Harley-Davidson Museum

Milwaukee, WI

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Mechanical Option

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[TECHNICAL REPORT THREE]

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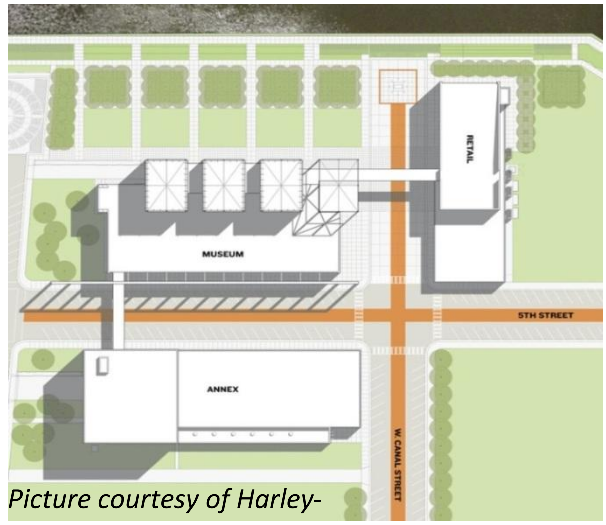
Executive Summary

This thesis technical report was conducted on the Harley-Davidson Museum in Milwaukee, Wisconsin. Separated into three distinct parts, the complex consist of a 60,000 SF Museum which houses the permanent exhibits; a 45,000 SF Annex Building which will accommodate temporary exhibits and Harley Davidson's extensive archives; and a 25,000 SF building which houses a 150-seat restaurant, a grab and go cafe, a retail space, and a special event space. The Museum has an exposed structure inside and outside, but many of the areas did not permit ductwork to be visible which created a challenge for the engineers at HGA.



Picture courtesy of Harley-

The design objectives, design conditions, energy usage, and heating and cooling loads, were examined in order to assess the mechanical design of the facility. Major equipment is presented in this report with a narrative of operation and diagrams that illustrate the heating and cooling systems. System cost information was limited, but the overall cost of site work, general construction, mechanical, and electrical work are discussed in this report. The facility was not designed to be LEED certified; therefore, a complete LEED analysis was conducted using LEED 2009 for new construction and renovations, in order to study areas of potential improvement, which could make the facility LEED certified.

This report is an evaluation of the mechanical system of the Harley-Davidson Museum and will be used as an analysis for areas of improvement. The report is broken into three sections. The first section addresses the mechanical design factors which influenced the design and an overall comparison to the actual design. The second section addresses the overall design of the systems relating to space, cost, and operations. The final section is a detailed summary of the LEED analysis that was conducted for this report.

Section 1 – Mechanical Design

This section addresses the mechanical design objectives and compares the intended design to actual data collected from the facility and modeled data that reflects the built facility.

Design Objectives

The architects of the Harley-Davidson Museum designed the building to be aesthetically pleasing while appropriately reflecting the true character of the Harley-Davidson Motor Company. To do this, they felt as though it was necessary to reveal the structure of the building while concealing HVAC equipment and distribution. This proposed a challenge to the MEP engineers at HGA. The engineers had to maintain a healthy and comfortable environment for the buildings occupants while fitting into the marginal space provided by the architects and still being economical. The designers did not aim for LEED certification; however, they did incorporate sensible sustainable solutions into the design.

The facility is multi-functional with several different occupancy types and many of the spaces require separate mechanical attention. The facility is separated in to three separate buildings. The chillers and boilers are distributed to all three buildings; however, each building has its own air handlers which do not distribute to the other buildings.

Design Conditions

The Harley-Davidson Museum was not designed to comply with ASHRAE section 6. The building owner wanted the museum to be designed for a high people count; however, because of the low frequency of when maximum occupancy would actually be seen, the engineers at HGA used ventilation rates to only meet the ventilation code of 7.5 CFM/person. Designed duct pressure ratings are shown in Table 1 and designed temperatures are shown in Table 2.

Table 1 – Design Duct Pressure

Duct Pressure Ratings	
Variable Volume Supply	4 inch wg.
Constant Volume Supply	2 inch wg.
Return Ducts	2 inch wg negative.
Exhaust Ducts	2 inch wg. Negative

Table 2 – Design Temperatures

Design Temperatures	
Outdoor Temperature; Cooling Season:	*95 deg. F db, 75 deg. F wb.*
Outdoor Temperature; Heating Season:	*minus 10 deg. F db.*
Indoor Occupied conditioned Space; Cooling season:	*75 deg. F db, 50 percent RH.*
Indoor Occupied conditioned Space; Heating season:	*72 deg. F db, 30 percent RH.*
Indoor Archive Storage Space; Cooling and Heating Seasons:	*72 deg. F db, 50 percent (max.) RH.*
Indoor temperatures will be maintained plus or minus 2 deg. F from design.	

Ventilation

Supply, return and exhaust air is ducted though galvanized steel sheet metal constructed to SMACNA standards. All supply, return and relief air ductwork has an acoustical insulating liner. Air handling units are constant air volume or variable air volume consisting of indoor modular or custom double-wall insulated cabinet construction, plenum-type supply and inline-type return fans controlled by dedicated variable speed controllers, 30% efficiency pre-filters, 95% final filters, hot water heating coil with dedicated circulating pump, chilled water cooling coil with stainless steel frames, natural gas or electric powered humidifier, air mixing blender, economizer air mixing and relief air plenums, discharge and return air duct connection plenums, access doors with inspection windows and interior service lights. Building relief is provided with roof mounted exhaust fans controlled with variable speed drive controllers. Exhaust fan systems for general, toilet, shop and kitchen exhaust are provided in each of the buildings.

The Museum Building has two central 42,000 CFM variable air volume air handling units with two central return air points. The Retail Building has five constant volume air handling units serving the five separate zones: retail, kitchen, café, restaurant, and special event space. The Annex Building has 4 air handling units. The exhibit space is served by a custom built 21,500 CFM constant air volume air handling unit. The workshop, exhibit prep and storage are served by the 1 modular 8,000 CFM constant air volume air handling unit. General offices are served by 1 modular 5,000 CFM variable air volume air handling unit. The loading dock, security, employee bream room, and remaining areas of the annex are served by 1 modular 5,000 CFM variable air volume air handling unit. IS computer room is served by a dedicated 10 ton Leibert computer room air conditioning unit. The unit includes a remote air cooled condensing unit located on the roof.

ASHRAE Standard 62.1-2007, section 6 outlines the Ventilation Rate Procedure used to design each ventilation system used in the building. A prescriptive approach is used to calculate the minimum outdoor air to individual zones in the buildings based on space category, occupancy, and floor area. Ventilation is intended to dilute contaminants in indoor spaced generated by primarily two types of sources: Occupants (bio-effluents) and off-gassing from building materials. A study was conducted in

Tech Report One that compared the calculated minimum ventilation to the designed ventilation of the Harley-Davidson Museum. The results from the study are shown in table 3.

Table 3 - Ventilation

Ventilation			
AHU	Minimum OA supplyed by AHU	Minimum OA required	Complies With ASHRAE 62.1
A3	2640	6056	No
A2	7500	1620	Yes
M1	8300	13795	No
M2	8300	10633	No
R1	1120	884	Yes
R2	750	609	Yes
R3	1500	438	Yes
R4	2400	1470	Yes
R5	4500	870	Yes

Critical zones where high occupancy is common (restaurant and retail) or zones where indoor air quality is vital (kitchen) far exceed the requirements specified by ASHRAE. Museum gallery spaces utilize a VAV system and do not comply with the ASHRAE standard. The indoor air quality and occupant comfort levels of the areas that do not comply with the ASHRAE standard should still be adequate. The Museum will rarely meet the occupancy load used in the ASHRAE calculations and when the occupancy load is maximum it will be for a short duration.

Heating & Cooling Loads

The building load and energy simulation program Trane Air Conditioning Economics 700 (TRACE) was used to evaluate the heating loads, cooling loads and energy consumption of the Harley-Davidson Museum. TRACE was used as an analysis tool for its application of techniques recommended by the American Society of Heating, Refrigerating and Air-Condition Engineers (ASHRAE) and user experience with the program. The information that follows reviews the results establish from the energy simulation. Assumptions and details related to the energy simulation can be reviewed in Tech Report Two.

The engineers at HGA did not conduct a full energy model for the Harley-Davidson Museum. Calculated heating and cooling loads were compared with information from the construction document schedules and ASHRAE standards. The ASHRAE 2005 Pocket guide cooling load check figures table, shown in Table 4, was compared with the calculated load from TRACE.

Table 4 – ASHRAE 2005 Pocket Guide Cooling Load Check Figures for Museums

Occ, Sq Ft/Person			Lights, Watts/Sq Ft			Refrigeration Sq Ft/ Ton			Supply Air Rate Internal, CFM		
Lo	Av	Hi	Lo	Av	Hi	Lo	Av	Hi	Lo	Av	Hi
80	60	40	1	1.5	3	340	280	200	0.9	1	1.1

The Harley-Davidson Museum gallery spaces were designed with 19 sq ft / person. This density is higher than the density found in the ASHRAE pocket guide and also higher than the density found in ASHRAE standard 62.1.2007. The designed Light density is also considerably higher than the density found in the ASHRAE pocket guide. This is most likely do to the uniqueness of exhibits and spaces compared to an ordinary museum. With this extra load on the space it would be expected that the refrigeration density would also be high, which it is. The TRACE calculations for refrigeration density and total tons match the designed values and are illustrated in Table 5 for comparison. The modeled peak heating plant load also falls in a reasonable range to the designed MBh and is illustrated in Table 6.

Table 5 – Cooling Loads

Peak Cooling Plant Loads		
Design	**TRACE MODEL**	**Design to Model**
ton	ton	%Δ
600	585.3	-2%
sq ft/ ton	sq ft/ ton	-
196.7783	201.7204852	3%

Table 6- Heating Loads

Peak Heating Plant Loads		
Desgin	**TRACE MODEL**	**Design to Model**
MBh	MBh	%Δ
8000	9073	13%
sq ft/ MBh	sq ft/ MBh	-
14.75838	13.01300562	-12%

A comparison of calculated CFM to actual designed CFM is illustrated in Table 8. Most of the AHU's fall in a reasonable rage to the actual AHU's; however, AHU-A4 has a supply air rate well below designed. This is most likely because the AHU was designed to maintain a constant environment for the paper archives of Harley-Davidson; however, it was modeled in TRACE as 7.5 CFM / person with minimum humidity of 30% and no occupants. It can also be viewed in Table 8 that AHU-A4 has an extremely high square foot per ton. To properly model this space a new schedule should be made to maintain a designed relative humidity specified by HGA of 50% and a supply air rate appropriate for an archive of this type instead of 7.5 CFM/ person.

Table 8 – CFM Comparison

System Summary			
	Designed	**TRACE Model**	**Design to Model**
	CFM	CFM	%Δ
AHU-A1	9500	7642	-20%
AHU-A2	25200	25005	-1%
AHU-A3	16500	17862	8%
AHU-A4	3000	365	-88%
AHU-M1	45000	39887	-11%
AHU-M2	45000	45886	2%
AHU-R1	10400	7635	-27%
AHU-R2	3200	4144	30%
AHU-R3	15000	15087	1%
AHU-R4	11000	8073	-27%
AHU-R5	14200	14095	-1%

Table 7 - TRACE Systems

TRACE System Summary		
	CFM/ton	Sq Ft/ton
AHU-A1	335.52	98.35
AHU-A2	290	104.37
AHU-A3	314.07	425.89
AHU-A4	523.58	2582.75
AHU-M1	297.31	171.7
AHU-M2	323.52	147.71
AHU-R1	359.82	179.09
AHU-R2	504.44	236.18
AHU-R3	309.18	38.2
AHU-R4	333.36	165.17
AHU-R5	277.56	121.3

There are several reasons why the calculated data is different from the designed data and ASHRAE standards. The designed model used four standard wall constructions. In reality, not every wall was constructed in accordance to one of the four walls. Similarity assumptions were made to save time. Vertical fenestration values differed minimally throughout the building; however, most fenestration was assumed to be equal.

