the water in the coils. See Table 7, below, for further properties of the hot water pumps.

PUMP NO.	LOCATION	SYSTEM	DESIGN PUMP DATA		
			CAPACITY [GPM]	HEAD [FT]	EFF. [%]
HWP - 1	B10 MECH	HWS	740	60	83.2
HWP - 2	B10 MECH	HWS	740	60	83.2
FPP - 1	AHU-1	HWS-COIL RECIRC	132	23	57.45
FPP - 2	AHU-2	HWS-COIL RECIRC	102	30	63.96
FPP - 3	AHU-3	HWS-COIL RECIRC	51.5	20	57.26
FPP - 4	AHU-5	HWS-COIL RECIRC	18.8	23	-
FPP - 5	AHU-5	HWS-COIL RECIRC	19.4	17	41.42

Table 7 Hot Water Pump Data (Source: Engineer of Record)

Chilled Water Pumps

From the chilled water plant, there are three double suction distribution pumps in parallel that serve the Auditorium and the rest of the campus. Additionally, there are four inline pumps that serve the active chilled beams in the performance support spaces. Each chilled beam pump (CBWP) supplies 21.4 gpm. On the return side, there are 3 double suction primary pumps that operate a constant volume to return water to the chillers. Further characteristics of the chilled water pumps can be seen on the next page in Table 8.

PUMP NO.	LOCATION	SYSTEM	DESIGN PUMP DATA		
			CAPACITY [GPM]	HEAD [FT]	EFF. [%]
CHWPP - 1	B10 MECH	CHWR	1600	50	-
CHWPP - 2	B10 MECH	CHWR	2000	50	-
CHWPP - 3	B10 MECH	CHWR	2800	108	82.21
CHWSP - 1	B10 MECH	CHWS	2000	95	79.72
CHWSP - 2	B10 MECH	CHWS	2000	95	79.72
CHWSP - 3	B10 MECH	CHWS	2000	95	79.72
CBWP - 1	AHU-1	CHILLED BEAM WATER	21.4	25	43.5
CBWP - 2	AHU-2	CHILLED BEAM WATER	21.4	25	43.5
CBWP - 3	AHU-3	CHILLED BEAM WATER	21.4	25	43.5
CBWP - 4	AHU-5	CHILLED BEAM WATER	21.4	25	43.5

Table 8 Chilled Water Pump Data (Source: Engineer of Record)

System Operation & Schematics

Campus Chilled Water Plant

The campus chilled water plant has a capacity of approximately 3000 tons. The chilled water is distributed to all campus buildings to serve cooling needs. The returned chilled water passes through one of three primary pumps operating in parallel sequence to provide constant volume through the three chillers. The condenser water is then sent to the packaged induced draft, cross flow cooling towers located on the roof to discharge the heat to the exterior of the building. After passing through the chillers, the chilled water passes through the variable speed distribution pumps to be sent to campus buildings. The supply pumps are controlled based on differential pressure of the system measured on the return and supply side at the plant. Flow meters are also placed on the chilled water supply and return to monitor flow rates. A schematic overview of the chilled water plant is shown in Figure 8.

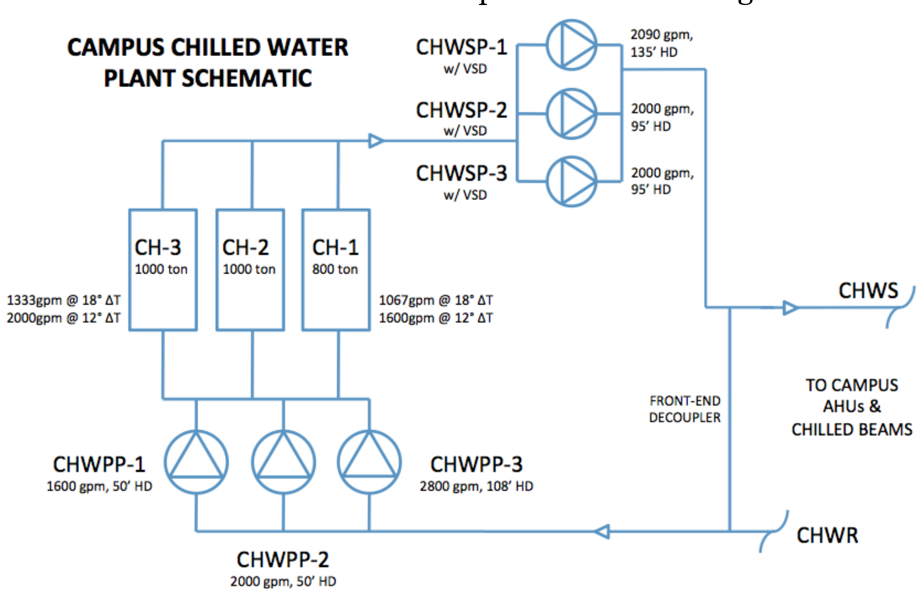


Figure 8 Campus Chilled Water Plant Schematic

Chilled Water - The Auditorium

Chilled water is distributed to the Auditorium and supplies the cooling coils in the air handling and fan coil units. The chilled water also serve the active chilled beam system. From the main supply line the chilled beam supply pipe branches off and serves four inline pumps (CBWP) as seen below in the system schematic in Figure 9. Depending on return water temperature from the chilled beams the chilled water is either recirculated back into the supply line through a 3-way valve or set back to the plant through the chilled water return line. Both the chilled beam and cooling coil distribution are a direct return system. Capacity at the load is controlled by a thermostat in each space that the chilled beam or fan coil unit serves.

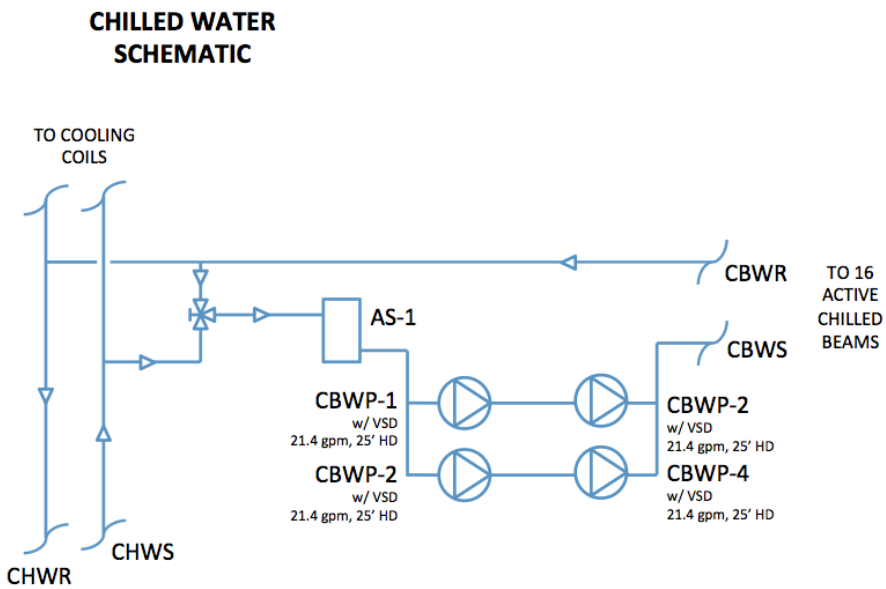


Figure 9 Building Chilled Water Schematic

Steam & Hot Water Schematic

High pressure steam is delivered to the Auditorium from a campus steam plant. The steam then enters a flooded heat exchanger (SHE-1) to heat up hot water for distribution to heating coils in the air handling and fan coil units. Furthermore, the steam condensate from the main supply line and flooded heat exchanger is then transferred to a flash tank to return condensate to the main plant. The designers included piping to accommodate a second heat exchanger if the capacity or flexibility is needed in the future.

