Harley-Davidson Museum

Milwaukee, WI

04/09/2012

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FINAL THESIS REPORT

Harley-Davidson Museum

Milwaukee, WI

Jonathan Rumbaugh

Architectural Engineering
Mechanical Option

Project Team

Owner:	Harley-Davidson Motor Company
Construction Manager:	M.A. Mortenson Company
Design Architect:	Pentagram Architecture
Architect of Record:	Hammel, Green & Abrahamson, Inc.
Engineers:	Hammel, Green & Abrahamson, Inc.
Environmental Services:	The Sigma Group
Landscape Architect:	Oslund And Associates

Size:	130,000 sf
Timeline:	April 2005- May 2008
Project Cost:	$75 million
Delivery Method:	Design-Bid-Build

Architecture

Design inspired by old factories
Transformed an underutilized site into award winning museum
Industrial design reflects company culture
Steel, brick, and glass palette reveals reality behing its unique aesthetic

MEP

Two roof mounted 300 ton air-cooled rotary screw, variable speed drive chillers
Four 2000 MBH combustion condensing boilers
11 AHU's (VAV & CAV),total: 150,000 CFM
300 kW emergancy gas generator
Three switchboads rated at 3,000 amps, 1,200 amps, and 1,200 amps
Linear LED fixtures are used to illuminate focal points of the exterior
Linear 28W T5 fluorescent luminaires stretch 174 feet

Structural

Steel structure on top of a concrete foundation.
Typical 20' x 20' bays
Variable weight W14 steel columns are typically used
66' -100' piles support a typical 2 way 10" slab resting on top of a grade beam system
Lateral forces are resisted by braced frames on the exterior of the building

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ACKNOWLEDGEMENTS

I would like to thank the many individuals who made this thesis possible.

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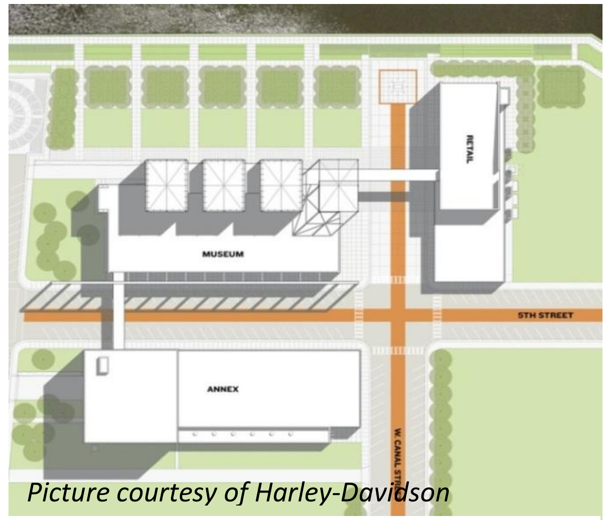
Dr. William Bahnfleth	Faculty Advisor, AE Professor, Penn State
Dr. Jelena Srebric	AE Mechanical Professor, Penn State
Dr. James Freihaut	AE Mechanical Associate Professor, Penn State
Mr. David Tran	Peer Consultant, Penn State AE Structural Option, BAE/MS

Family and friends for their support

Executive Summary

This thesis report was conducted on the Harley-Davidson Museum (HDM) 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; furthermore, many of the interior areas did not permit ductwork to be visible which created a challenge for the engineers at Hammel, Green and Abrahamson, Inc (HGA).



Picture courtesy of Harley-Davidson

Figure 1 – Site Plan

This thesis report discusses the topics, methods, and results that were investigated during a two semester study on the HDM. Investigations of the HDM existing design were conducted in the fall semester. The objective of the existing design investigation was to find areas that could be studied further in the spring semester and develop engineering and architectural design alternatives that prove to be more effective and efficient both economically and environmentally while being economically affordable. The spring semester was dedicated to the alternative analysis and extracting information from the study to form an in-depth thesis on building design and engineering.

This thesis is comprised of a three part depth analysis of the HDM mechanical systems and two breadth topics focused on electrical and structural engineering. The mechanical depth is an investigation into potential advantages of switching the existing air-cooled chilled water system to a water-cooled chilled water system. The study looks into two water-cooled alternatives. The first alternative is a conventional water-cooled system that utilizes a cooling tower as the means of heat rejection. The second alternative utilizes the river as the means of heat rejection.