Operating schedules were used in the model to reduce loads and energy used in the building. The designers from HGA may not have utilized schedules in their design calculations.

Weather data used in TRACE is extracted from ASHRAE Climatic Data saved within TRACE. The designers at HGA may have used different weather design conditions than the data used in this report.

For the most part, the TRACE model was in accordance to the designed systems by HGA with a few exceptions and is a reasonable tool to illustrate the Harley-Davidson Museum. Energy consumption, cost, and emissions are discussed in the next section of this report.

Annual Energy Consumption

Trane TRACE 700 was also used to model a full year energy simulation of the Harley-Davidson Museum. TRACE calculations were then compared to actual energy usage data and utility bills supplied by Harley-Davidson. Assumptions and details related to the energy simulation can be reviewed in Tech Report Two.

Table 9 below is a breakdown of energy consumption calculated from the TRACE energy model. Figure 1 and 2 illustrates the data in Table 9 and shows that lighting is the major contributor to energy usage in the building. It is also noteworthy that primary heating uses 24% of the building's energy, but only 10% of total source energy and primary cooling uses 15% of the building's energy and 17% of total source energy. This is because most of the primary heating uses onsite combustion as opposed to the primary cooling which uses electricity from WE Energies. Auxiliary energy which is fans and pumps, is the second leading contributor to energy consumption.

Table 9 – Energy Consumption

Energy Consumption Summary				
	Elec Cons.	**Gas Cons.**	**Total Building Energy**	**Total Source Energy**
	kWh	kBtu	kBtu/yr	kBtu/yr
Primary Heating	16,095	3,642,586	3,697,518	3,999,115
Primary Cooling	653,708		2,231,106	6,693,987
Auxiliary	1,234,713		4,214,076	12,643,493
Lighting	1,509,076		5,150,476	15,452,973
Total	3,413,592	3,642,586	15,293,176	38,789,568

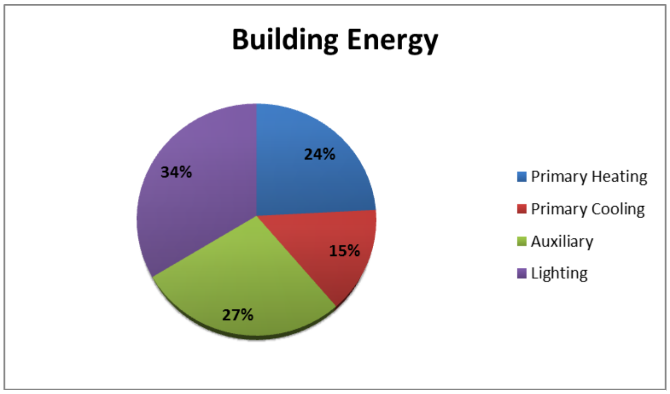


Figure 2 - Energy

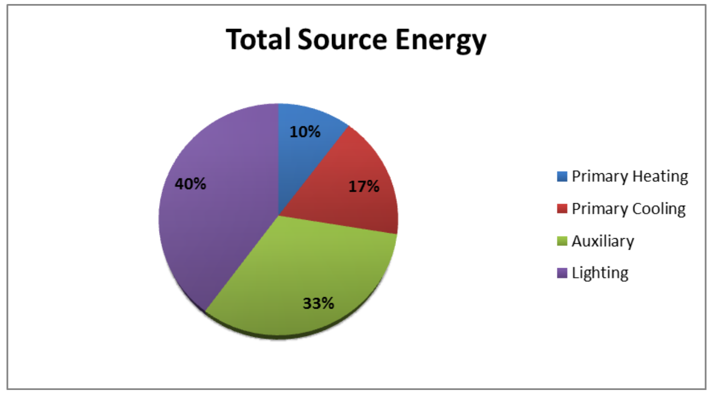


Figure 1 – Source Energy

Figure 3 illustrates the monthly electricity usage calculated in the model and average monthly temperatures used in the calculations. Most of the electricity is used in the summer months when cooling demand is high. This is because there is no cooling demand in the winter and the heating demand consumes energy in the form of onsite combustion through natural gas. Figure 4 shows the actual monthly electricity used with actual temperatures for each month. Figure 5 compares the modeled data with the actual data. Relative to outside air temperature there is a close comparison; however, the modeled data peaks earlier than the actual data. This is because the weather also peaked earlier.