After the flooded heat exchanger, the hot water supply then passes through two, end-suction pumps that serve the Auditorium, as seen on the next page in Figure 10. The hot water distribution is a direct return system, providing heating water to 107 VAV boxes, 4 air handling units, and several fan coil units throughout the Auditorium. Additionally, the hot water supply is also used to heat the domestic water in a brazed plate heat exchanger (HE-1).

The high pressure steam is also converted to low pressure steam , which can be used in the steam humidifiers located in the air handling units. An unfired steam generator (USG-1) is used to convert the high pressure steam at 125 psi to 10 psi for use in the Auditorium. Capacity for the Auditorium is controlled based on the return water temperature of the hot water supplied to the building.

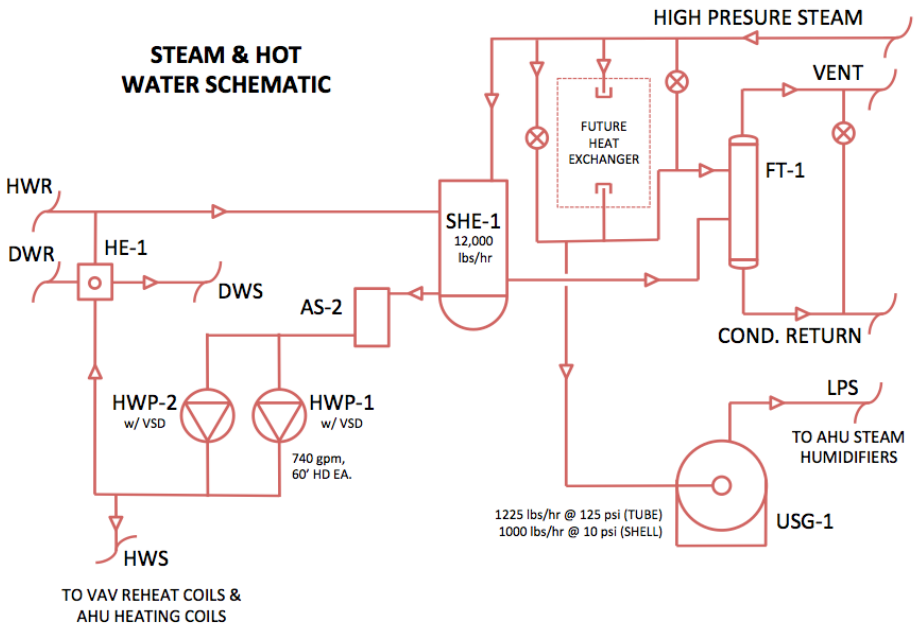


Figure 10 Building Steam & Hot Water Schematic

Airflow Schematic

To achieve required ventilation air flow rates in the Auditorium, there are 4 air handling units that take in outdoor air and condition it to supply spaces in the building. AHU-1 is a multi-zone variable volume and variable temperature packaged unit. AHU-2 is a single-zone variable volume and variable temperature packaged unit that serves the underfloor air distribution system in the audience chamber. AHU-3 serves the performance spaces with a multi-zone variable volume and variable temperature packaged unit with additional humidification and dehumidification capabilities. AHU-5 is variable volume, variable temperature and 100% outdoor air packaged unit that provides ventilation to the active chilled beam areas of the building.

All AHUs operate automatically on a direct digital control (DDC) system is PI and PID control methods. The supply air temperature for each unit is reset based on the temperature sensor located in the supply air plenum which transmits information to the economizer, heating and cooling coils. Additional pressure and temperature sensors are placed in the supply air plenums in each of the three balconies and main floor level in the audience chamber to control the air supplied from AHU-2. All units have an optimal start control sequence and air side economizers. See Figure 11 for a schematic of AHU-1, AHU-2, and AHU-3.

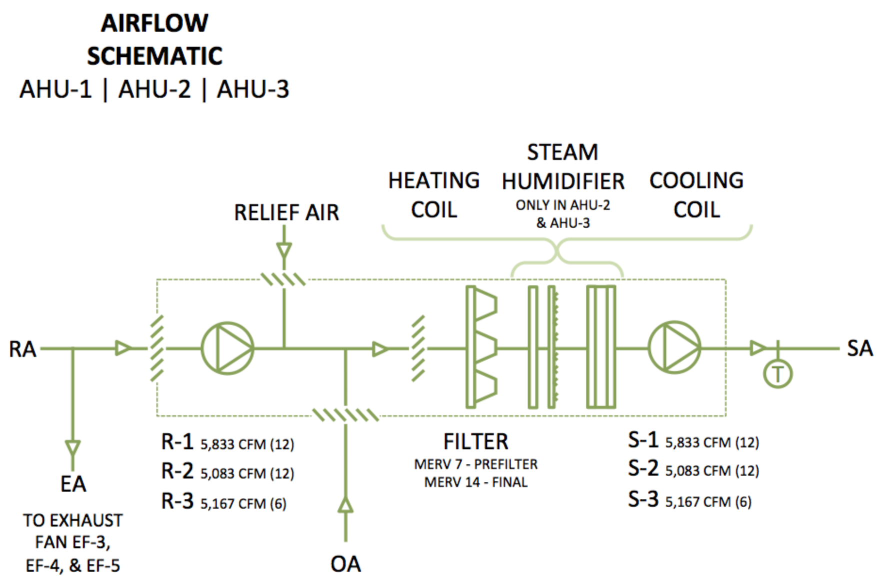


Figure 11 AHU-1, AHU-2, & AHU-3 Airflow Schematic

AHU-5 is a dedicated outdoor air system and supplies only the minimum required ventilation. It employs a dual energy recovery wheel; one wheel for passive dehumidification and another for energy recovery. Return air passes through one side of the unit and is then completely exhausted. While on the other side of the unit outdoor air enters and is pre heated or cooled down by the return air through the turning of the dual-energy wheels. Chilled water coils and hot water coils provide additional capacity for the outdoor air to be conditioned to the required supply air temperature. Figure 12, below, illustrates how the return air and outdoor air pass through the unit.

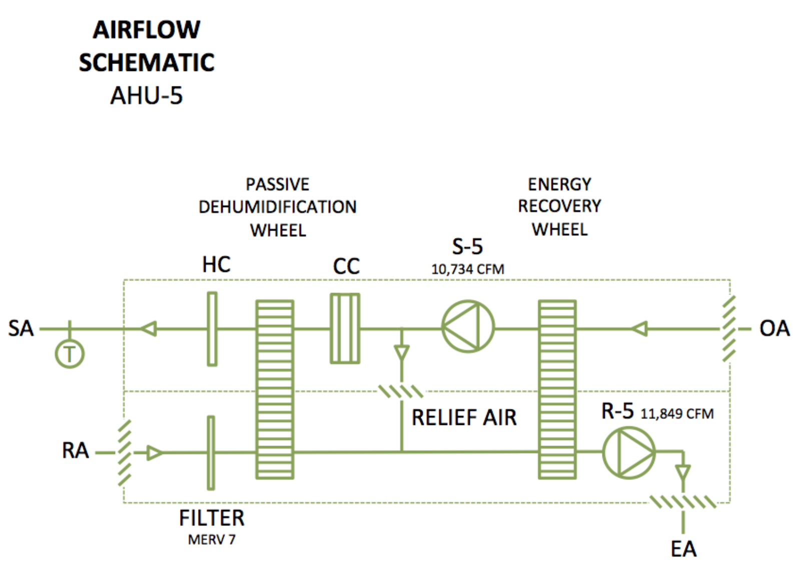


Figure 12 AHU-5 Airflow Schematic

Space Consideration

There is a fairly large space allotted for mechanical equipment in the basement of the Auditorium apart from the central chilled water plant in the basement as well. It also should be noted that the shaft space requirement is also increased due to the several offset shaft openings and the very large ductwork needed to supply the underfloor air distribution system for the audience chamber. Below is a breakdown of each of the space types and their associated gross square floor areas (Table 9). The total lost usable space amounts to approximately 7,100 SF.