In addition to the redesign of the mechanical system, two breadth studies were also conducted. The first breadth is an investigation on the application of on-site energy production and waste heat recovery, also known as combined heat and power or cogeneration. The study will investigate the feasibility of cogeneration at the Harley-Davidson Museum facility and will investigate the electrical design consideration such as the paralleled generator and utility connection.

The second breadth is an investigation of thermal bridging through the structural system. The structural system is currently designed with many areas of significant thermal bridging that could lead to wasted energy and mold growth. This breadth examines the benefits of implementing thermal breaks in the structural system compared to the existing solution of using heat trace. The thermal break will be investigated both thermally and structurally to determine if it is an adequate solution to the thermal bridging problem.

The following are main points determined from this thesis:

- Mechanical Depth
  - Air-Cooled vs. Water-Cooled with Cooling Tower
    - Annual operating cost reduced by 5% [$7,159.00]
    - 30 year LCC reduced 5% [$184,814.00]
    - Capital cost reduced 8% [$42,855.00]
  - Air-Cooled vs. Water-Cooled with River Water
    - Annual operating cost reduced by 14% [$21,732.00]
    - 30 year LCC reduced 10% [$389,986.00]
    - Capital cost increased 10% [$61,400.00]
    - Simple Payback 3 years
- Electrical Breadth
  - CHP Proven to be Feasible
    - Annual Savings of $140,000
    - CO_2 reduction of 62%
    - Simple payback of 4.04 years
- Structural Breadth
  - Thermal break proven to support structural loads
  - Thermal break proven to be a successful solution to thermal bridging
    - Annual savings of $1,271.00 in main gallery space

Section One Thesis Background

This section is an overview of information acquired throughout the fall semester of 2011 and project background information applicable to thesis research.

1.1 Project Background

HGA worked with Pentagram Architecture to transform an underutilized site with environmental and geotechnical challenges in to an award winning Museum for Harley-Davidson that attracts 350,000 visitors annually. The museum serves as a catalyst for redevelopment of the old historical warehouse neighborhood. Suitably located in Milwaukee, a city built around manufacturing, the design of the Museum was inspired by factories. The style of architecture is industrial, yet refined, particularly appropriate to which it reflects the character of Harley-Davidson. An honest architectural palette of steel, brick, and glass creates a straightforward understanding of the building's form and reveals the reality behind its unique aesthetic.

Careful consideration went in to the design to properly reflect the industrial character of Harley-Davidson. The layout of the Museum was designed to follow a chronological path. The use of motorcycles, posters, film clips, and interactive displays form a narrative of the history of Harley-Davison from its founding to the present. Encompassing a 20 acre site, this project creates an additional amenity on the riverfront for the public by creating five acres of terrace and park space on the 20 acre site.

The Harley-Davidson Museum's façade is comprised of brick metal and glass. Ebony black matte field brick covers the majority of the façade on all three buildings in the museum complex. Larger areas not covered by brick utilize a pre-fabricated, field assembled, curtain wall. The curtain wall is a high-rise aluminum thermally broken curtain wall framing system with windows and entrance framing systems designed to accept 1 inch of glazing material. Harley-Davidson's colors of gray, orange, and black, were applied in the design and application of the curtain wall system. Extruded bars give the curtain wall texture. Exterior aluminum decorative louvers are used to conceal rooftop mechanical systems.

All three buildings making up the Harley-Davidson Museum have a roofing system comprised of fully adhered thermoplastic single ply membrane over tapered insulation and vapor retarder on metal decking. The roof deck is 3" 20 gage galvanized steel.

Careful consideration went in to making the Harley-Davidson Museum sustainable without compromising the architectural integrity. A study was conducted on solar angles to minimize the amount of solar radiation entering the Museum. Automatic louvers open and close according to the amount of sun entering the building. Extended overhangs over the windows block the sun during the hottest times of the day and year. It was important for the architects to preserve as much of the site as possible. Two water towers from the existing site were preserved and serve as architectural focal points instead of filling up a landfill. Local vegetation was planted to minimize excess watering. The river walk was preserved creating a sense of community next to the river. The river walk also serves as an alternate carbon free way to travel to and from the Museum.

1.2 Existing Mechanical Systems Summary

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.