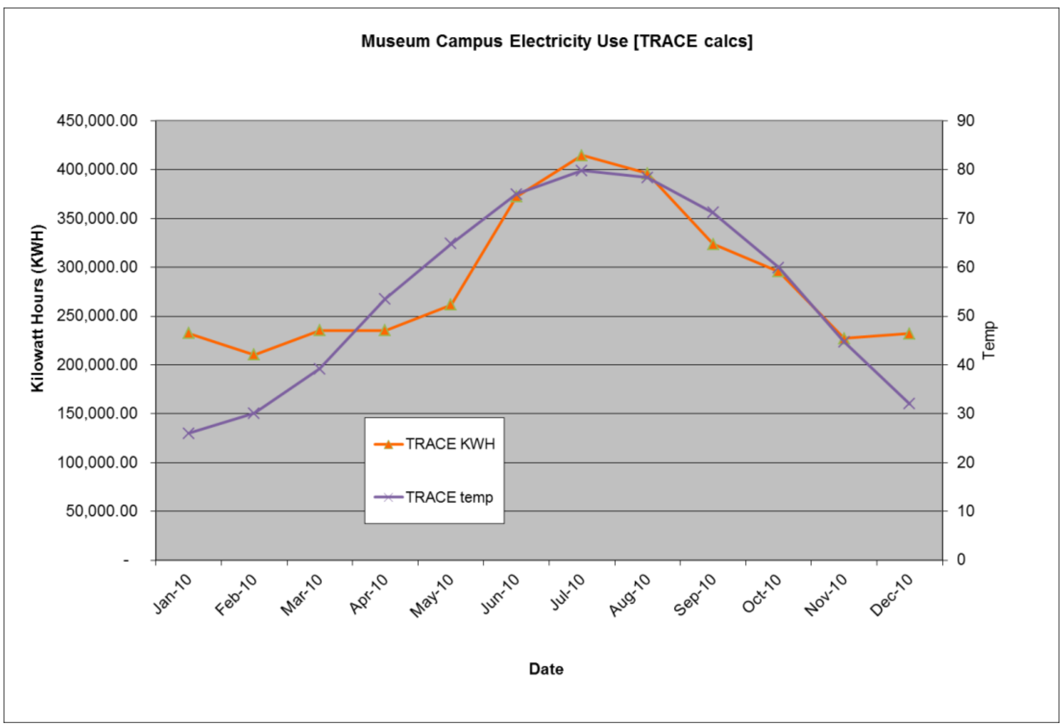


Figure 3 – Modeled Museum Electricity Usage

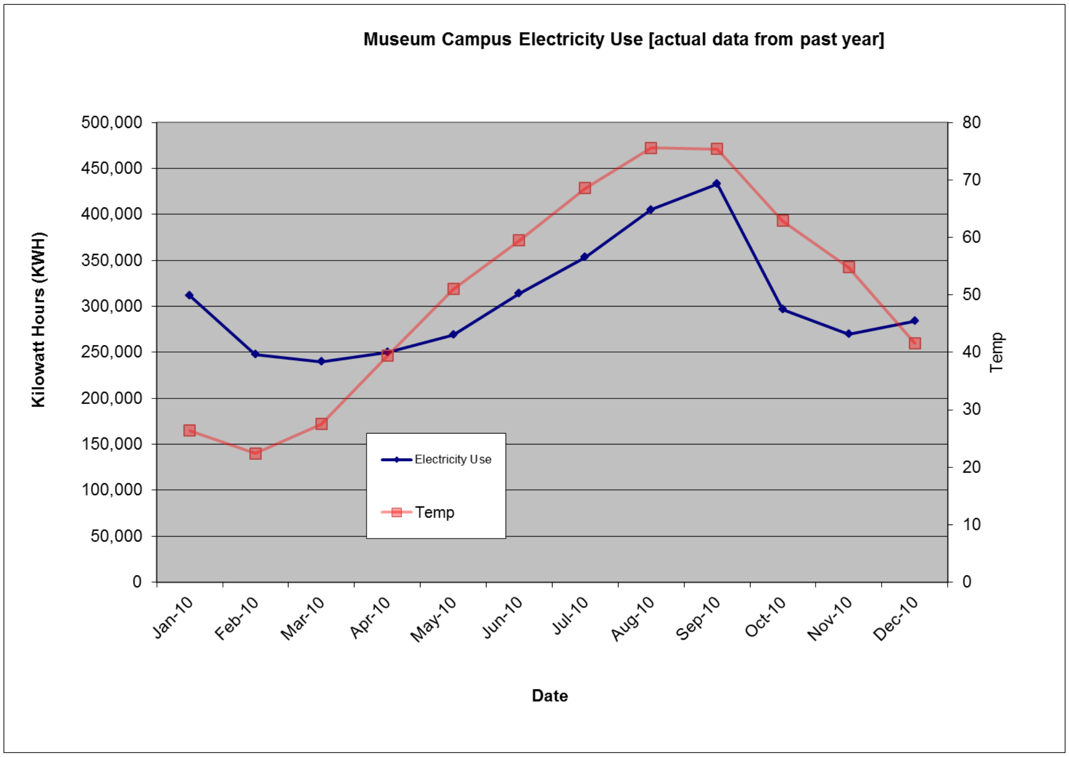


Figure 4 - Actual Museum Electricity Usage

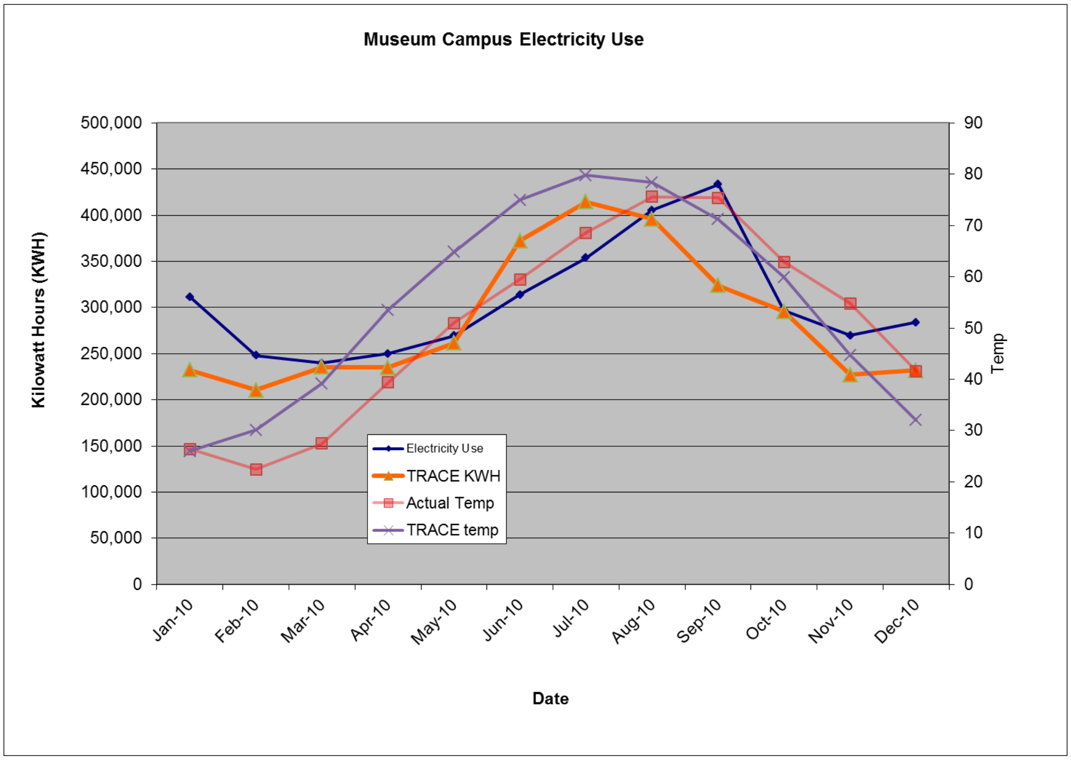


Figure 5 – Comparison of Model to Actual Energy Usage

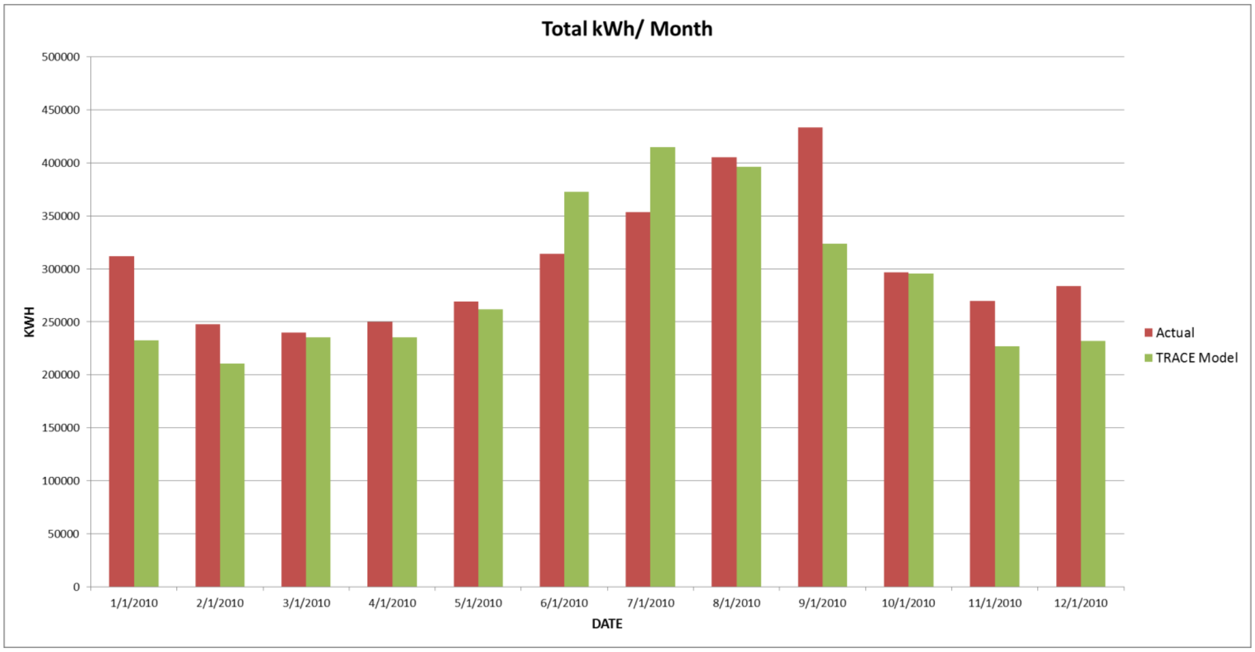


Figure 6 – Summary of Total kWh/ Month for Actual Data vs. Modeled Data

The TRACE energy model only modeled natural gas used for heating. In actuality, natural gas is used in other areas in the building, for example, the appliances in the kitchen. This is the main reason why the model data in Table 10 is significantly lower than the actual data provided by Harley-Davidson.

Table 10 – Actual vs Modeled

Natural Gas				
Month	Actual Therms	Temp	Model Therms	%∆
1/11/2010	28438.00	26.40	7540.00	-
2/8/2010	23092.00	22.40	5077.00	-
3/9/2010	19611.00	27.50	2212.00	-
4/9/2010	14710.00	39.40	1223.00	-
5/10/2010	12535.00	51.00	489.00	-
6/10/2010	8717.00	59.50	108.00	-
7/8/2010	6875.00	68.60	9.00	-
8/6/2010	6366.00	75.60	26.00	-
9/8/2010	6598.00	75.40	191.00	-
10/6/2010	8335.00	62.90	347.00	-
11/5/2010	10012.00	54.80	1481.00	-
12/8/2010	19644.00	41.60	6612.00	-
Total:	164933.00		25315.00	85%

Figure 7 shows how the modeled natural gas follows the same projection, but is significantly lower than the actual data. Natural gas usage is at its lowest in the warmer months because there is a lower heating demand.

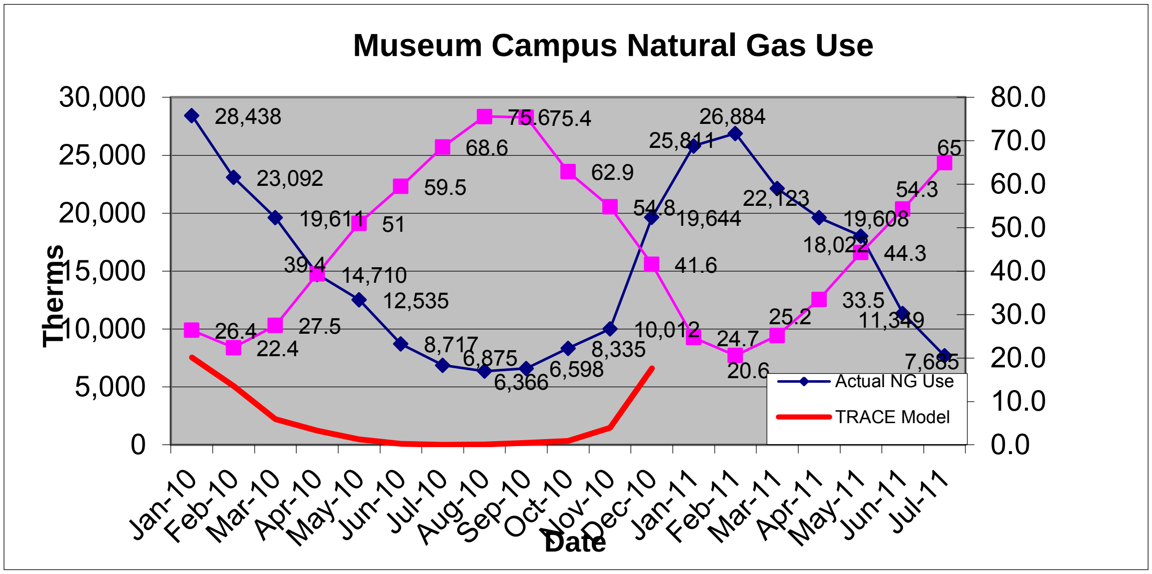


Figure 7 – Natural Gas Usage

Energy Cost Information

A cost analysis was conducted to evaluate utility rates and building operation cost. Utility rate structure level three from WE Energies was used to evaluate the Harley-Davidson Museum. Data for rate structure level three is shown in Figure 8 and 9. An electric demand of $10.00/kW was used in the Model. This rate structure seamed high and in Figure 12 it is clear that the rates were relatively high and is not the correct rate structure used by Harley-Davidson. After further investigation of the information provided by Harley-Davidson it was concluded that the rate structure was simply $0.09/kW. This more closely matched the actual cost and is shown in Figure 12. Another analysis was conducted using a standard built in rate structure from TRACE and was concluded to be similar to the $0.09/kW rate structure.

Time periods and prices

Off-Peak

8 p.m. to 8 a.m. weekdays
All day on weekends and selected holidays
Cost: 5 cents/kWh all year

Mid-Peak

8 a.m. to 2 p.m. weekdays
6 p.m. to 8 p.m. weekdays
Cost: 19 cents/kWh Oct. 1 to May 31
25 cents/kWh June 1 to Sept. 30

On-Peak

2 p.m. to 6 p.m. weekdays
Cost: 25 cents/kWh Oct. 1 to May 31
29 cents/kWh June 1 to Sept. 30

Figure 8 – WE Energy Level 3 Rates

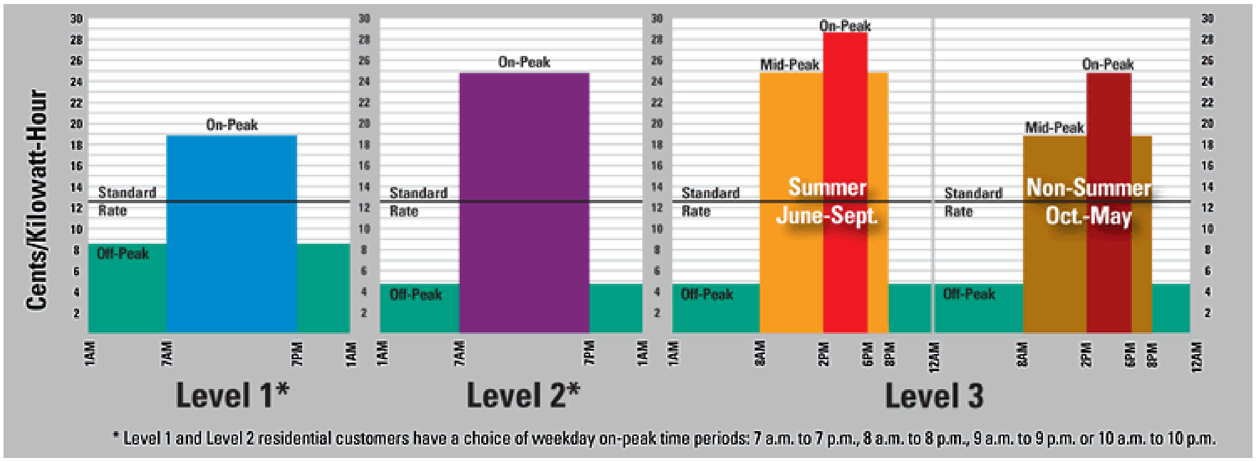


Figure 9 – WE Energy Rate Structure

An average price per therm, equaling $0.80/therm, was calculated from the utility bill from Harley-Davidson and was used to calculate the cost of natural gas monthly and annually for heating. Because natural gas was not modeled in TRACE for total consumption this cost will be considerably lower than the actual cost of total gas consumption.

The overall utility cost per area was calculated in Tech Report Two to be $2.14 per square foot and is broken down in Table 11 and Figure 11. It is interesting to see how primary heating cost is only 6% of the total, but consumes 24% of the total energy, shown in Figure 1. This is largely due to the fact that primary heating is only 10% when converted to source energy. More cost information can be found in Tech Report Two.