SPACE TYPE	AREA (SF)
Mechanical Room	2065
Steam Room	471
Chiller Room	2480
Shafts	2020
Total Lost Usable Space:	**7036**

Table 9 Mechanical Space Areas

System Renovation First Cost

The overall project construction cost is approximately $75 million dollars. The mechanical system material and labor costs total $8,472,706. Table 10 below shows the cost breakdown by system type for the initial first cost of the renovated systems. Both ductwork and piping installation and materials contribute largely to the mechanical system cost.

	ITEM	LABOR	MATERIALS	TOTAL
WET SYSTEM	Demolition	$ 24,368	$ 6,092	$ 30,460
	Pumps & Accessories	$ -	$ 33,503	$ 33,503
	Piping	$ 1,711,305	$ 938,816	$ 2,650,121
	Heat Exchangers	$ -	$ 13,305	$ 13,305
	Heating Equipment	$ -	$ 142,572	$ 142,572
	Hydronic Equipment	$ -	$ 181,763	$ 181,763
DRY SYSTEM	Ducts & Accessories	$ 2,790,498	$ 1,187,949	$ 3,978,447
	Chilled Beam	$ 180,562	$ 157,013	$ 337,575
	HVAC Equipment	$ 94,243	$ 878,232	$ 972,475
	VAV Units	$ 15,300	$ 14,230	$ 29,530
	Exhaust Fans	$ 5,400	$ 73,129	$ 78,529
	Instruments & Controls	$ 359,342	$ 239,561	$ 598,903
	Test & Balance	$ 112,201	$ -	$ 112,201
ALT	Misc. Alternates & Contingency	$ (209,802)	$ (476,876)	$ (686,678)
TOTAL		**$ 5,083,417**	**$ 3,389,289**	**$ 8,472,706**

Table 10 Mechanical Cost Breakdown

LEED Evaluation

The Auditorium renovation did not aim to achieve a LEED Certification. Below the breakdown of points for the mechanical system sections of the USGBC LEED 2009 for New Construction and Major Renovations is included below.

Energy & Atmosphere Credits

✓ EA Prerequisite 1: Fundamental Commissioning of Building Energy Systems

The purpose of this prerequisite is to verify that the mechanical system is installed and operates as the design intended. It is not known at this time if a commissioning professional was hired however it is required by 2006 Minnesota State Building Code. Therefore it is conservative to assume a professional was hired to verify the building energy systems.

✓ EA Prerequisite 2: Minimum Energy Performance

This prerequisite requires that the minimum level of improved energy efficiency is at least 5% over the baseline building performance rating for major renovations. The Auditorium would need to comply with Option 1: Whole Building Energy Simulation. A third-party consultant was contracted to perform the energy simulation. Their conclusions exceed the 5% improvement requirement. See EA Credit 1: Optimize Energy Performance for further results.

✓ EA Prerequisite 3: Fundamental Refrigerant Management

The use of chlorofluorocarbon (CFC) refrigerants are prohibited from use in the building. The Auditorium does not directly incorporate the use of refrigerant, however the campus chilled water plant utilizes R-123; a commonly used HCFC type of refrigerant.

✓ EA Credit 1: Optimize Energy Performance (3/19 pts)

This credit awards points based on the percentage improvement of the building performance rating when compared to a baseline building. The third-party consultant that performed an energy analysis concluded that the Auditorium improved 12% over the baseline building performance.

Existing Building Renovations	Points
8%	1
10%	2
12%	3
14%	4
16%	5
18%	6
20%	7
22%	8
24%	9
26%	10
28%	11
30%	12
32%	13
34%	14
36%	15
38%	16
40%	17
42%	18
44%	19

Figure 13 EA Credit 1 (Source: LEED 2009 for New Contruction & Major Renovations)

✗ EA Credit 2: On-site Renewable Energy (0/7 pts)

Based on the point scale, a building can receive up to 7 points for using on-site renewable energy (ie solar radiation and wind power). The Auditorium currently does not utilize any on-site renewable energy sources.

Percentage Renewable Energy	Points
1%	1
3%	2
5%	3
7%	4
9%	5
11%	6
13%	7

Figure 14 EA Credit 2 (Source: LEED 2009 for New Construction & Major Renovations)

✗ EA Credit 3: Enhanced Commissioning (0/2 pts)

EA credit 3 requires that prior to the start of construction a commissioning authority is brought on to evaluate the design throughout the design and submittal process. The Auditorium did not implement this process during design and construction.

✗ EA Credit 4: Enhanced Refrigerant Management (0/2 pts)

As previously stated the Auditorium does not directly utilize any refrigerant, however indirectly the campus chilled water plan uses R-123 (HCFC-123). Using the given procedure and equations listed in Option 2, the HCFC-123 does not comply for the Enhanced Refrigerant Management credit. The calculations in Table 11, below, are based on the global warming potential and the ozone depletion potential; values determined by the U.S. Environmental Protection Agency (EPA) and Title 40 of the Code of Federal Regulations.

LCGWP+LCODPx10^5 ≤ 100

	GWP	ODP	LCODP	LCGWP	COMPLY?	VALUE
HCFC-123	93	0.02	0.0024	11.16	No	251.16

VARIABLES: *Worst Case & Default Values*

Lr	2%	Refrigerant Leakage Rate
Mr	10%	End-ofLife Refrigerant Loss
Rc	5	lbm/ton
Life	25	years

Table 11 LEED Refrigerant Management Calculations

Through further research, both the upstream and downstream building systems must comply with the EA Credit 4 requirements ("Treatment of District or Campus Thermal Energy in LEED V2 and LEED 2009 – Design & Construction " 16). This therefore eliminates the Auditorium from receiving these credits.

✗ EA Credit 5: Measurement and Verification (0/3 pts)

This credit aims to ensure a continuing standard level of building performance after main construction or renovation is complete. Currently the Francis Michael Performing Arts Academy has a commitment to sustainable building use and has plans in place to evaluate the performance of all its buildings through their lifetime. However this plan does not conform directly with either Option 1 or 2 outlined in EA Credit 5: Measurement & Verification.

✗ EA Credit 6: Green power (0/2 pts)

To receive credits, the building must engage in a least a 2 year contract with an electricity provider that supplies power generated from renewable resources. The percentage of the "green" power must be 35% of the buildings electricity consumption proven through either EA Credit 1: Optimized Energy Performance calculations or through the US Department of Energy's Commercial Building Consumption Survey database.

Since the Auditorium resides on a campus of buildings owned by the Francis Michael Performing Arts Academy, electricity is purchased at large from a provider for the entire academy. No points from this credit can be awarded.

Indoor Environmental Air Quality Credits

✓ IEQ Prerequisite 1: Minimum Indoor Air Quality Performance
This prerequisite is met by following sections 4 through 7 of ASHRAE Standard 62.1-2007 and complying with ASHRAE 62.1-2010 ventilation rate procedures for mechanically ventilated spaces. See Technical Report 1 for a more in-depth evaluation of the Auditorium's compliance with ASHRAE 62.1-2010.

✓ IEQ Prerequisite 2: Environmental Tobacco Smoke (ETS) Control
The Auditorium is a non-smoking facility and designated signage is in place to prohibit smoking within 25 feet of the building. This ensures the limited exposure of tobacco smoke to the building occupants, indoor surfaces and air distribution equipment.