The heating water system consists of four 2000MBH sealed combustion condensing boilers with gas fired burners. The heating water system distribution is a variable-primary pumping system. Primary pumps are 386 GPM, 25 HP, variable speed, end suction base mounted type. One pump is used for stand-by. Variable speed pumps have dedicated variable speed drive controllers. This heating system provides hot water heat to air handling unit hot water coils, variable air volume box reheat coils, hot water finned tube radiation, unit heaters, and similar devices throughout the building.

The cooling plant consists of 2 roof mounted 300 ton air cooled rotary screw chillers and utilize R134A refrigerant. The chillers have variable speed drive control. A variable-primary pumping system with 747 GPM, 125 HP, and variable speed end suction base mounted type is utilized. The chilled water system uses a 35 percent glycol solution for freeze protection.

Hydronic piping distribution systems throughout the building are schedule 40 steel pipe through 10 inches and standard weight for pipe sizes 12 inches and larger. Welded joints for 3 inch and larger pipe sizes and threaded joints for 2-1/2 inch and smaller pipe sizes were preferred. Hard drawn copper pipe was acceptable for pipe sizes 1 inch and smaller.

1.3 Existing Energy Load and Emissions Summary

This section evaluates the HVAC loads, energy consumption, utility cost, and emissions of the Harley-Davidson Museum. An in-depth analysis in these four areas is a helpful forecast as to how the building will perform once built. It can also be used by building designers to compare design alternatives to create a more efficient, affective, healthy, and comfortable building. In this case, the analysis was done to survey the existing conditions of the newly built building as it stands today.

A comprehensive load and energy model was created using the computer simulation program Trane TRACE 700. The calculated HVAC loads were then compared to the construction documents and design information provided by HGA. Energy consumption and operating costs were compared to actual monthly energy data and utility bills provided by Harley-Davidson. The 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 15,466,022 kBTU and has a CO_2 global warming potential equivalent annual emission rate of over 9 million pounds. 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 of the existing built environment and can be used to compare the designed thesis alternatives. The following subsection provides details of the energy model.

1.3.1 Energy Model

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.

Design Conditions:

The Harley-Davidson Museum is classified as nonresidential conditioned space located in Milwaukee, WI, corresponding to the cold-humid 6a climate zone determined by Figure/Table B-1 located in ASHRAE 90.1.2007. Weather data was selected in TRACE to correspond with ASHRAE weather conditions for Milwaukee. The Engineers at HGA specifide one thermostat condition listed in Table 1

Table 1 - Thermostat

Typical Thermostat Parameter	
Cooling Dry Bulb (°F)	75
Heating Dry Bulb (°F)	72
Relative Humidity %	50
Cooling Drift point	85
Heating Drift point	55

Model Design:

Zones were separated on a room by room basis because of the contrasting separation of room characteristics. Each room was then classified using the assumptions below and the design documents provided by HGA. Large rooms were broken down into smaller rooms by separating exterior spaces from interior spaces. Rooms that are served by more than one system, for example the temporary exhibit space, was also separated into smaller rooms. Rooms were then assigned to a system which were designed in accordance to the construction documents and assigned to the modeled heating and cooling plants. The plants were also modeled from the information in the construction documents and are described above in the mechanical summary.

Load Assumptions:

The information used to develop the TRACE model of the Harley-Davidson Museum was taken from the construction documents, specifications, and relevant design calculations supplied by the engineers at HGA. When information was not found in the above information ASHRAE standards of design were used.

Occupancy Assumptions:

The number of occupants per space for the Harley-Davidson Museum was taken from occupancy calculations provided by the architects at HGA. When consulting with ASHRAE 62.1.2007

Table 6-1, the designed occupant density (Sq Ft/person) is 6 square feet per person lower than the standard. The higher occupancy density will create a higher refrigeration density and latent load, discussed more in the calculated load vs. designed load section of this section.

Ventilation Assumptions:

The engineers at HGA designed the Harley-Davidson Museum to have a ventilation rate of 7.5 CFM/person. This ventilation rate was used in the model for all typical occupied spaces except for the kitchen which was modeled with 100% outside air. Infiltration was assumed to be 0.3 air changes/hr. which corresponds to a neutral tight construction in TRACE.

Lighting and Equipment Electrical Load Assumptions:

A lighting fixture schedule was available for this analysis; however, many of the exhibits have lighting not listed in the schedule. Lighting load information for the model was taken from calculations provided by the engineers at HGA for cooling load. Table 3 shows typical lighting densities compared to lighting densities in table 9.6.1 of ASHRAE standard 90.1.2007. All lighting densities used in the model are higher than the standards set forth by ASHRAE. This will result in higher energy usage and higher cooling load compared to standards.