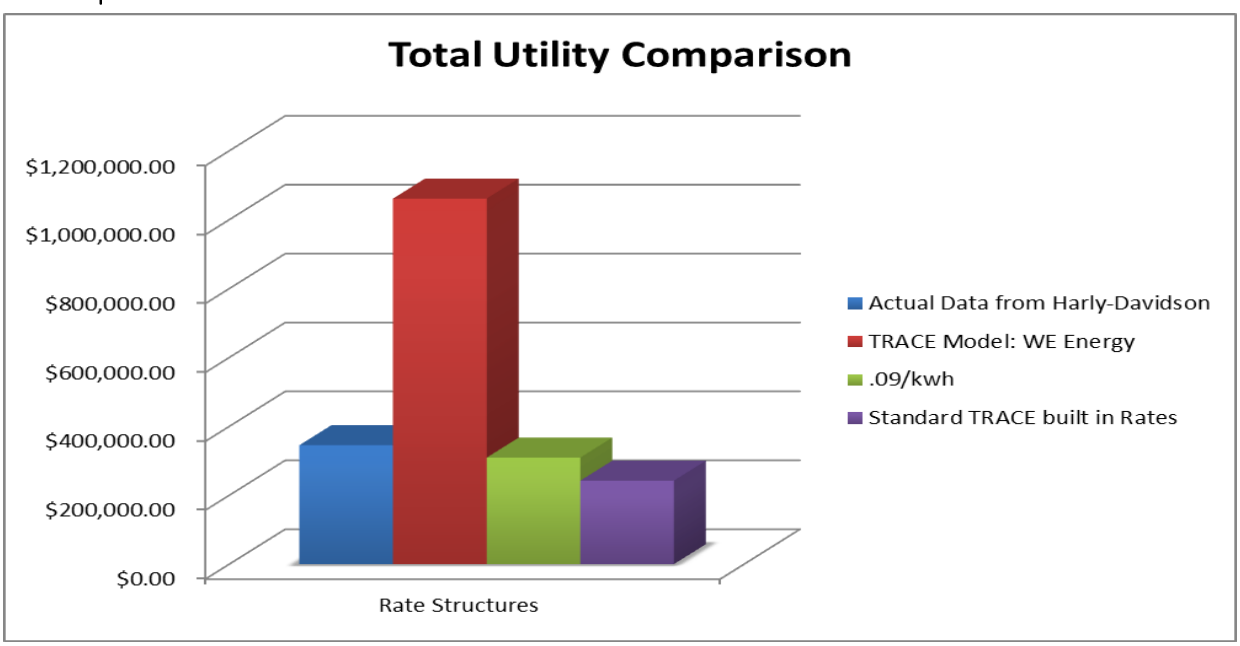


Figure 10 – Utility Comparison

Table 11 – Annual Cost

Cost Breakdown		
	Cost	
Primary Heating	$	20,252.00
Primary Cooling	$	58,833.72
Auxiliary	$	111,124.17
Lighting	$	135,816.84

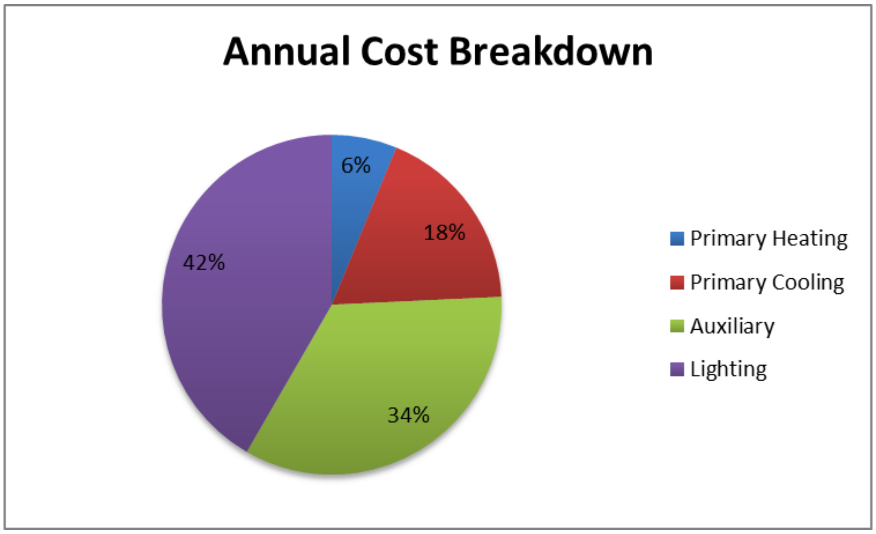


Figure 11 – Percentage Cost Breakdown

Section 2 – Mechanical Operation & Schematics

This section goes over the mechanical system of operations. It also reviews lost usable space due to the mechanical systems and the overall cost of the mechanical systems along with related construction costs.

Major Equipment

The figures below summarize the major equipment in the facility and will be referenced in the next sub-section of this report.

Table 12 – Air Handling Units

Air Handling Units								
		SUPPLY	SUPPLY	TSP	ESP	MOTOR	FAN	
AHU	SERVICE	(CFM)	(CFM)	(IN WG)	(IN WG)	HP	RPM	MANUFACTURER
AHU-A1	TEMP. EXHIBIT	9,500	4,750	4.53	0.94	15	1,657	YORK
AHU-A2	TEMP. EXHIBIT	25,200	12,600	4.63	0.88	30	1,079	YORK
AHU-A3	GENERAL AREAS	16,500	6,600	5.35	1.75	30	1,765	YORK
AHU-A4	ARCHIVES	3,000	3,000	4.71	0.46	7.5	2,990	YORK
AHU-M1	MUSEUM	45,000	15,000	5.50	2.31	60	825	GREENHECK
AHU-M2	MUSEUM	45,000	15,000	5.50	2.31	60	825	GREENHECK
AHU-R1	RETAIL	10,400	5,200	4.20	0.52	15	1,664	YORK
AHU-R2	CAFÉ	3,200	1,600	4.35	0.61	7.5	2,982	YORK
AHU-R3	KITCHEN	15,000	15,000	4.35	0.55	25	1,598	YORK
AHU-R4	RESTAURANT	11,000	5,500	4.37	0.56	15	1,412	YORK
AHU-R5	SPECIAL EVENTS	14,200	7,100	4.35	0.65	20	1,557	YORK

Table 13 - Boilers

Condensing Boiler								
	INPUT	OUTPUT	MIN	DESIGN			FLOW	
BOILER	CAP	CAP	EFF	PRESSURE	EWT	LWT	RATE	
HP	(MBH)	(MBH)	(%)	(PSI)	(DEG)	(DEG)	(GPM)	MANUFACTURER
60	2000	1720	86	150	140	180	140	AERCO
60	2000	1720	86	150	140	180	140	AERCO
60	2000	1720	86	150	140	180	140	AERCO
60	2000	1720	86	150	140	180	140	AERCO

Table 14 - Chillers

Air Cooled Chiller												
COOLING CAP		COMPRESSORS		EVAPORATOR					CONDENSER			
NOMINAL	ACTUAL		UNLOADING	EWT	LWT	FLOW	WPD	FOULING	QTY OF	EAT		
TONS	TONS	QTY	STEPS	(DEG F)	(DEG F)	(GPM)	(FT WG)	FACTOR	FANS	(DEG F)	EER	MANUFACTURER
300	299.2	3	VARIABLE	53	44	880	28.7	0.0001	14	95	9.5	YORK
300	299.2	3	VARIABLE	53	44	880	28.7	0.0001	14	95	9.5	YORK

Table 15 - Pumps

Pumps							
	PUMP	FLOW	HEAD	EFF.	MOTOR		
SYSTEM	TYPE	(GPM)	(FT WG)	(%)	HP	RPM	MANUFACTURER
AHU-A2 HW COIL	INLINE	29	3	-	0.17	3300	BELL & GOSSETT
AHU-A3 HW COIL	INLINE	14	4	-	0.08	2650	BELL & GOSSETT
AHU-M1 HW COIL	INLINE	24	10	-	0.17	3300	BELL & GOSSETT
AHU-M2 HW COIL	INLINE	24	10	-	0.17	3300	BELL & GOSSETT
HOT WATER	END SUCTION	740	158	79	50	1750	BELL & GOSSETT
HOT WATER	END SUCTION	740	158	79	50	1750	BELL & GOSSETT
CHILLED WATER	END SUCTION	1675	177	85	125	1770	BELL & GOSSETT
CHILLED WATER	END SUCTION	1675	177	85	125	1770	BELL & GOSSETT
CHILLED WATER	INLINE	100	34	66	2	1750	BELL & GOSSETT
FINNED TUBE HEAT	INLINE	11	44	-	0.3	3250	BELL & GOSSETT
RAD. FLOOR HEAT	INLINE	3	28	-	0.17	3300	BELL & GOSSETT
AHU-R1 HW COIL	INLINE	8	2	-	0.08	2650	BELL & GOSSETT
AHU-R2 HW COIL	INLINE	4	2	-	0.08	2650	BELL & GOSSETT
AHU-R3 HW COIL	INLINE	166	31	-	3	1750	BELL & GOSSETT
AHU-R4 HW COIL	INLINE	14	4	-	0.08	2650	BELL & GOSSETT
AHU-R5 HW COIL	INLINE	19	3	-	0.08	2650	BELL & GOSSETT
FINNED TUBE HEAT	INLINE	5	36	-	0.3	3250	BELL & GOSSETT
FINNED TUBE HEAT	INLINE	3	25	-	0.17	3300	BELL & GOSSETT
FINNED TUBE HEAT	INLINE	7	34	-	0.3	3250	BELL & GOSSETT

System Operation

The temperature control system has Direct Digital throughout all buildings as a component of a complete integrated building automation system. The system includes full diagnostics and color graphics. Valves and dampers have electric actuators. The system is BACNet compliant with Intranet access via the Web.

Heating System

The heating plant consists of four 2000 MBH sealed combustion condensing boilers with gas fired burners controlled by a boiler management system (BMS). The heating water system distribution is a variable-primary pumping system and the primary pumps are 550 GPM, 30 HP, variable speed, end suction base mounted type. One pump is for stand-by use. The pump with the least hours of runtime is designated as "lead" while the other is designated as "lag." Variable speed pumps have a dedicated variable speed drive controller and they are located in the upper level Mechanical Room of the museum building. The heating system provides hot water heat to air handling unit hot water coils, variable air volume box reheat coils, hot water finned tube radiations, unit heaters and similar devices throughout the building. The BMS and associated circulating pumps are controlled by an outdoor air temperature hot water system enable set point. Outdoor air temperature and relative humidity sensors are mounted at a serviceable location, with northern exposure, away from air intakes or outlets, and shielded from direct sunlight. The initial set point value is 61 degrees Fahrenheit with a 3 degree differential. The DDC-HWS is monitors flow of each pump through differential pressure switches located between each pump's suction and discharge piping and is show if Appendix A. If flow status of the lead pump is not proven within 30 seconds of a command to start, the command will be cancelled, an alarm will be issued at the operator, and the lag pump will commanded to start.

Cooling System

The cooling plant will consist of two roof mounted 350 ton air cooled rotary screw chillers and utilizes R135A refrigerant. The chillers have variable speed drive control. The chilled water distribution system is a variable-primary drive control with 1008 GPM, 125 HP variable speed end suction base mounted type pumps. The chiller with the least hours of runtime is designated as "lead." The other chiller will be designated as "lag." When outdoor air temperature is above the chilled water economizer set point, the lead chiller will be enabled. The chiller starts when it senses flow and when it reaches 100% capacity and higher, the lag chiller will start. When both chillers reach 40% capacity and lower, the lead chiller will stop and the lag chiller will continue to run. If either chiller fails, while operating as lead, an alarm will be issued and the lag chiller will start. When outdoor air temperature is below the chilled water economizer set point, initially set at 49 degrees Fahrenheit the chiller and primary chilled water circulating will be disabled, the chilled water economizer pump will start for freeze protection. This system is illustrated in Appendix A.

Mechanical System Space and Economic Analysis.

The Harley-Davidson Museum's mechanical systems are densely placed inside and on top of the facility. Minimizing lost usable space the facility's mechanical system takes up only 9,590 square feet. This is only seven percent of the overall facility's area.