✗ IEQ Credit 1: Outdoor Air Delivery Monitoring (0/1 pts)
Outdoor air is not monitored at the room level to ensure design ventilation airflow rates are being met.

✗ IEQ Credit 2: Increased Ventilation (0/1 pts)
The Auditorium was not designed to incorporate a 30% increase in outdoor ventilation airflow rates based on ASHRAE 62.1-2007 for mechanically vented spaces.

✗ IEQ Credit 3.1: Construction IAQ Management Plan—During Construction (0/1 pts)

✗ IEQ Credit 3.2: Construction IAQ Management Plan—Before Occupancy (0/1 pts)
An Indoor Air Quality (IAQ) plan was not developed in accordance with IEQ Credit 3.1 or 3.2 for during and before construction.

✗ IEQ Credit 4.1: Low-Emitting Materials—Adhesives and Sealants (0/1 pts)

✗IEQ Credit 4.2: Low-Emitting Materials—Paints and Coatings (0/1 pts)

✗IEQ Credit 4.3: Low-Emitting Materials—Flooring Systems (0/1 pts)

✗IEQ Credit 4.4: Low-Emitting Materials—Composite Wood and Agrifiber Products (0/1 pts)
After review of the drawings and specifications, low-emitting materials are recommended for use in some categories, however there is limited resources to determine if low VOC materials were used.

✗ IEQ Credit 5: Indoor Chemical and Pollutant Source Control (0/1 pts)
There is no dedicated strategy that complies with IEQ Credit 5 to contain and control chemical pollutants. The credit requires specific exhaust strategies to contain chemical contaminants, air filtration with a MERV of 13 or higher, and permanent entry ways fitted with 10ft of grated space to capture debris and particulates or regularly serviced mats.

✗ IEQ Credit 6.1: Controllability of Systems—Lighting (0/1 pts)
This credit is not satisfied because 90% of the lighting can not be individually controlled by the occupant.

✗ IEQ Credit 6.2: Controllability of Systems—Thermal Comfort (0/1 pts)
Thermal comfort is not controllable by 50% of the occupants and therefore does not meet the requirements for this credit

✓IEQ Credit 7.1: Thermal Comfort—Design (1/1 pts)
The basis of the design is derived from ASHRAE Standard 55-2004 and the design engineer was observant of Standard 55 in his design of the system. The requirement for achieving IEQ Credit 7.1 is compliance with ASHRAE 55-2004 and therefore has been met.

✗ IEQ Credit 7.2: Thermal Comfort—Verification (0/1 pts)
A thermal verification survey has not been planned for the permanent occupants of the Auditorium and therefore is not compliance with IEQ Credit 7.2.

✗ IEQ Credit 8.1: Daylight and Views—Daylight (0/1 pts)
To comply with this credit, 75% of the occupiable space must be lit with adequate daylight levels. One of four options for verification must be performed to prove the required light levels are met. They include simulation, prescriptive, measurement, and a combination. With a major historical renovation, changing the exterior of the building was not an option for the architects. Therefore a daylight analysis was not performed for the Auditorium and does not meet the requirements.

✗ IEQ Credit 8.2: Daylight and Views—Views (0/1 pts)
This credit requires a view to the exterior environment in at least 90% of the regularly occupiable spaces. This will not be achieved with the renovation design of the Auditorium and this credit can not be awarded points.

LEED Analysis Summary

The combined credits in both sections are tabulated below. Based on these results it is unlikely that the building will receive a LEED Certified rating. The priorities of the building owner seem to be directed toward restoring the Auditorium to a functional state rather than an extremely high performing building.

Energy & Atmosphere: 3/35
Indoor Environmental Air Quality: 1/15

Further credits could be realized through evaluating the benefits and costs of refrigerant management and further energy saving measures to increase the building's performance over the baseline building. Additionally supplementary control systems at the occupant level would aid in achieving additional credits.

Overall Mechanical System Evaluation

The goal for this renovation project was to recapture vital space on the campus of FMPAA and reengineer the performance space to create a world-class performing arts facility. The Auditorium's mechanical system adequately meets the requirements to properly heat and cool the building. Sufficient ventilation to achieve satisfactory indoor air quality, and comfort standards are also being met.

The overall renovation first cost for the project is approximately $8.5 million and results in an annual operation cost of approximately $283,000 ($1.65/SF). Considering that only 4% of the gross square footage of the project is devoted to mechanical space, the design team needed to use every square foot to achieve the proper ventilation and comfort standards. Tight floor to floor heights also restricted types of equipment that could be used.

Based on the analysis performed to evaluate the Auditorium's existing systems, there could be several areas to consider changes to the renovation design. One such area of consideration is the implementation of additional active chilled beams in other spaces than the performance support spaces. Examination of ceiling space, airflow, and dehumidification requirements will be required to justify adding chilled beams to other spaces.

Further energy saving improvements could be realized through adding energy recovery devices in the remaining three air handling units, similar to AHU-5. Also considering the efficiency of the cooling equipment, a study into optimization of the chilled water plant located in the basement of the Auditorium could help reduce the energy required to run the plant, impacting not only the Auditorium but all the buildings on FMPAA's campus. Finally, keeping in mind that the Auditorium borders a nationally recognized historic district, the grassy mall could be converted into a geothermal well field designed to reject a percentage of the heat from chiller condenser water loop into the ground.

Overall, the current renovation design achieves the design objectives and requirements set forth by the owner and local building codes. However, with further analysis other viable options could be presented to allow the Auditorium to exceed the minimum requirements. These design strategies mentioned and others deemed effective for the Auditorium's location and function will be discussed further in the Proposal Report.

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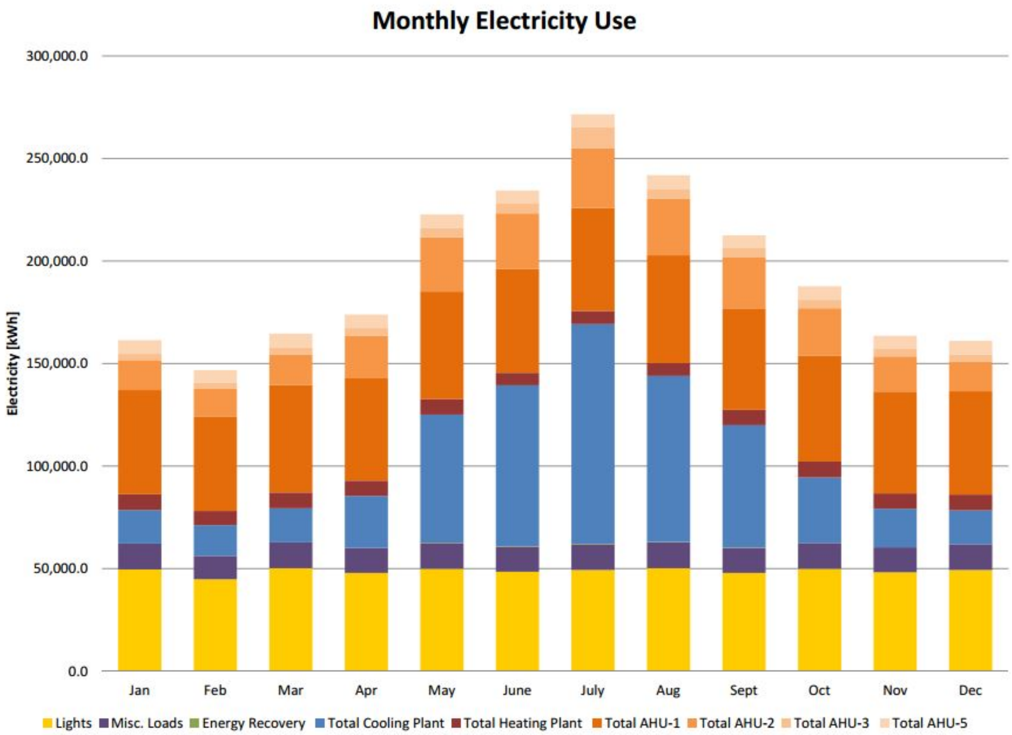
United States. Environmental Protection Agency. *Class II Ozone-depleting Substances*. Washington, DC: , 2010. Web.<http://www.epa.gov/ozone/science/ods/ classtwo.html>.