Equipment and electrical loads were also taken from data supplied by the engineers at HGA. These loads were considered to be miscellaneous loads in the model and were entered in space by space. Many of the exhibits add a considerable load to the space and were also listed space by space as miscellaneous loads. Typical Miscellaneous loads are listed below; however, each of the 142 spaces varied from the information in Table 2.

Table 3 – Lighting Densities

Lighting Densities		
Space	**Design**	**ASHRAE**
	W/ sq ft	W/ sq ft
Exhibit	4	1
Rent Space	1.5	1.1
Retail	2.2	1.7
Offices	1.5	1.1
Shop	2.5	1.9
Storage	1	0.8

Table 2 - Misc. Loads

Example Misc. Power Densities		
	W/ sq ft	Mbh
Security	5	-
Office	1.5	-
Rent Space	1.5	-
Exhibits	30.7	0-40.8
Kitchen	5	-
Electrical	-	49.8

Construction:

The Harley-Davidson Museum is designed with four major wall types and one roof type and summarized in Table 4. Information used in the construction templates were taken from construction documents and specifications provided by the architects and engineers at HGA.

Table 4 - Construction Heat transfer Values

Construction Summary		
	U-factor	Shading Coeff.
Wall 1	0.092207	-
Wall 2	0.086685	-
Wall 3	0.088577	-
Wall 4,7,8	0.096145	
Fenestration	-	0.57
Roof	0.044658	-

Schedules:

There are 22 different schedules used in the TRACE model: seven for lighting, eight for miscellaneous loads, and seven for people. Cooling schedules assumed 100% utilization for lights, people, and miscellaneous loads and heating schedules assumed 0% utilization. This was done to reflect worse case scenarios. All other schedules provide reasonable assumptions to the operation and utilization of lighting, miscellaneous power, and occupant loads, which will properly reflect actual energy consumption. Schedules were designed to reflect actual operation and utilization of each space in the building. Detailed schedules are in Appendix C of Technical Report 2.

Calculated Load vs. Design Load Analysis:

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 5, was compared with the calculated load from TRACE.

Table 5 - 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 (discussed above in occupancy assumptions). Light density is also considerably higher than the density found in the ASHRAE pocket guide. This is most likely due 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 also match the designed values and are illustrated in Table 6 for comparison. The modeled peak heating plant load also falls in a reasonable range to the designed MBh and is illustrated in Table 7.

Table 6 - Cooling Load Comparison

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 7 – Heating Load Comparison

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 9 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 9 - 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.

Collectively 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.

1.3.2 Existing Facility Energy

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.

Table 10 below is a breakdown of energy consumption calculated from the TRACE energy model. Figure 2 and Figure 3 illustrates the data in Table 10 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 14% of the building's energy and 10% 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.

Table 10 - Energy Consumption

Energy Consumption Summary Air Cooled				
	Elec Cons.	**Gas Cons.**	**Total Building Energy**	**Total Source Energy**
	kWh	kBtu	kBtu/yr	kBtu/yr
Primary Heating	3,614	3,773,631	3,785,965	4,009,250
Primary Cooling	622,235		2,123,688	6,371,700
Auxiliary	631,848		2,156,499	6,470,143
Lighting	1,509,076		5,150,476	15,452,973
Receptacle	659,066		2,249,394	6,748,855
Total	3,425,839	3,773,631	15,466,022	39,052,921