Little information about cost was provided for this thesis. Only an overall number for mechanical, site, electrical, and general cost was provided and can be viewed and Table 16 and illustrated in Figure 12. For comparison an overall cost comparison of similar facilities can be found in Appendix A. This information was gathered by Bucksbaum Center for the Arts at Grinnell College. The Harley-Davidson Museum is about the same cost as Frank Gehry's Guggenheim in Spain on a per square foot basis.

Table 16 – Cost Breakdown

Harley-Davidson Museum Cost Breakdown						
	Square Footage	General	Site	Mechanical	Electrical	Adjusted Construction Cost Total
	130000	$ 36,255,763.00	$ 14,386,281.00	$ 7,121,366.00	$631,597.00	$ 58,395,007.00
Per sf		$ 278.89	$ 110.66	$ 54.78	$ 4.86	$ 449.19

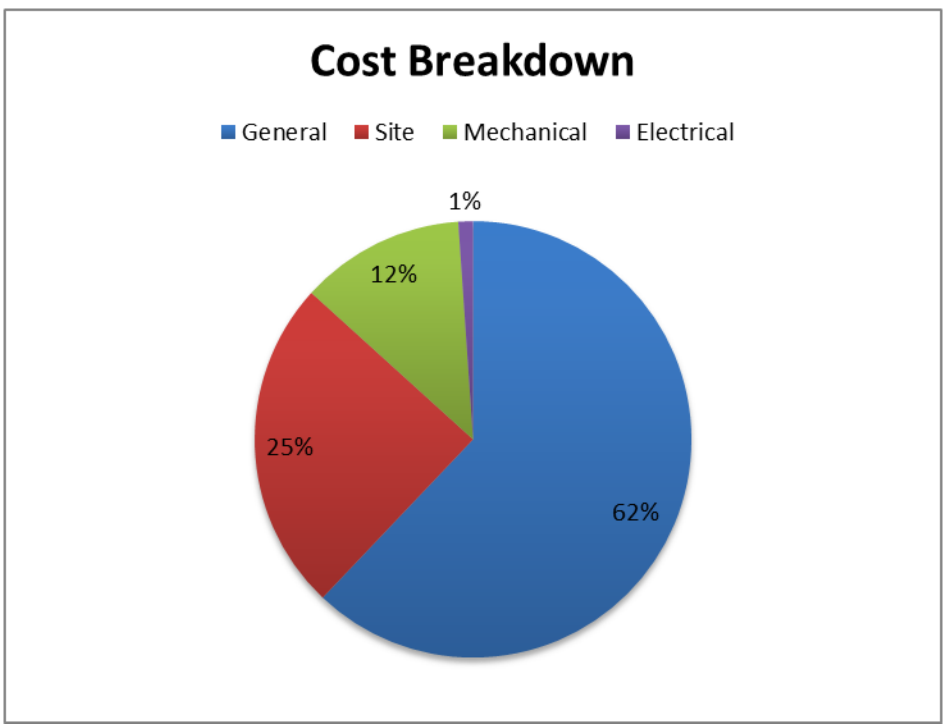


Figure 12- Cost Breakdown

Section 3 – LEED Analysis

The U.S. Green Building Council developed LEED, or Leadership in Energy and Environmental Design in March 2000 to promote sustainable building. The LEED rating system provides an outline for designers, owners, and operators to implement sustainable practices. If the facility achieves enough points the building can become certified, silver, gold, or platinum, and recognized publicly as a healthy environment for its occupants and a sustainable design that has minimal environmental impact on its surroundings.

The Harley-Davidson Museum did not attempt to become a LEED certified building because of the limitations in design and economic reasons. However, several years after the building was completed the owner commissioned The Sigma Group to perform a LEED for Existing Building Gap Analysis. The purpose of the analysis was to determine the gap between current points the facility has that would apply towards LEED Certification versus necessary points to obtain LEED Certification. The analysis indicated that the facility currently would have 12 points assuming all prerequisites would be met. To obtain basic LEED Certification, 40 points are necessary.

To develop understanding of potential areas for improvement a full LEED analysis was conducted for this tech report and is outlined in the following. The LEED 2009 rating system for New Construction and Major Renovations was used in this study. The USGBC explicitly states the intent of each credit and is listed in this report verbatim. The analysis concluded that only 26 points would have been achieved if that building was rated before completion. 80 points were not achieved and seven points could not be concluded. This means that 14 additional points would need to be achieved in order for the facility to reach minimum LEED certification. It is possible that the facility could have more points than concluded in this study because there was an insufficient amount of information relating to several credits.

Sustainable Sites:

SS Credit 1: Site Selection

The intent of this credit is to avoid the development of inappropriate sites and reduce the environmental impact from the location of a building on a site. The site was previously a warehouse that was no longer in use. It is not prime farmland as defined by the United State Department of Agriculture and is not specifically identified as habitat for any species on Federal or State threatened or endangered lists.

Points Achieved: 1 of 1

SS Credit 2: Development Density & Community Connectivity

The intent of this credit is to channel development to urban areas with existing infrastructure, protect greenfields, and preserve habitat and natural resources. The site is located within the dense urban space of downtown Milwaukee. This density is higher than 60,000 square feet per acre net. This site is also located within ½ mile of more than 10 basic services and has pedestrian access between the building and the services.

Points Achieved: 5 of 5

SS Credit 3: Brownfield Redevelopment

The intent of this credit is to rehabilitate damaged sites where development is complicated by environmental contamination and to reduce pressure on undeveloped land. The site was not documented to be contaminated by means of an ASTM1903-97 Phase II Environmental Site Assessment or a local voluntary cleanup program.

Points Achieved: 0 of 1

SS Credit 4.1: Alternative Transportation – Public Transportation Access

The intent of this credit is to reduce pollution and land development impacts from automobile use. The building is located within ¼-mile walking distance of 2 public bus stops which are usable by the building occupants.

Points Achieved: 6 of 6

SS Credit 4.2: Alternative Transportation – Bicycle Storage and Changing Rooms

The intent of this credit is to reduce pollution and land development impacts from automobile use. The building does not provide a shower and changing facilities.

Points Achieved: 0 of 1

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

The intent of this credit is to reduce pollution and land development impacts from automobile use. The building was not designed to promote low emitting and fuel-efficient vehicles; therefore, there are not any preferred parking spaces and no alternative-fuel fueling stations.

Points Achieved: o of 3

SS Credit 4.4: Alternative Transportation – Parking Capacity

The intent of this credit is to reduce pollution and land development impacts from automobile use. There is not preferred parking for carpools or vanpools; therefore, this credit is not achieved.

Points Achieved: o of 3

SS Credit 5.1: Site Development – Protect or restore Habitat

The intent of this credit is to conserve existing natural areas and restore damaged areas to provide habitat and promote biodiversity. The native or adaptive vegetation credit requirement is 50% of the site area (excluding the building footprint) for this building. The total site area excluding building footprint is approximately 803,000 s.f., the current native/adaptive vegetation area (assuming all plants meet the native or adaptive requirement) is roughly 50,000 s.f., which represents approximately 6% of the site (excluding building footprint); therefore, the facility does not qualify for this point.

Points Achieved: 0 of 1

SS Credit 5.2: Site Development – Maximize Open Space

The intent of this credit is to promote biodiversity by providing a high ratio of open space to development footprint. There is adequate vegetation to meet this credit.

Points Achieved: 1 of 1

SS Credit 6.1: Stormwater Design – Quantity Control

The intent of this credit is to limit disruption of natural hydrology by reducing impervious cover, increasing on-site infiltration, reducing or eliminating pollution from stormwater runoff and eliminating contaminants. There is not a stormwater management plan that prevents the post development peak discharge rate and quantity from exceeding the predevelopment peak discharge rate and quantity for the one and two year 24 hour design storms.

Points Achieved: 0 of 1

SS Credit 6.2: Stormwater Design – Quality Control

The intent of this credit is to limit disruption and pollution of natural water flows by managing stormwater runoff. Building roofs and landscape are drained directly to storm sewers which are connected to the adjacent river. With exception of the parking gardens across 6th street, there are no engineered infiltration areas. The parking gardens provide limited infiltration. On the whole, the site does not currently infiltrate (or collect and reuse) 25% of total precipitation falling on site and therefore, does not meet the requirements for this credit.

Points Achieved: 0 of 1

SS Credit 7.1: Heat Island Effect – Non-roof

The intent of this credit is to reduce heat islands to minimize impacts on microclimates and human and wildlife habitats. According to the analysis conducted by The Sigma Group, the site hardscape includes regular whitish-gray colored concrete walks and pavement along with colored concrete pavement/walks and asphalt paving. Based on Table 1 provided in the LEED reference manual, the existing concrete walks and pavement would have an SRI of at least 35 (typical new gray concrete). Based on review of the areas occupied by concrete walks/pavement, the site meets the requirements for this credit by providing more than 50% of the hardscape with an SRI of at least 29.

Points Achieved: 1 of 1

SS Credit 7.2: Heat Island Effect – Roof

The intent of this credit is to reduce heat islands to minimize impacts on microclimates and human and wildlife habitats. All roof areas have a white colored single ply roof membrane that meets or exceeds a SRI of 78 and therefore meets this credit requirement.

Points Achieved: 1 of 1

SS Credit 8: Light Pollution Reduction

The intent of this credit is to minimize light trespass from the building and site, reduce sky-glow to increase night sky access, improve night time visibility through glare reduction and reduce development impact from lighting on nocturnal environments. The lighting of the Harley-Davidson Museum does not comply with this credit because there are exterior lights that point towards the sky and some non-emergency lights on the interior are on after hours.

Points Achieved: 0 of 1

Water Efficiency:

According to the analysis conducted by The Sigma Group, if all fixtures meet the 2006 editions of the Uniform Plumbing Code and International Plumbing Code pertaining to fitting and fixture performance, then the facility's applicable indoor plumbing fixtures and fittings should be below the baseline requirement of 120% of the water use. Therefore, the prerequisite for water efficiency points is met.

WE Credit 1: Water Efficient Landscaping

The intent of this credit is to limit or eliminate the use of potable water or other natural surface or subsurface water resources available on or near the project site for landscape irrigation. Roughly 10% of the site area is irrigated via an automatic system. The facility does not have separate water metering for the irrigation system, thus it is unknown whether or not the facility has reduced its water consumption for irrigation from conventional means of irrigation. The irrigation system has no special features that would significantly reduce water use.

Points Achieved: 0 of 2-4

WE Credit 2: Innovation Wastewater Technologies

The intent of this credit is to reduce wastewater generation and potable water demand while increasing the local aquifer recharge. The facility has low flow water efficient toilet room fixtures in each toilet room including waterless urinals. Based on calculations by The Sigma Group, the facility toilet room fixtures have a use reduction of 26% from baseline values; however, this is less than the 50% requirement to achieve the points.

Points Achieved: 0 of 4

Energy & Atmosphere:

Prerequisite 1: Fundamental Commissioning of the Building System

The facility does not have the proper plans for this prerequisite which include an operating plan, system narratives and energy audit for the HVAC and lighting systems. The first prerequisite is not met for energy and atmosphere; therefore, the points in this section cannot be achieved.

Prerequisite 2: Minimum Energy Performance

An energy analysis was not done for the building performance by the designers and engineers. Based on the energy analysis conducted in Technical Report Two and baseline calculations found in Appendix G of ASHRAE standard 90.1-2007 the facility meets the second prerequisite.

Prerequisite 3: Fundamental Refrigerant Management

The facility uses chillers with R134a refrigerant. This refrigerant meets the third prerequisite of non CFC-based refrigerant.