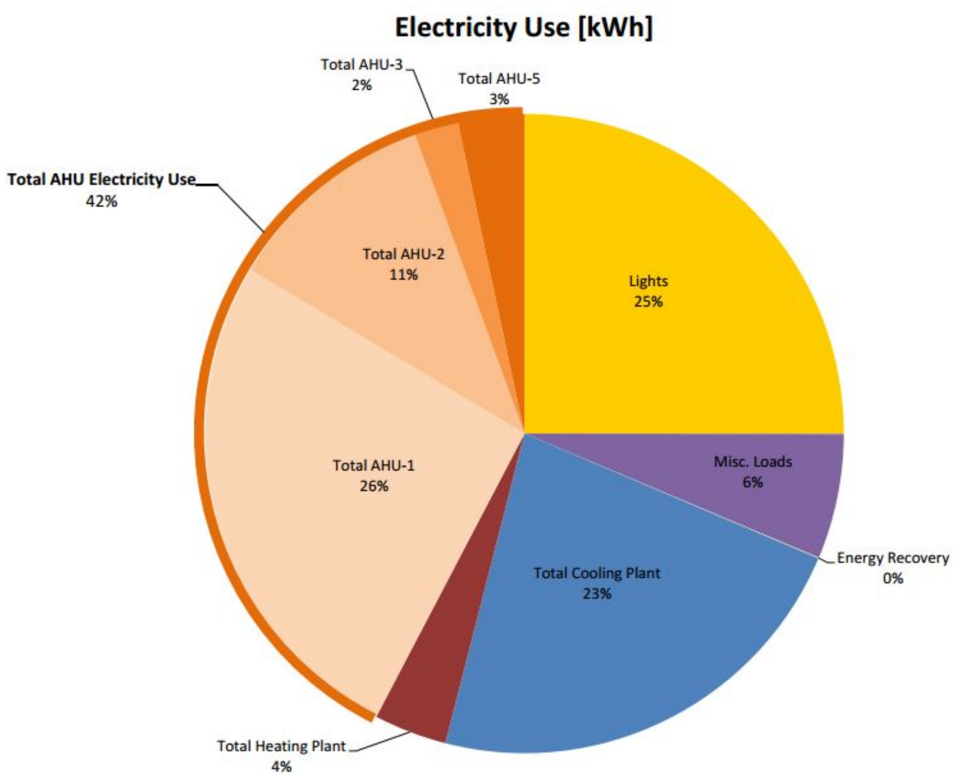
Note: *At the request of the owner, the identity of the project team is not to be published. For the sources related to the drawings or specifications referenced, please contact Erin Miller at erin.c.miller@psu.edu*.

Appendix A

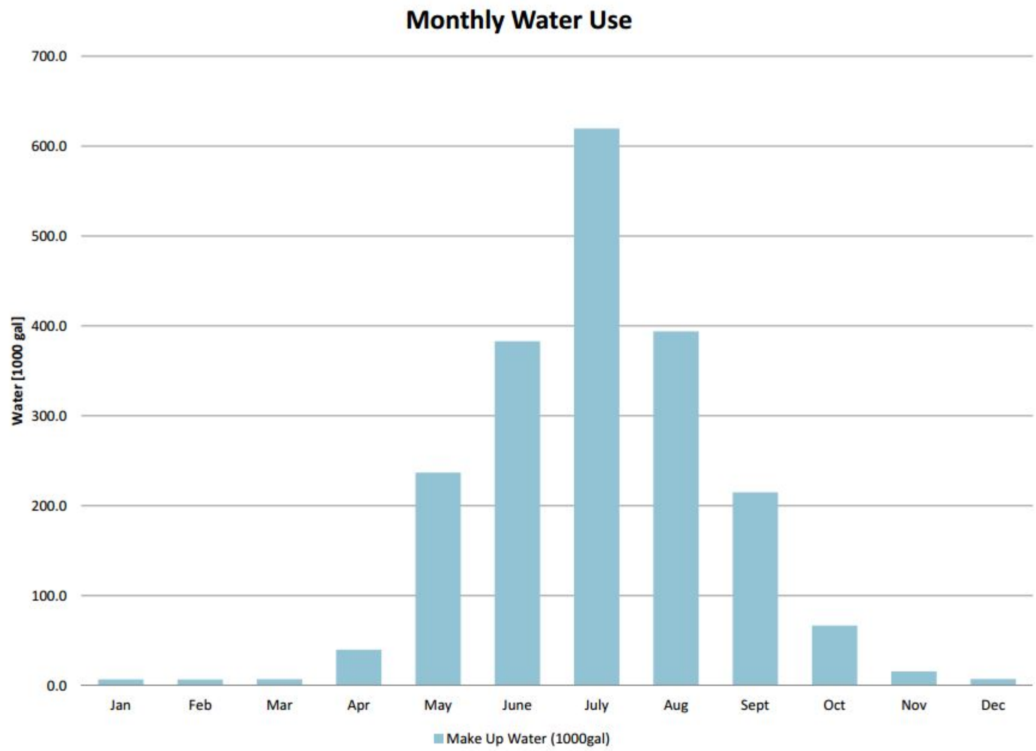
Appendix B



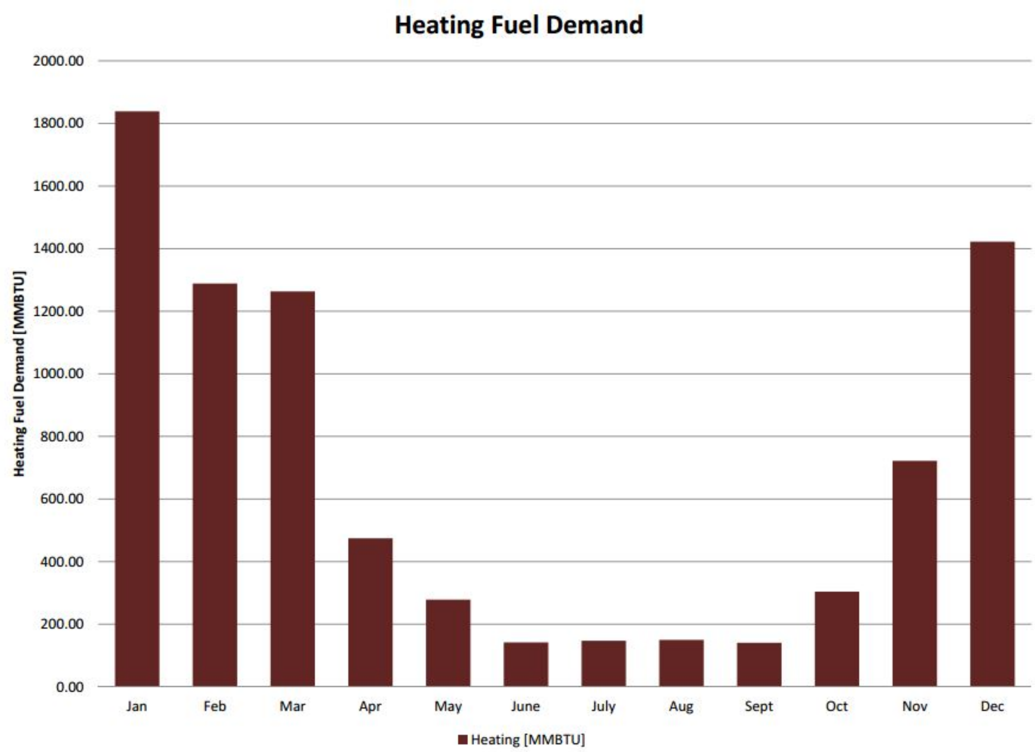
Appendix A: Figure 1 - Monthly Electricity Use