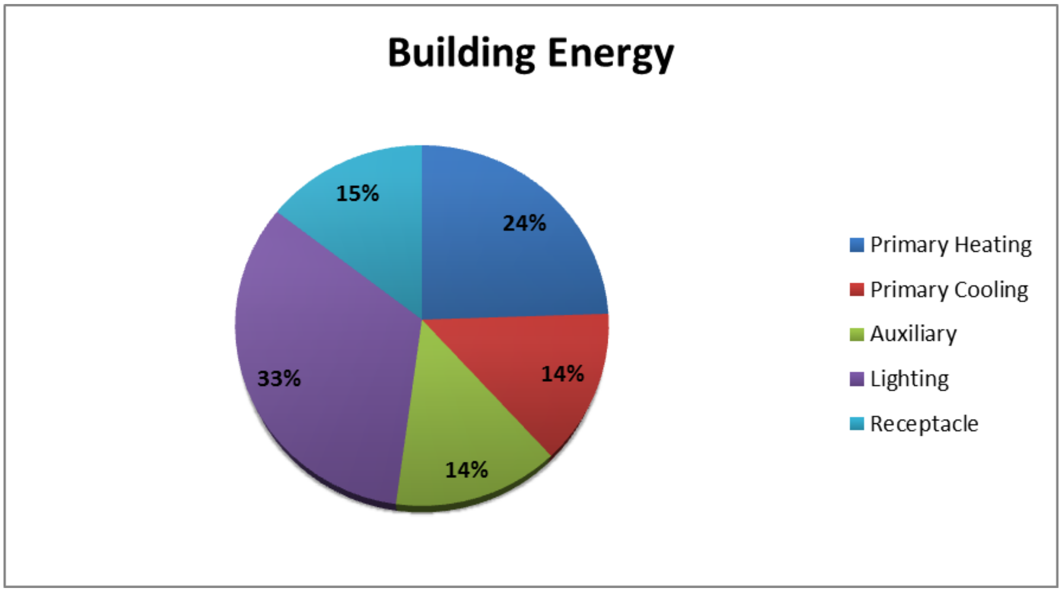


Figure 2 – Building Energy Breakdown

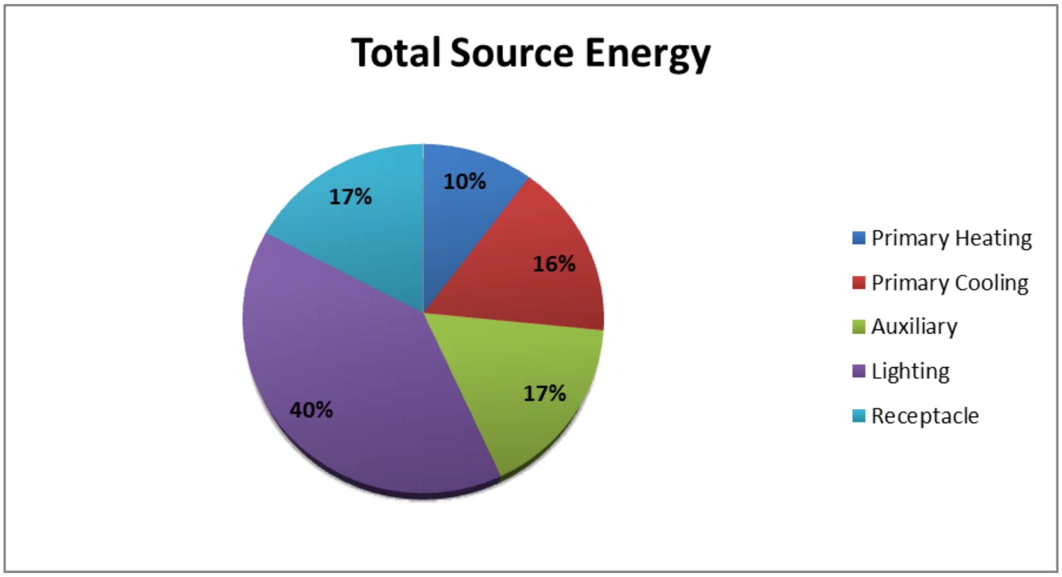


Figure 3– Building Total Source Energy Breakdown

Energy Comparison:

Figure 4 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 5 shows the actual monthly electricity used with actual temperatures for each month. Figure 6 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.