EA Credit 1: Optimize Energy Performance

The intent of this credit is to achieve increasing levels of energy performance beyond the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use. According to The Sigma Group the facility meets a minimum of 21% above baseline calculations found in Appendix G of ASHRAE standard 90.1-2007. For a new building five points are achievable.

Points Achieved: 5 of 19

EA Credit 2: On-site Renewable Energy

The intent of this credit is to encourage and recognize increasing levels of on-site renewable energy self-supply to reduce environmental and economic impacts associated with fossil fuel energy use. The facility does not use renewable energy systems to offset building energy costs; therefore, no points are achieved.

Points Achieved: 0 of 7

EA Credit 3: Enhanced Commissioning

The intent of this credit is to begin the commissioning process early in the design process and execute additional activities after systems performance verification is completed. The facility does not have a developed commissioning plan for facility major energy using systems; therefore, no points are achieved.

Points Achieved: 0 of 2

EA Credit 4: Enhanced Refrigerant Management

The intent of this credit is to reduce ozone depletion and support early compliance with the Montreal Protocol while minimizing direct contributions to climate change. Information applicable to this credit was not provided by HGA. The data below illustrates worst case and best case scenarios for three refrigerants. The facility utilizes R-134a.

Worst-Case		U.S. EPA		Life Cycle			
Name	Refrigerant	ODP	GWP	LCGWP lb/ton-yr	LCODP CO2/ton-yr	LCGWP + LCODP *10^5	<100 Credit?
CFC-11	R-11	1	4000	600	0.15	15600	**No**
HCFC-123	R-123	0.02	93	13.95	0.003	313.95	**No**
HFC-134a	R-134a	0	1300	195	0	195	**No**

Lr	0.02	
life	10	years
Mr	0.1	
RC	5	lbm/ton

Figure 13 – Worst Case Refrigerant case

Optimistic Case		U.S. EPA		Life Cycle			
Name	Refrigerant	ODP	GWP	LCGWP lb/ton-yr	LCODP CO2/ton-yr	LCGWP + LCODP *10^5	<100 Credit?
CFC-11	R-11	1	4000	11.6	0.0029	301.6	**No**
HCFC-123	R-123	0.02	93	0.2697	0.000058	6.0697	**Yes**
HFC-134a	R-134a	0	1300	3.77	0	3.77	**Yes**

Lr	0.005	
life	25	years
Mr	0.02	
RC	0.5	lbm/ton

Figure 14 – Most Optimistic Case

Points Achieved:? of 2

EA Credit 5: Measurement and Verification

The intent of this credit is to provide for the ongoing accountability of building energy consumption over time. The BAS does not have a system energy metering that meets this credit.

Points Achieved: 0 of 3

EA Credit 6: Green Power

The intent of this credit is to encourage the development and use of grid-source, renewable energy technologies on a net zero pollution basis. The facility does not purchase green power; therefore, does not achieve this point.

Points Achieved: 0 of 2

Materials & Resources:

Prerequisite 1: Storage and Collection of Recyclables

The storage and collection of recyclables prerequisite is met because there is an easily-accessible dedicated area for collection and storage of materials for recycling.

MR Credit 1.1: Building Reuse – Maintain Existing walls, Floors and Roof

The intent of this credit is to extend the lifecycle of the existing building by retaining cultural resources, reduce waste, and reduce environmental impacts of the new building as it relates to materials manufacturing and transport. An accurate estimate of the requirements of this section cannot be made with the information at provided; however, it can be assumed that the design did not use any elements from other buildings.

Points Achieved: 0 of 2

MR Credit 1.2: Building Reuse – Maintain Interior Nonstructural Elements

For similar reasons in MR credit 1.1, this credit is not achievable.

Points Achieved: 0 of 1

MR Credit 2: Construction Waste Management

The intent of this credit is to divert construction and demolition debris from disposal in landfills and incineration facilities. The percentage of debris recycled or salvaged from construction is below 50%; therefore, this point is not achieved.

Points Achieved: 0 of 2

MR Credit 3: Materials Reuse

The intent of this credit is to encourage the reuse of building materials and products to reduce demand for virgin materials and reduce waste. The facility did not reuse any materials; therefore, the points are not achieved.

Points Achieved: 0 of 2

MR Credit 4: Recycled Content

The intent of this credit is increase demand for building products that incorporate recycled content materials, thereby reducing impacts resulting from extraction and processing of virgin materials. The facility does not have materials with recycled content such that the sum of postconsumer recycled plus ½ of the preconsumer content constitutes at least 10%; therefore, no points are achieved.

Points Achieved: 0 of 2

MR Credit 5: Regional Materials

The intent of this credit is to increase demand for building products which are products that are extracted and manufactured within the region, thereby supporting the use of indigenous resources and reducing the environmental impacts resulting from transportation. There is not adequate documentation to determine if building materials or products that have been extracted, harvested or recovered, as well as manufactured, within 500 miles of the project site make up a minimum of 10% based on cost, of the total materials value.

Points Achieved: ? of 2

MR Credit 6: Rapidly Renewable Materials

The intent of this credit is to reduce the use and depletion of finite raw materials and long-cycle renewable materials by replacing them with rapidly renewable materials. There isn't any renewable building products such as bamboo, wool, cotton insulation, agrifiber, wheatboard, strawboard or cork used in the facility. These points are not achieved.

Points Achieved: 0 of 1

MR Credit 7: Certified Wood

The intent of this credit is to encourage environmentally responsible forest management. The wood used for structural framing and general dimensional framing, flooring, subflooring, wood doors and finishes is not certified in accordance with the Forest Stewardship Council's principles and criteria, for wood building components. No points are achieved.

Points Achieved: 0 of 1

Indoor Environmental Quality:

Prerequisite 1: Minimum Indoor Air Quality Performance

This prerequisite is not met because the facility does not meet the minimum requirements for section four through seven of ASHRAE Standard 62.1-2007.

Prerequisite 2: Environmental Tobacco Smoke (ETS) Control Required.

This prerequisite is met by prohibiting smoking in the building.

IEQ Credit 1: Outdoor Air Delivery Monitoring

The intent of this credit is to provide capacity for ventilation system monitoring to help promote occupant comfort and well-being. The facility air handling units have measuring devices for the outside airflow rate; however, the devices do not currently have alarms that are activated to warn the system operator when the airflow rate falls more than 15% below the design minimum rate. No points are achieved.

Points Achieved: 0 of 1

IEQ Credit 2: increased Ventilation

The intent of this credit is to provide outdoor air ventilation to improve indoor air quality and promote occupant comfort, well-being and productivity. Every zone in the facility does not meet ASHRAE Standard 62.1-2007; therefore, the facility does not attain an outdoor air ventilation of 30% above the ASHRAE Standard and does not achieve this point.

Points Achieved: 0 of 1

IEQ Credit 3.1: Construction Indoor Air Quality Management Plan – During Construction

The intent of this credit is to reduce indoor air quality problems resulting from construction and promote the comfort and well-being of construction workers and building occupants. A construction indoor air quality management plan was not provided by HGA or Mortenson Construction for analysis; therefore, it is not known if this credit is achieved or not.

Points Achieved: ? of 1

IEQ Credit 3.2: Construction Indoor Air Quality Management Plan – Before Occupancy

The intent of this credit is to reduce indoor air quality problems resulting from construction and promote the comfort and well-being of construction workers and building occupants. A construction indoor air quality management plan was not provided by HGA or Mortenson Construction for analysis; therefore, it is not known if this credit is achieved or not.

Points Achieved: ? of 1

IEQ Credit 4.1: Low-Emitting Materials – Adhesives and Sealants

The intent of this credit is to reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants. Sealants used for architectural applications do not comply with South Coast Air Quality Management District Rule #1168; therefore, this point is not achieved.

Points Achieved: 0 of 1

IEQ Credit 4.2: Low-Emitting Materials – Paints and Coatings

The intent of this credit is to reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants. Architectural paints and coating applied to the interior walls and ceilings exceed the volatile organic compound content limits established in Green Seal Standard GC-03, Anticorrosive Paints, 2nd Edition, January 7, 1997.

Points Achieved: 0 of 1

IEQ Credit 4.2: Low-Emitting Materials – Paints and Coatings

The intent of this credit is to reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants. Architectural paints and coating applied to the interior walls and ceilings exceed the volatile organic compound content limits established in Green Seal Standard GC-03, Anticorrosive Paints, 2nd Edition, January 7, 1997.

Points Achieved: 0 of 1

IEQ Credit 4.3: Low-Emitting Materials – Flooring Systems

The intent of this credit is to reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants. This point is not achieved because there are adhesives used in the flooring system that do not comply with South Coast Air Quality Management District Rule #1113. It is also not known if the carpet installed in the building interior meets the testing and product requirements of the Carpet and Rug Institute Green Label Plus program. Information relative to this credit is not clearly specified in the construction documents.

Points Achieved: 0 of 1

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

The intent of this credit is to reduce the quantity of indoor air contaminants that are odorous, irritating and or harmful to the comfort and well-being of installers and occupants. Information relative to this credit is not clearly specified in the construction documents. Therefore, it is unknown if composite wood and agrifiber products used on the interior of the building contain no added urea-formaldehyde resins and it cannot be determined if this point is achieved.

Points Achieved: ? of 1

IEQ Credit 5: Indoor Chemical and Pollutant Source Control

The intent of this credit is to minimize building occupant exposure to potentially hazardous particulates and chemical pollutants. The facility has a filtration media in place that meet the minimum efficiency reporting value (MERV) of 13 for all outside air intakes and inside air recirculation. The facility air handling units use a combination of paper and box filters for their filtration media. The first, paper filter, has a minimum efficiency reporting value (MERV) of 8, and the second, box filter, MERC of 15. This qualifies the facility for this credit since the requirement is MERVE of 13 or greater. The design of the exhaust and entryway systems also complies with this credit.

Points Achieved: 1 of 1

IEQ Credit 6.1: Controllability of Systems - Lighting

The intent of this credit is to provide a high level of lighting system control by individual occupants or groups in multi-occupant spaces and promote their productivity, comfort and well-being. The facility has Individual lighting controls for more than 90% of the building occupants which qualifies the facility for this credit.

Points Achieved: 1 of 1

IEQ Credit 6.2: Controllability of Systems - Lighting

The intent of this credit is to provide a high level of thermal comfort system control by individual occupants or groups in multi-occupant spaces and promote their productivity, comfort, and well-being. The facility is equipped with individual comfort controls to allow adjustments to suit individual needs or those of groups in shared spaces. This qualifies the facility to achieve this credit.

Points Achieved: 1 of 1

IEQ Credit 7.1: Thermal Comfort - Lighting

The intent of this credit is to provide a comfortable thermal environment that promotes occupant productivity, comfort, and well-being. The facility is equipped with a BAS that enables continuous tracking and optimization of indoor comfort and conditions (humidity, temperature, air speed, etc.) and therefore, qualifies the facility for this point.

Points Achieved: 1 of 1

IEQ Credit 7.2: Thermal Comfort - Verification

The intent of this credit is for assessment of building occupant thermal comfort over time. The facility has implemented an occupant survey that addresses some of the comfort issues; however, the current facility survey does not address all comfort issues. Therefore, the facility does not qualify for this credit.

Points Achieved: 0 of 1

IEQ Credit 8.1: Daylight and Views - Daylight

The intent of this credit is to provide building occupants with connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building. According to The Sigma Group it appears the facility may meet the requirement of day lighting assuming the Museum display and archive areas (which are not conducive to day lighting) are not included in the regular occupied spaced.