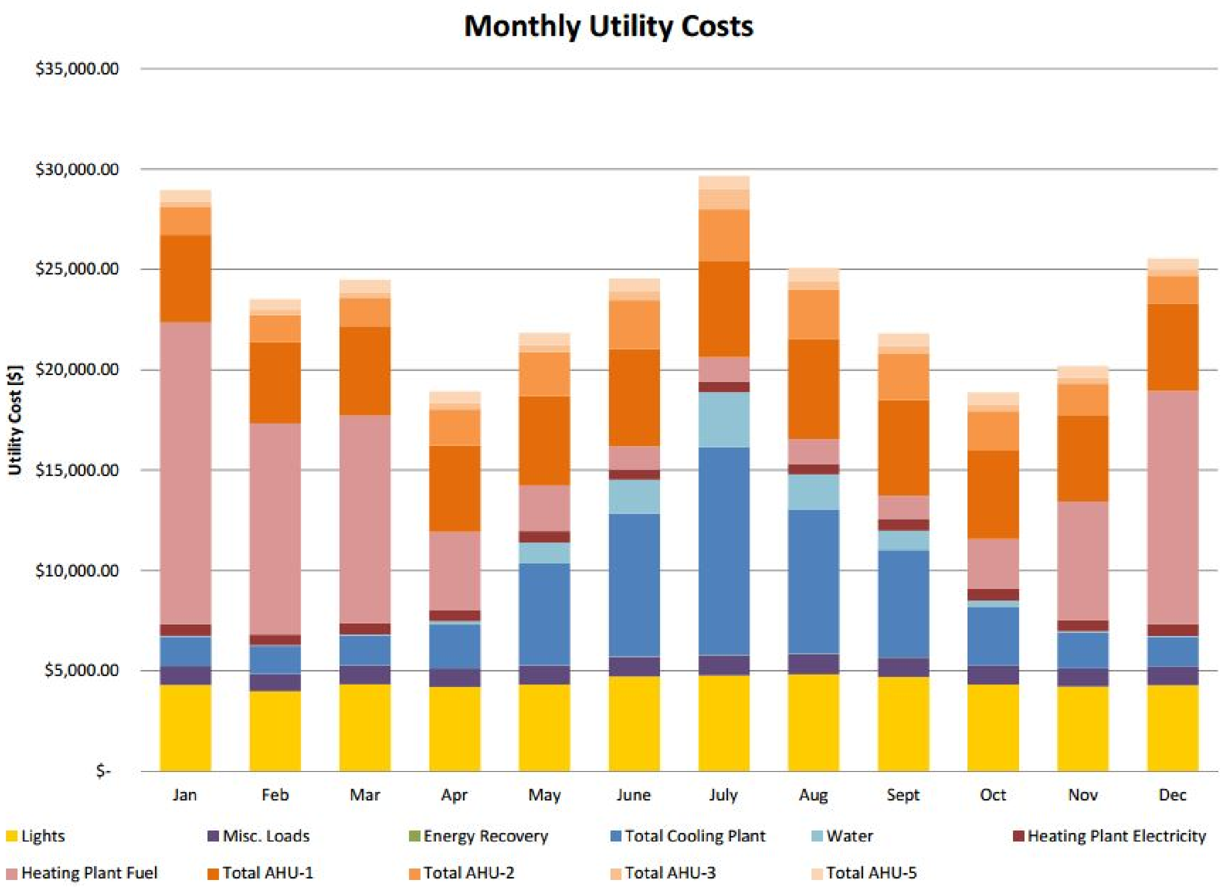
Appendix A: Figure 2 - Annual Electricity Consumption (Annual Total 1,671 MWh)



Appendix A: Figure 3 - Monthly Make-up Water Demand



Appendix A: Figure 4 - Heating Fuel Demand



Appendix A: Figure 5 - Monthly Utility Cost (Annual Utility Cost $283,729)