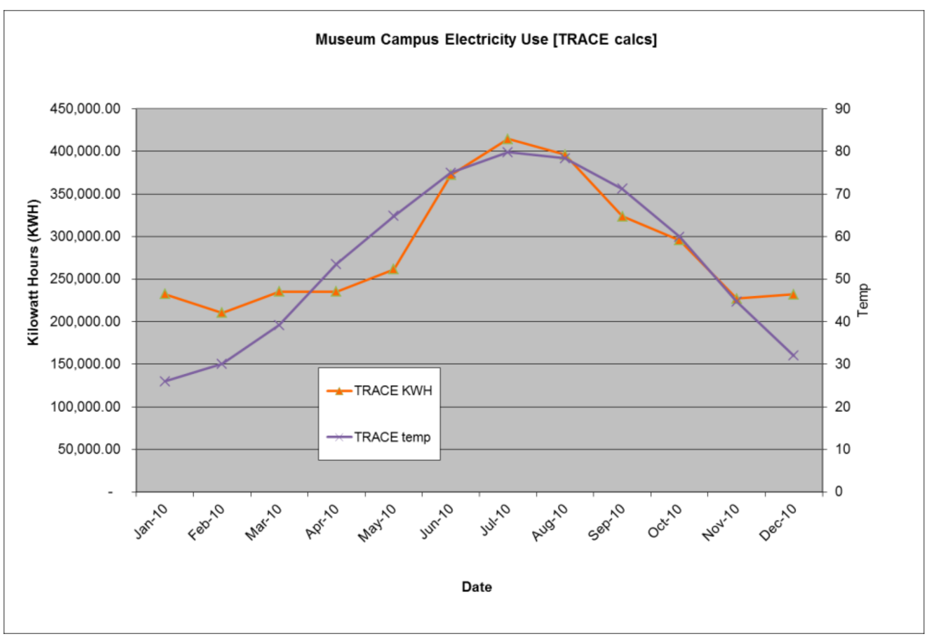


Figure 4- TRACE Electricity Use

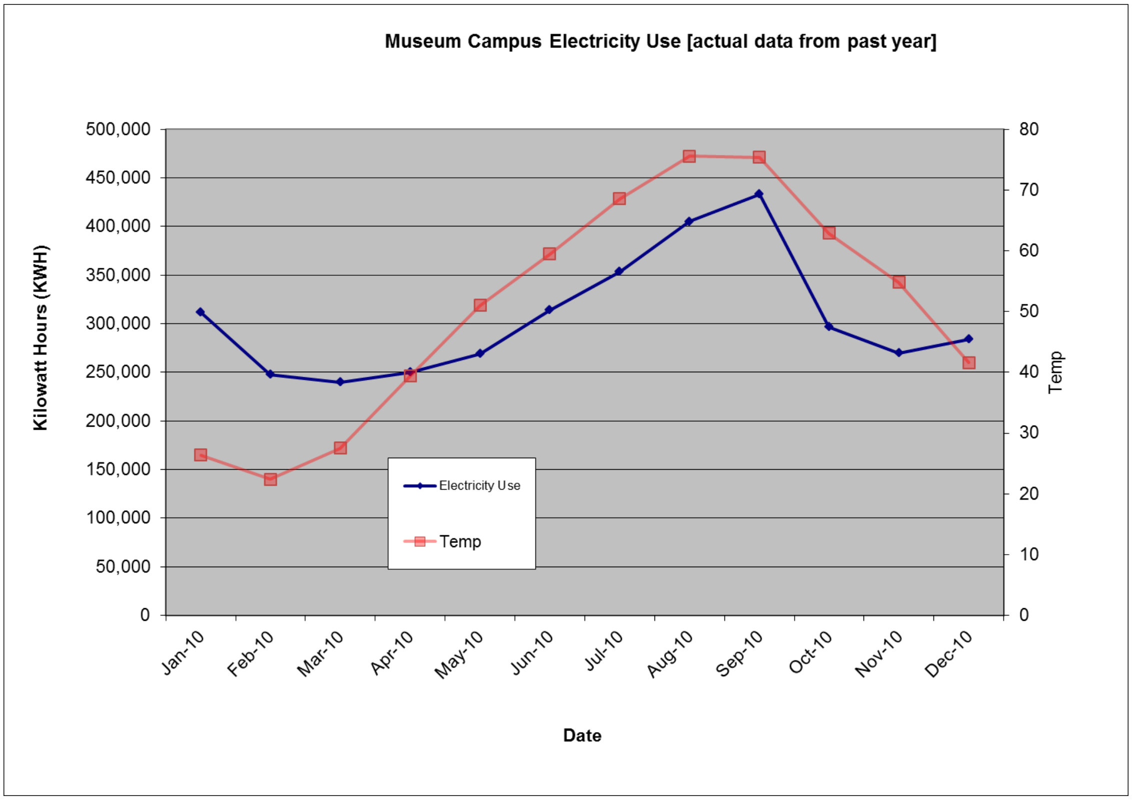


Figure 5 – Actual Museum Electricity Usage

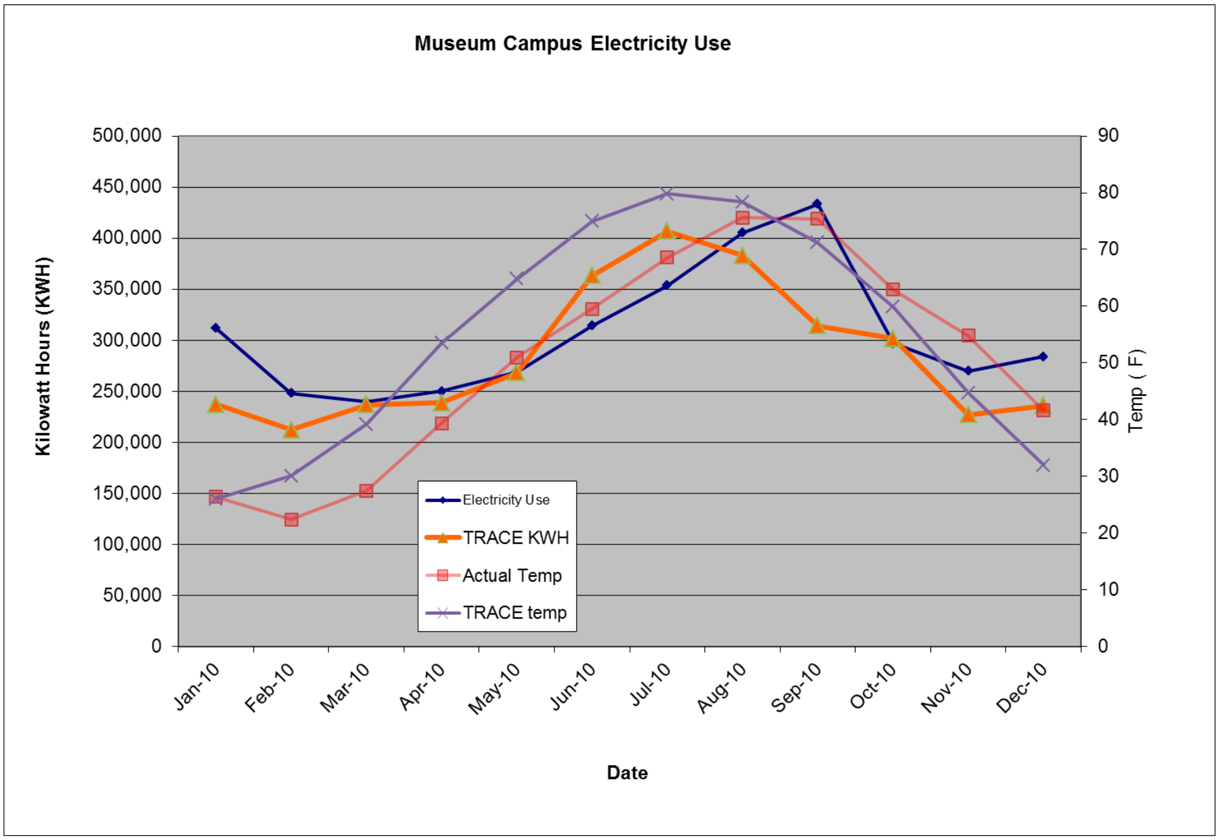


Figure 6 – Comparison of Model to Actual Energy Usage

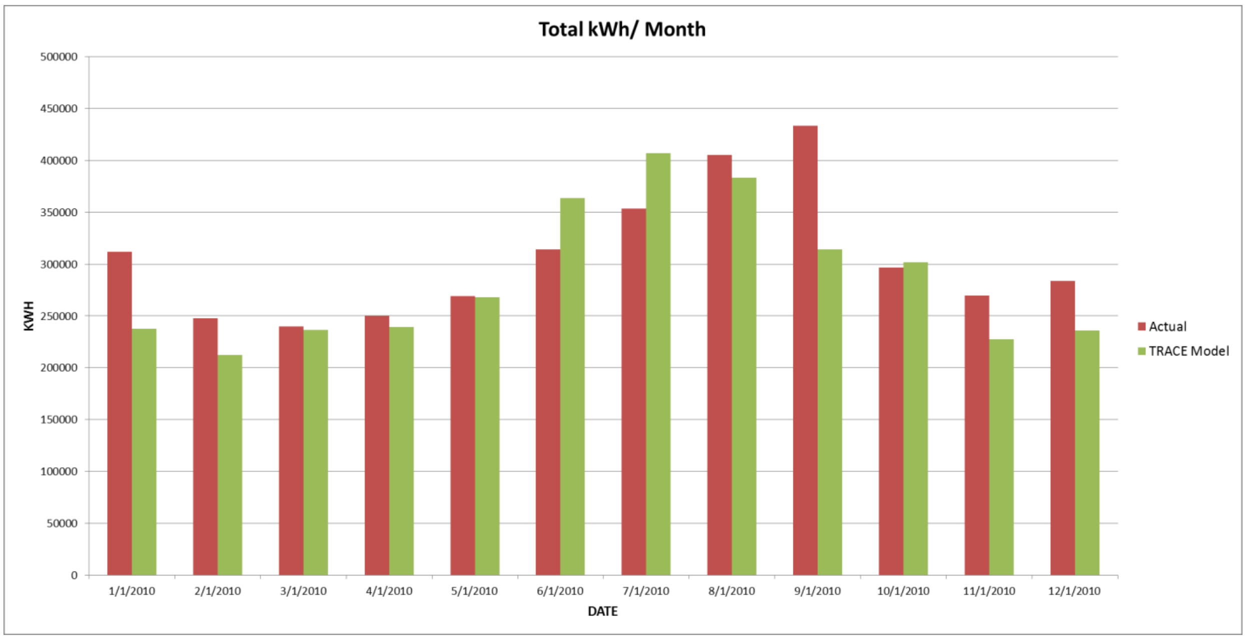


Figure 7 – Summary of Total kWh/ Month for Actual Data vs. Modeled Data

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 11 is significantly lower than the actual data provided by Harley-Davidson.