Points Achieved: 1 of 1

IEQ Credit 8.2: Daylight and Views - Views

The intent of this credit is to provide building occupants with connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building. The facility meets the requirements for views assuming the Museum display and archive areas (which are not conducive to day lighting) are not included in the regular occupied spaced.

Points Achieved: 1 of 1

Innovation in Design:

ID Credit 1.1-4: Innovation in Design

The intent of this credit is to provide design teams and projects the opportunity to achieve exception performance above the requirements set by the LEED Green Building Rating System and/or innovative performance in Green Building categories not specifically addressed by the LEED Green Building Rating System. The design team did not attempt to design a LEED certified building; therefore, the documentation to achieve this credit was not completed. The design of the facility does not incorporate any unusual design features that have not already been addressed in this LEED analysis or that should be considered to be a significant measurable environmental performance not addressed by LEED 2009.

Points Achieved: 0 of 4

ID Credit 2: LEED Accredited Professional

The intent of this credit is to support and encourage the design integration required by LEED to streamline the application and certification process. There was at least one principal participant of the project team that is a LEED Accredited Professional; therefore, this point is achieved.

Points Achieved: 1 of 1

Regional Priority:

RP Credit 1.1-4: Regional Priority

The intent of this credit is to provide an incentive for the achievement of credits that address geographically – specific environmental priorities. According to The Sigma Group there are no points for this credit, but it is likely that one point could be obtained through material and resources Credit #8 which relates to recycling durable goods.

Points Achieved: 0 of 1

LEED 2009 for New Construction and Major Renovations

Project Checklist

HARLEY-DAVIDSON MUSEUM

NOV, 2012

Y	?	N			
15		11		**Sustainable Sites**	**Possible Points: 26**
Y			Prereq 1	Construction Activity Pollution Prevention	
1			Credit 1	Site Selection	1
5			Credit 2	Development Density and Community Connectivity	5
		1	Credit 3	Brownfield Redevelopment	1
6			Credit 4.1	Alternative Transportation—Public Transportation Access	6
		1	Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Roon	1
		3	Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Ve	3
		2	Credit 4.4	Alternative Transportation—Parking Capacity	2
		1	Credit 5.1	Site Development—Protect or Restore Habitat	1
1			Credit 5.2	Site Development—Maximize Open Space	1
		1	Credit 6.1	Stormwater Design—Quantity Control	1
		1	Credit 6.2	Stormwater Design—Quality Control	1
1			Credit 7.1	Heat Island Effect—Non-roof	1
1			Credit 7.2	Heat Island Effect—Roof	1
		1	Credit 8	Light Pollution Reduction	1
		12		**Water Efficiency**	**Possible Points: 10**
Y			Prereq 1	Water Use Reduction—20% Reduction	
		4	Credit 1	Water Efficient Landscaping	2 to 4
		4	Credit 2	Innovative Wastewater Technologies	2
		4	Credit 3	Water Use Reduction	2 to 4
5	2	28		**Energy and Atmosphere**	**Possible Points: 35**
Y			Prereq 1	Fundamental Commissioning of Building Energy Systems	
Y			Prereq 2	Minimum Energy Performance	
Y			Prereq 3	Fundamental Refrigerant Management	
5		14	Credit 1	Optimize Energy Performance	1 to 19
		7	Credit 2	On-Site Renewable Energy	1 to 7
		2	Credit 3	Enhanced Commissioning	2
	2		Credit 4	Enhanced Refrigerant Management	2
		3	Credit 5	Measurement and Verification	3
		2	Credit 6	Green Power	2
	2	13		**Materials and Resources**	**Possible Points: 14**
Y			Prereq 1	Storage and Collection of Recyclables	
		3	Credit 1.1	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 3
		2	Credit 1.2	Building Reuse—Maintain 50% of Interior Non-Structural Element	1
		2	Credit 2	Construction Waste Management	1 to 2
		2	Credit 3	Materials Reuse	1 to 2
				Materials and Resources, Continued	
		2	Credit 4	Recycled Content	1 to 2
	2		Credit 5	Regional Materials	1 to 2
		1	Credit 6	Rapidly Renewable Materials	1
		1	Credit 7	Certified Wood	1
6	3	6		**Indoor Environmental Quality**	**Possible Points: 15**
Y			Prereq 1	Minimum Indoor Air Quality Performance	
Y			Prereq 2	Environmental Tobacco Smoke (ETS) Control	
		1	Credit 1	Outdoor Air Delivery Monitoring	1
		1	Credit 2	Increased Ventilation	1
	1		Credit 3.1	Construction IAQ Management Plan—During Construction	1
	1		Credit 3.2	Construction IAQ Management Plan—Before Occupancy	1
		1	Credit 4.1	Low-Emitting Materials—Adhesives and Sealants	1
		1	Credit 4.2	Low-Emitting Materials—Paints and Coatings	1
		1	Credit 4.3	Low-Emitting Materials—Flooring Systems	1
	1		Credit 4.4	Low-Emitting Materials—Composite Wood and Agrifiber Product	1
1			Credit 5	Indoor Chemical and Pollutant Source Control	1
1			Credit 6.1	Controllability of Systems—Lighting	1
1			Credit 6.2	Controllability of Systems—Thermal Comfort	1
1			Credit 7.1	Thermal Comfort—Design	1
		1	Credit 7.2	Thermal Comfort—Verification	1
1			Credit 8.1	Daylight and Views—Daylight	1
1			Credit 8.2	Daylight and Views—Views	1
		6		**Innovation and Design Process**	**Possible Points: 6**
		1	Credit 1.1	Innovation in Design: Specific Title	1
		1	Credit 1.2	Innovation in Design: Specific Title	1
		1	Credit 1.3	Innovation in Design: Specific Title	1
		1	Credit 1.4	Innovation in Design: Specific Title	1
		1	Credit 1.5	Innovation in Design: Specific Title	1
		1	Credit 2	LEED Accredited Professional	1
		4		**Regional Priority Credits**	**Possible Points: 4**
		1	Credit 1.1	Regional Priority: Specific Credit	1
		1	Credit 1.2	Regional Priority: Specific Credit	1
		1	Credit 1.3	Regional Priority: Specific Credit	1
		1	Credit 1.4	Regional Priority: Specific Credit	1
26	7	80		**Total**	**Possible Points: 110**

Certified 40 to 49 points Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110

Figure 15 – LEED Checklist

Overall Evaluation

The mechanical design of the Harley-Davidson Museum is typical relative to similar buildings. The systems were designed to meet design objectives and did not strive to obtain maximum efficiency through investing in up-front capital cost. Some energy efficiency features in the mechanical design include; operating pumps using variable speed drive controllers, multiple boilers operating at part load capacity, multiple chiller with variable speed capacity adjustment, use of outdoor air for making chilled water during winter, operating air handling units using variable speed drive controllers, use of air flow measuring stations in outdoor air intake, and use of outdoor air for cooling during cooler days.

The facility was not designed to comply with ASHRAE section 6. Because of the high people count the Museum owner wanted the buildings to be designed for and the low frequency of when maximum occupancy would actually be seen, the engineers at HGA used ventilation rates to only meet the ventilation code of 7.5 CFM/person. Critical zones where high occupancy is common (restaurant and retail) or zones where indoor air quality is vital (kitchen) far exceed the requirements specified by ASHRAE. The excess ventilation provides a high quality of indoor air; however, without heat recovery these systems use more energy than required to meet space loads. Museum gallery spaces utilize a VAV system and do not comply with the ASHRAE standard. The indoor air quality and occupant comfort levels of the areas that do not comply with the ASHRAE standard should still be adequate. The Museum will rarely meet the occupancy load used in the ASHRAE calculations and when the occupancy load is maximum it will be for a short duration.

The TRACE model calculated a peak cooling load of 200 ft^2 per ton and a peak heating load of 13 ft^2 per MBh, which is only 2% and -12% different from the actual design respectively. The calculated total kBTU per year is 15,293,176 kBTU and has a CO_2 global warming potential equivalent annual emission rate of over 9 million pounds. Using information from the United States Environmental Protection Agency, this amount of CO_2 equivalent is equal to the annual greenhouse gas emissions from 797 passenger cars and it would take 867 acres of pine forest to sequester the CO_2 equivalent out of the atmosphere. The monthly kWh also matches sensibly to the actual data. The Harley-Davidson Museum is estimated to have a utility cost of $2.14/ft^2$. Through the comparisons it was concluded that the TRACE model is a reasonably accurate estimate and will be a vital tool in analyzing new alternative designs in future investigations.

The mechanical system only consumes 7% of the overall square footage of the building and is $54.75 per square foot which is a reasonable number for a building of its type. Areas for improvement should focus on efficiency rather than reducing space or overall first cost. Harley-Davidson invested a lot of capital on architectural detail; for example, according to the structural engineer at HGA the design uses 40% more steel than it requires to be structurally stable. More money could have been invested in the mechanical systems resulting in a higher efficient system. This will be investigated further in my thesis proposal.

The LEED analysis concluded that only 26 points would have been achieved if that building was rated before completion. 80 points were not achieved and seven points could not be concluded. This means that 14 additional points would need to be achieved in order for the facility to reach minimum LEED certification. The 14 additional points needed to become certified could be earned in the Energy and Atmosphere section. The points could have been achieved through the utilization of green power and renewable energy. This will be investigated further and discussed in my thesis proposal.

References

ANSI/ASHRAE. (2007). Standard 62.1 – 2007, Ventilation for Acceptable Indoor Air Quality. Atlanta, GA: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.

ANSI/ASHRAE. (2007). Standard 90.1 – 2007, Energy Standard for Buildings Except Low-Rise Residential Buildings. Atlanta, GA: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.

Deru, M., & Torcellini, P. (2007). Source Energy and Emission Factors for Energy Use in Buildings. National Renewable Energy Laboratory, 5-28

HGA, Inc. Construction Documents. HGA, Milwaukee, WI.

Pocket Guide. Atlanta: ASHRAE, 2005

U.S. Green Building Council. LEED 2009 For New Construction and Major Renovations. Washington D.C., 2008

Project Team

- Owner: Harley-Davidson Motor Company, www.harley-davidson.com
- Construction Manager: M.A. Mortenson Company, www.mortenson.com
- Design Architect: Pentagram Architecture
- Architect of Record: Hammel, Green & Abrahamson, Inc.
- Structural and MEP Engineers: Hammel, Green & Abrahamson, Inc.
- Environmental Services: The Sigma Group
- Landscape Architect: Oslund and Associates
- Civil Engineer: Graef Anhalt