Equipment - Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	*Total*	
Lights														
Electric (kWh)	49,626.7	44,833.3	50,195.2	47,934.1	49,910.9	48,502.6	49,342.5	50,195.2	47,934.2	49,910.9	48,218.4	49,342.5	*585,946.3*	
Peak (kW)	148.5	148.5	148.5	148.5	148.5	148.5	148.5	148.5	148.5	148.5	148.5	148.5	*148.5*	
Cost	$ 4,326.20	$ 4,016.45	$ 4,362.93	$ 4,216.83	$ 4,344.57	$ 4,749.52	$ 4,803.79	$ 4,858.89	$ 4,712.78	$ 4,344.57	$ 4,235.19	$ 4,307.83	$ 53,279.55	
Misc. Loads														
Electric (kWh)	12,582.4	11,364.7	12,582.4	12,176.5	12,582.4	12,176.5	12,582.4	12,582.4	12,176.5	12,582.4	12,176.5	12,582.4	*148,147.3*	
Peak (kW)	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	*16.9*	
Cost	$ 962.69	$ 884.00	$ 962.69	$ 936.46	$ 962.69	$ 992.94	$ 1,019.17	$ 1,019.17	$ 992.94	$ 962.69	$ 936.46	$ 962.69	$ 11,594.57	
Energy Recovery														
Electric (kWh)	0.0	0.0	0.0	0.0	205.6	235.2	249.6	242.4	172.0	0.0	0.0	0.0	*1,104.8*	
Peak (kW)	0.0	0.0	0.0	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.0	0.0	*0.4*	
Cost	$ 25.00	$ 25.00	$ 25.00	$ 27.95	$ 41.23	$ 44.48	$ 45.41	$ 44.95	$ 40.40	$ 27.95	$ 25.00	$ 25.00	$ 397.37	
Cooling Coil Condensate														
Recoverable Water (1000gal)	0.3	0.2	0.3	1.6	17.4	44.5	88.9	50.5	25.3	2.3	0.9	0.3	*232.5*	
Peak (1000gal/Hr)	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.2	0.1	0.1	0.1	0.0	*0.3*	
Cpl 1: Cooling plant - 001 [Sum of dsn coil capacities=650.1 tons]														
Water-cooled chiller - 001 [Clg Nominal Capacity/F.L.Rate=650.1 tons / 374.8 kW] (Cooling Equipment)														
Electric (kWh)	973.2	953.8	1,003.3	5,700.5	28,275.5	42,545.0	69,880.5	43,797.7	26,216.4	9,535.2	2,177.6	1,023.9	*232,082.3*	
Peak (kW)	34.2	34.2	34.2	34.3	90.7	141.2	271.0	134.7	89.5	68.1	48.1	34.2	*271.0*	
Cooling tower for Cent. Chillers [Design Heat Rejection/F.L.Rate=756.7 tons / 49.94 kW]														
Electric (kWh)	15,392.1	14,014.3	15,630.2	19,631.1	34,139.0	35,959.9	37,158.6	37,158.6	33,497.4	22,453.8	16,637.4	15,450.6	*297,122.8*	
Peak (kW)	20.9	21.8	22.2	40.5	49.9	49.9	49.9	49.9	49.9	49.7	28.3	21.6	*49.9*	
Cooling tower for Cent. Chillers														
Make Up Water (1000gal)	6.8	6.7	7.0	39.9	236.8	382.9	619.6	393.9	214.8	66.7	15.7	7.2	*1,998.0*	
Peak (1000gal/Hr)	0.0	0.0	0.0	0.2	0.9	1.3	2.0	1.2	0.8	0.8	0.5	0.0	*2.0*	
Net Water (Make-up - Recovered)	6.5	6.4	6.7	38.3	219.4	338.4	530.7	343.4	189.5	64.4	14.8	6.9	1,765.5	
Water Utility Cost	$ 38.29	$ 37.67	$ 39.21	$ 183.74	$ 1,049.96	$ 1,692.48	$ 2,733.40	$ 1,741.04	$ 953.11	$ 301.75	$ 77.48	$ 39.83	$ 8,887.95	
Total Cooling Plant	16,365.2	14,968.0	16,633.4	25,331.6	62,414.5	78,504.8	107,039.1	80,956.2	59,713.8	31,989.0	18,815.1	16,474.5	*529,205.1*	(kWh)
Total Peak Cooling Plant	55.1	56.0	56.4	74.8	140.7	191.2	321.0	184.6	139.4	117.8	76.4	55.7	*321.0*	(kW)
Cost	$ 1,488.66	$ 1,405.01	$ 1,515.58	$ 2,213.25	$ 5,094.83	$ 7,145.23	$ 10,379.35	$ 7,233.70	$ 5,376.72	$ 2,960.43	$ 1,804.17	$ 1,500.29	$ 48,117.22	
Hpl 1: Heating plant - 002 [Sum of dsn coil capacities=9,854 mbh]														
Boiler - 001 [Nominal Capacity/F.L.Rate=9,854 mbh / 126.3 Therms] (Heating Equipment)														
Gas (therms)	18,387.6	12,885.7	12,633.4	4,745.3	2,784.9	1,416.8	1,470.0	1,499.4	1,404.4	3,039.2	7,220.8	14,223.7	*81,711.1*	
Peak (therms/Hr)	62.0	52.8	43.6	26.0	5.9	5.9	5.5	3.6	5.2	23.7	40.7	53.7	*62.0*	
Boiler forced draft fan (Misc Accessory Equipment)														
Electric (kWh)	7,332.1	6,622.6	7,332.1	7,095.6	7,174.4	5,794.7	6,149.5	5,972.1	7,095.6	7,332.1	7,095.6	7,332.1	*82,328.5*	
Peak (kW)	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	*9.9*	
Cntl panel & interlocks - 0.5 KW (Misc Accessory Equipment)														
Electric (kWh)	372.0	336.0	372.0	360.0	364.0	294.0	312.0	303.0	360.0	372.0	360.0	372.0	*4,177.0*	
Peak (kW)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	*0.5*	
Total Heating Plant	7,704.1	6,958.6	7,704.1	7,455.6	7,538.4	6,088.7	6,461.5	6,275.1	7,455.6	7,704.1	7,455.6	7,704.1	*86,505.5*	(kWh)
Total Peak Heating Plant	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	*10.4*	(kW)
Cost	$ 599.11	$ 550.93	$ 599.11	$ 583.05	$ 588.40	$ 529.30	$ 553.38	$ 541.34	$ 617.62	$ 599.11	$ 583.05	$ 599.11	$ 6,943.53	
Heating [MMBTU]	1838.76	1288.57	1263.34	474.53	278.49	141.68	147.00	149.94	140.44	303.92	722.08	1422.37	8171.11	
Fuel Cost	$ 15,044.70	$ 10,543.08	$ 10,336.61	$ 3,882.62	$ 2,278.59	$ 1,159.26	$ 1,202.75	$ 1,226.78	$ 1,149.10	$ 2,486.67	$ 5,908.05	$ 11,637.84	$ 66,856.03	
Sys 1: AHU-1														
FC Centrifugal var freq drv [DsnAirflow/F.L.Rate=58,151 cfm / 102.1 kW] (Main Clg Fan)														
Electric (kWh)	36,265.9	32,772.1	37,248.6	34,937.5	36,757.2	35,920.2	35,774.5	37,248.6	34,937.5	36,757.2	35,428.9	35,774.5	*429,822.5*	
Peak (kW)	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	*102.4*	
FC Centrifugal const vol [DsnAirflow/F.L.Rate=4,002 cfm / 0.91 kW] (Room Exhaust Fan)														

Equipment - Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	*Total*	
Electric (kWh)	287.6	269.9	315.8	298.7	303.0	296.3	295.7	304.8	285.9	307.3	294.0	283.4	*3,542.3*	
Peak (kW)	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	*0.9*	
FC Centrifugal var freq drv [DsnAirflow/F.L.Rate=61,932 cfm / 48.31 kW] (Main Return Fan)														
Electric (kWh)	14,202.5	13,026.9	14,905.6	14,657.8	15,330.1	14,467.2	14,179.9	14,951.7	14,192.5	14,653.3	13,934.1	14,323.4	*172,824.8*	
Peak (kW)	43.7	43.9	43.9	43.9	44.1	44.1	44.1	44.1	44.1	44.1	44.1	43.7	*44.1*	
Total AHU-1	50,755.9	46,068.9	52,470.0	49,893.9	52,390.4	50,683.7	50,250.0	52,505.1	49,415.8	51,717.8	49,657.0	50,381.2	*606,189.6*	(kWh)
Total Peak AHU-1	147.0	147.1	147.1	147.1	147.3	147.3	147.3	147.3	147.3	147.3	147.3	147.0	*147.3*	(kW)
Cost	$ 4,387.89	$ 4,086.05	$ 4,499.68	$ 4,333.22	$ 4,496.31	$ 4,878.14	$ 4,850.12	$ 4,995.84	$ 4,796.21	$ 4,452.85	$ 4,319.38	$ 4,363.75	$ 54,459.45	
Sys 2: AHU-2														
FC Centrifugal var freq drv [DsnAirflow/F.L.Rate=29,824 cfm / 46.53 kW] (Main Clg Fan)														
Electric (kWh)	9,792.3	8,976.9	9,683.9	13,778.1	18,556.0	19,325.5	20,983.2	19,776.5	17,649.0	16,055.4	11,639.9	9,561.7	*175,778.4*	
Peak (kW)	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	*46.7*	
FC Centrifugal var freq drv [DsnAirflow/F.L.Rate=56,651 cfm / 44.19 kW] (Main Return Fan)														
Electric (kWh)	4,881.8	4,525.6	5,034.4	6,885.2	8,060.7	7,762.5	8,009.7	7,929.6	7,481.1	7,029.6	5,539.4	4,911.5	*78,051.1*	
Peak (kW)	14.7	14.8	15.1	15.9	17.1	17.1	17.1	17.1	17.1	17.1	15.2	14.9	*17.1*	
Total AHU-2	14,674.0	13,502.5	14,718.2	20,663.3	26,616.7	27,088.0	28,993.0	27,706.1	25,130.1	23,085.0	17,179.4	14,473.2	*253,829.5*	(kWh)
Total Peak AHU-2	61.4	61.5	61.8	62.5	63.8	63.8	63.8	63.8	63.8	63.8	61.9	61.6	*63.8*	(kW)
Cost	$ 1,425.88	$ 1,350.77	$ 1,431.69	$ 1,821.16	$ 2,215.15	$ 2,458.70	$ 2,581.79	$ 2,498.64	$ 2,332.18	$ 1,986.94	$ 1,591.46	$ 1,413.87	$ 23,108.24	
Sys 3: AHU-3														
FC Centrifugal var freq drv [DsnAirflow/F.L.Rate=13,489 cfm / 23.67 kW] (Main Clg Fan)														
Electric (kWh)	1,938.7	1,898.0	2,092.7	2,368.1	2,736.4	3,063.3	7,308.6	3,111.6	2,771.3	2,621.9	2,347.9	2,176.2	*34,434.7*	
Peak (kW)	4.8	5.6	5.6	5.6	6.0	7.9	23.8	8.1	6.9	6.9	6.9	6.5	*23.8*	
FC Centrifugal var freq drv [DsnAirflow/F.L.Rate=16,449 cfm / 11.23 kW] (Main Return Fan)														
Electric (kWh)	1,079.8	1,065.3	1,259.4	1,474.2	1,612.2	1,613.2	2,964.1	1,628.3	1,492.9	1,395.9	1,234.7	1,247.8	*18,067.8*	
Peak (kW)	2.7	3.2	3.4	3.4	3.6	4.0	11.3	4.6	4.0	4.0	4.0	3.6	*11.3*	
Total AHU-3	3,018.6	2,963.2	3,352.2	3,842.3	4,348.6	4,676.5	10,272.7	4,739.9	4,264.2	4,017.8	3,582.6	3,424.0	*52,502.4*	(kWh)
Total Peak AHU-3	7.6	8.8	9.1	9.1	9.7	11.8	35.0	12.8	10.9	10.9	10.9	10.1	*35.0*	(kW)
Cost	$ 275.77	$ 281.63	$ 308.46	$ 340.20	$ 377.20	$ 453.89	$ 1,063.77	$ 468.16	$ 417.39	$ 365.03	$ 336.83	$ 320.47	$ 5,008.81	
Sys 4: AHU-5														
FC Centrifugal var freq drv [DsnAirflow/F.L.Rate=4,906 cfm / 12.53 kW] (Main Clg Fan)														
Electric (kWh)	4,643.8	4,187.0	4,748.6	4,403.1	4,514.3	4,411.5	4,393.6	4,574.7	4,290.8	4,603.3	4,482.0	4,598.9	*53,851.7*	
Peak (kW)	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	*12.6*	
FC Centrifugal const vol [DsnAirflow/F.L.Rate=2,664 cfm / 1.51 kW] (Room Exhaust Fan)														
Electric (kWh)	520.7	473.9	530.7	523.6	526.1	499.6	511.0	514.9	507.0	526.8	510.8	526.6	*6,171.6*	
Peak (kW)	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	*1.4*	
FC Centrifugal var freq drv [DsnAirflow/F.L.Rate=5,840 cfm / 9.80 kW] (Main Return Fan)														
Electric (kWh)	1,535.5	1,419.7	1,648.7	1,688.1	1,662.8	1,514.0	1,456.8	1,552.5	1,495.5	1,537.0	1,473.5	1,599.4	*18,583.4*	
Peak (kW)	6.7	6.6	6.6	6.6	6.8	6.8	6.8	6.8	6.6	6.6	6.6	6.6	*6.8*	
Total AHU-5	6,700.0	6,080.6	6,927.9	6,614.8	6,703.2	6,425.1	6,361.4	6,642.1	6,293.3	6,667.2	6,466.3	6,724.9	*78,606.7*	(kWh)
Total Peak AHU-5	20.6	20.6	20.6	20.5	20.7	20.7	20.7	20.7	20.5	20.5	20.5	20.6	*20.7*	(kW)
Cost	$ 609.84	$ 569.52	$ 624.20	$ 603.67	$ 610.64	$ 661.77	$ 657.66	$ 675.80	$ 651.44	$ 607.06	$ 594.22	$ 611.23	$ 7,477.05	

Template UPDATED 11/9/13	**People**		**Lighting**		**Misc**		**AIRFLOW**			**CONSTRUCTION**	
	TYPE	DENSITY SF/PERSON	TYPE	HEAT GAIN W/SF	TYPE	ENERGY W/SF	VENTILATION TYPE 62.1	VAV CONTROL	EXHAUST CFM/SF	FLR-FLR HEIGHT	ABOVE/BELOW GRADE
Auditorium Seating Area	Auditorium	6.7	Flourescent, hung below ceiling, 100% load to space	2.60	Plug Loads	0.10	Auditorium seating area	30% Min Clg Airflow	0.0	100	ABOVE
Balcony Seating Area	Auditorium	6.7	Flourescent, hung below ceiling, 100% load to space	2.60	Plug Loads	0.10	Auditorium seating area	30% Min Clg Airflow	0.0	24	ABOVE
Breakrooms	General Office Space	143	Recessed flourescent, not vented, 80% load to space	0.89	Appliances	3.00	Breakrooms	30% Min Clg Airflow	0.5	10	ABOVE
Coffee Stations	General Office Space	143	Recessed flourescent, not vented, 80% load to space	1.20	Appliances	5.00	Coffee Stations	30% Min Clg Airflow	0.5	10	ABOVE
Conference/Meeting	Conference Room	20	Recessed flourescent, not vented, 80% load to space	1.30	Office Equipment	0.50	Conference / meeting	30% Min Clg Airflow	0.0	10	ABOVE
Corridor	None	0	Recessed flourescent, not vented, 80% load to space	0.50	Plug Loads	0.10	Corridors	30% Min Clg Airflow	0.0	10	ABOVE
Dressing Room/Locker Room (Below Grade)	Conference Room	20	Flourescent, hung below ceiling, 100% load to space	0.60	Plug Loads	0.50	Default Std62	30% Min Clg Airflow	0.5	10	BELOW
Dressing Room/Locker Room (Above Grade)	Conference Room	20	Flourescent, hung below ceiling, 100% load to space	0.60	Plug Loads	0.50	Default Std63	30% Min Clg Airflow	0.5	10	ABOVE
Janitorial (Below Grade)	None	0	Recessed flourescent, not vented, 80% load to space	1.30	Plug Loads	0.50	Storage rooms	30% Min Clg Airflow	1.0	10	BELOW
Janitorial (Above Grade)	None	0	Recessed flourescent, not vented, 80% load to space	1.30	Plug Loads	0.50	Storage rooms	30% Min Clg Airflow	0.0	10	ABOVE
Laundry	None	0	Recessed flourescent, not vented, 80% load to space	0.60	Equipment	2.00	Laundries	30% Min Clg Airflow	0.0	10	ABOVE
Lecture Classroom	Classroom	20	Recessed flourescent, not vented, 80% load to space	1.45	Office Equipment	1.20	Lecture Classroom	30% Min Clg Airflow	0.0	10	ABOVE
Lobbies	Reception Area	45	Recessed flourescent, not vented, 80% load to space	1.30	Plug Loads	0.25	Lobbies	30% Min Clg Airflow	0.0	10	ABOVE
Music/Dance/Theater	Classroom	20	Recessed flourescent, not vented, 80% load to space	2.60	Plug Loads	0.10	Music/theater/dance	30% Min Clg Airflow	0.0	10	ABOVE
Office Space	General Office Space	143	Recessed flourescent, not vented, 80% load to space	1.45	Office Equipment	1.20	Office space	30% Min Clg Airflow	0.0	10	ABOVE
Restrooms	None	0	Recessed flourescent, not vented, 80% load to space	0.90	Plug Loads	0.10	Default Std62	30% Min Clg Airflow	0.5	10	ABOVE
Stages/Studios	Classroom	20	Recessed flourescent, not vented, 80% load to space	2.60	Plug Loads	0.10	Stages, studios	30% Min Clg Airflow	0.0	10	ABOVE
Storage Room	None	0	Recessed flourescent, not vented, 80% load to space	0.80	Plug Loads	0.10	Storage rooms	30% Min Clg Airflow	0.0	100	ABOVE

Appendix B: Figure 1 - Handbook of Fundamentals - Weather Data

2005 ASHRAE Handbook - Fundamentals (IP)

Design conditions for [redacted] 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*
[redacted]	**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%	WB	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		