APPENDIX A: MUSEUM COMPARISON

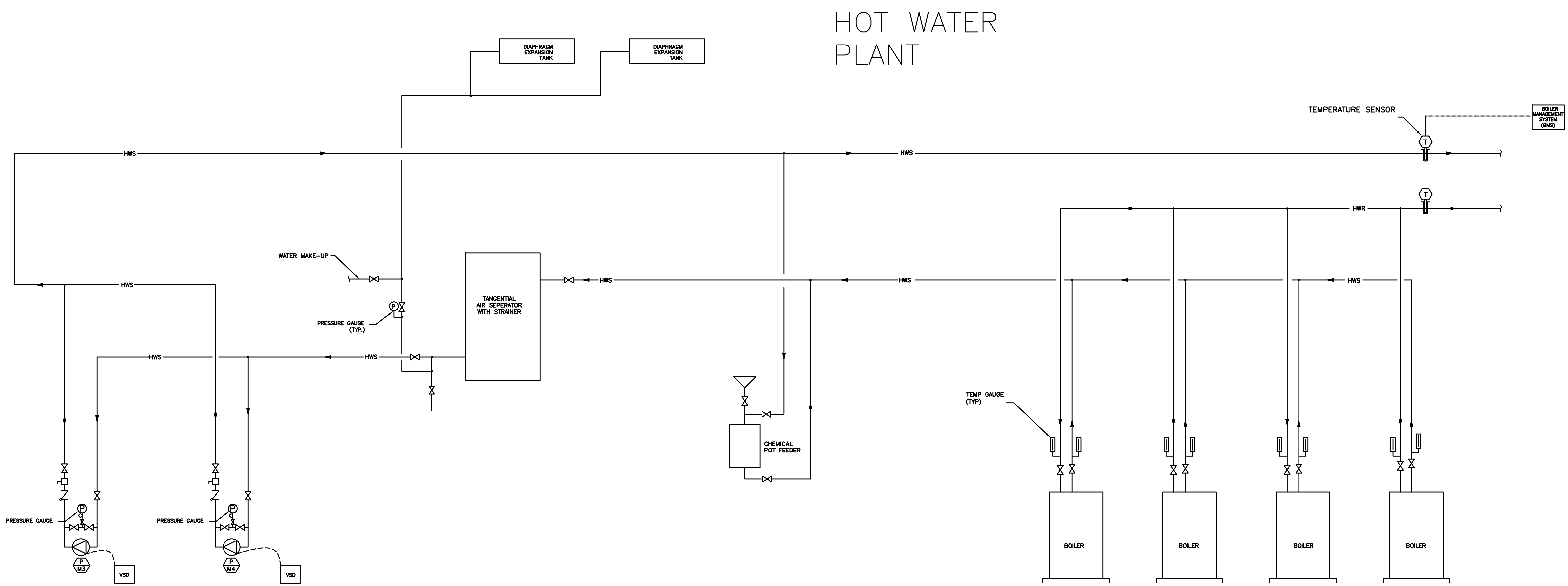
Provided by Bucksbaum Center for the Arts

	GSF	Const. Cost	Date Bid	Total Cost In Minneapolis 6/03	Cost /SF
Guggenheim New York (Gehry) New York City	560,000	$678,000,000	-	$678,000,000	$1,211 /SF
Getty Museum (Meier) Los Angeles, California	945,000	$733,000,000	1994	$902,390,756	$955 /SF
Rock and Roll Hall of Fame (I.M. Pei) Cleveland, Ohio	143,000	$92,000,000	1993	$132,266,928	$925 /SF
The Tech: Museum of Innovation (Legorreta) San Jose, California	132,000	$96,000,000	1996	$102,807,018	$779 /SF
Peabody Essex Museum (Safdie) Salem, Massachusetts	100,000	$70,000,000	2001	$72,782,115	$728 /SF
Milwaukee Art Museum (Calatrava) Milwaukee, Wisconsin	142,050	$95,000,000 (100 car parking ramp not included)	1999	$100,000,000	$704 /SF
National Museum of the American Indian (Polshek) Washington, D.C.	225,000	$110,000,000	1997	$151,456,767	$673 /SF
Albany Institute of History and Art Albany, New York	25,000	$12,500,000	1998	$16,205,752	$648 /SF
Cy Twombly Gallery (Piano) Houston, Texas	9,000	$3,500,000	1994	$5,489,829	$610 /SF
Nelson Atkins Museum of Art (Holl) Kansas City, Missouri	160,000	$77,000,000 ($95M incl. 450 car ramp)	2000	$95,435,702	$596 /SF
Bigelow Chapel (HGA) New Brighton, Minnesota	5,000	$2,925,000	2003	$2,955,259	$591 /SF
Seattle Art Museum (Venturi) Seattle, Washington	155,000	$62,000,000	1990	$90,739,261	$585 /SF
San Antonio Museum of Art (Expansion) San Antonio, Texas	30,000	$11,000,000	1996	$17,459,372	$582 /SF
Mashantucket Pequot Museum and Research Center (Polshek) Mashantucket, Connecticut	308,000	$135,000,000	1997	$165,502,092	$537 /SF
Denver Art Museum (Liebeskind) Denver, Colorado	146,000	$62,500,000	2002	$75,484,336	$517 /SF
Contemporary Arts Center (Hadid) Cincinnati, Ohio	50,900	$20,600,000	2001	$26,038,827	$512 /SF

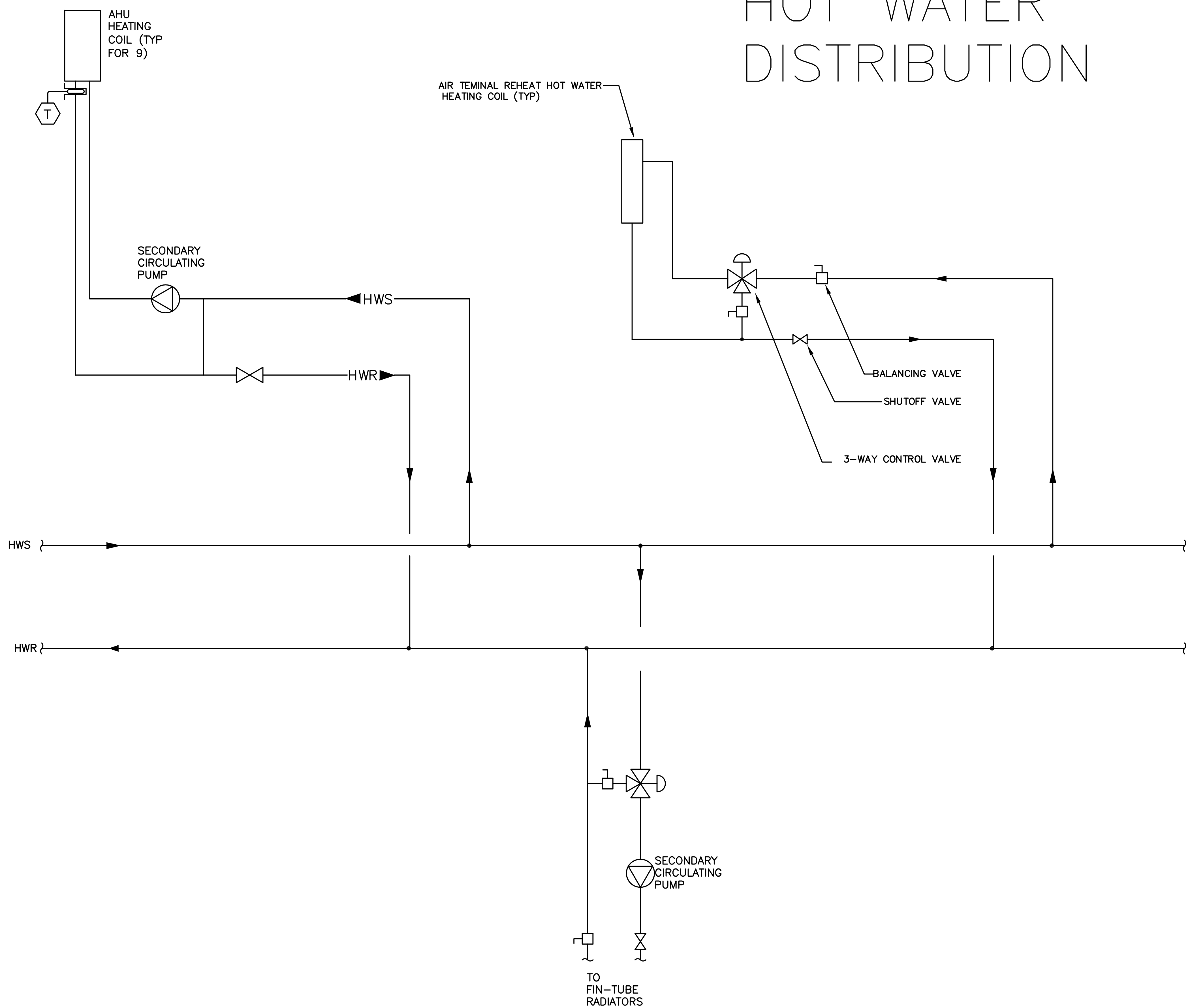
Bellevue Art Museum (Holl) Bellevue, Washington	36,000	$15,000,000	1999	$17,822,384	$495 /SF
Guggenheim/Bilbao (Gehry) Bilbao, Spain	257,000	$100,000,000	1995	$126,402,071	$492 /SF
Henry Art Gallery Seattle, Washington	46,000	$17,500,000	1996	$22,254,774	$484 /SF
Rose Art Museum, Lois Foster Wing @ Brandeis University (Gund) Waltham, Massachusetts	8,800	$4,000,000	2000	$4,218,862	$479 /SF
Cultural Resource Center Suitland, Maryland	200,000	$66,000,000	1997	$94,608,611	$473 /SF
Kiasma Museum of Contemporary Art (Holl) Helsinki, Finland	130,000	$41,000,000	1996	$58,542,885	$450 /SF
Museum of African American History Detroit, Michigan	120,000	$38,000,000	1995	$50,563,124	$421 /SF
Weisman Art Museum Expansion (Gehry) Minneapolis, Minnesota	10,500	$4,200,000	2007	$4,200,000	$400 /SF
University Of Alaska Museum (HGA) Fairbanks, Alaska	40,000	$14,500,000	2002	$15,505,474	$388 /SF
Menil Collection Museum (Piano) Houston, Texas	106,304	$25,000,000	1986	$38,190,824	$359 /SF
Madison Children's Museum (HGA) Madison, Wisconsin	32,500	$8,828,200	2005	$10,167,699	$313 /SF
Loeb Art Center @ Vassar College (Pelli) Poughkeepsie, New York	59,700 (30,200 GSF New)	$15,600,000	1991	$18,371,383	$308 /SF
Sam Noble Oklahoma Museum of Natural History Norman, Oklahoma	190,000	$37,500,000	1998	$58,134,921	$306 /SF
San Francisco MOMA (Botta) San Francisco, California	225,000	$60,000,000	1994	$66,894,977	$297 /SF
Tang Teaching Museum (Predock) Skidmore College	39,000	$10,200,000	1999	$10,828,261	$278 /SF
Chicago MCA (Kleihues) Chicago, Illinois	220,000	$46,000,000	1993	$60,548,068	$275 /SF
Weisman Art Museum (Gehry) Minneapolis, Minnesota	45,000	$8,415,000	1991	$12,327,975	$274 /SF
Walker Art Center (Herzog & de Meuron) Minneapolis, Minnesota	126,000	$34,500,000	2003	$34,500,000	$274 /SF
Brown Fine Arts Center @ Smith College (Polshek) Northampton, Massachusetts	164,000 (36,000 GSF New)	$35,000,000	1999	$43,160,774	$263 /SF
Davis Museum and Cultural Center @ Wellesley College (Moneo) Wellesley, Massachusetts	61,000	$11,700,000	1990	$15,455,816	$253 /SF
Mount Holyoke College Art Museum (Hillier) South Hadley, Massachusetts	25,700 (3,700 GSF New)	$6,100,000	2000	$6,433,765	$250 /SF

Appendix B: Mechanical Schematics

The following pages are schematics developed for illustrative purposes for this report and future reports for this thesis only.


HOT WATER PLANT
DIAPHRAGM EXPANSION TANK
DIAPHRAGM EXPANSION TANK
TEMPERATURE SENSOR
BOILER MANAGEMENT SYSTEM (BMS)
HWS
HWS
HWR
WATER MAKE-UP
PRESSURE GAUGE (TYP.)
TANGENTIAL AIR SEPERATOR WITH STRAINER
CHEMICAL POT FEEDER
TEMP GAUGE (TYP)
PRESSURE GAUGE
PRESSURE GAUGE
P M3
P M4
VSD
VSD
BOILER
BOILER
BOILER
BOILER

HOT WATER DISTRIBUTION



CHILLED WATER SYSTEM