Table 11- Natural Gas Modeled Therms and Actual Therms

Natural Gas				
Month	**Actual Therms**	**Temp**	**Model Therms**	**%Δ**
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 8 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.

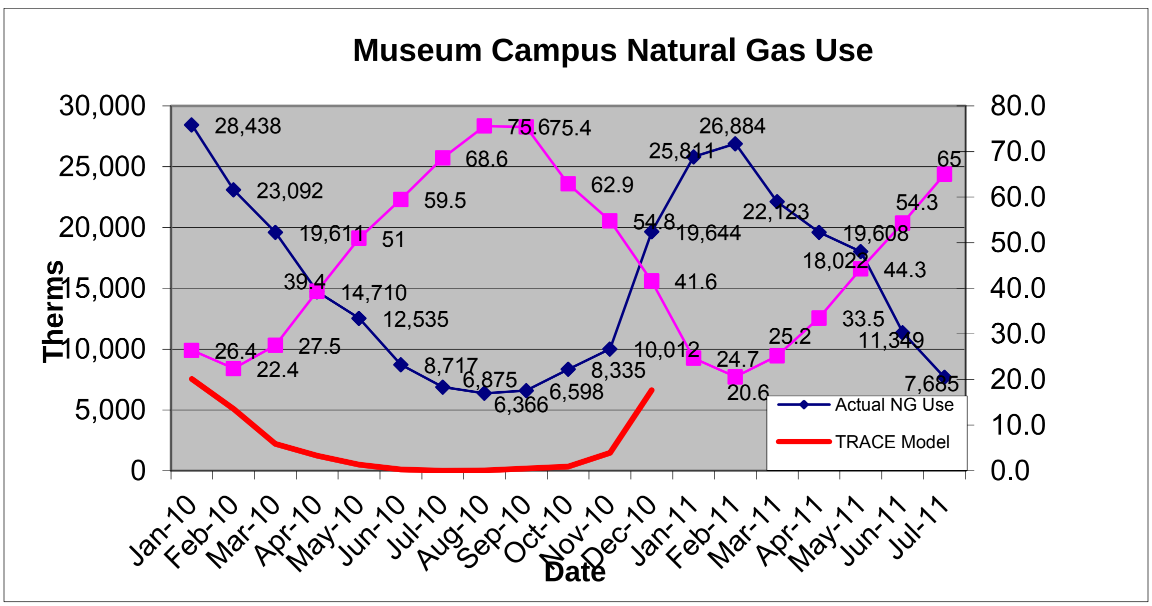


Figure 8 – Natural Gas Monthly Profile: Actual vs. Model

1.3.3 Existing Facility Economics

Cost Analysis:

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 9 and Figure 10. An electric demand of $10.00/kW was used in the Model. This rate structure seamed high and in Table 12 and Figure 11 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 $0.10/kW. This more closely matched the actual cost and are 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 $0.10/kW 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, shown in Table 14. 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.

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 9 – WE Energy Level 3 Rates

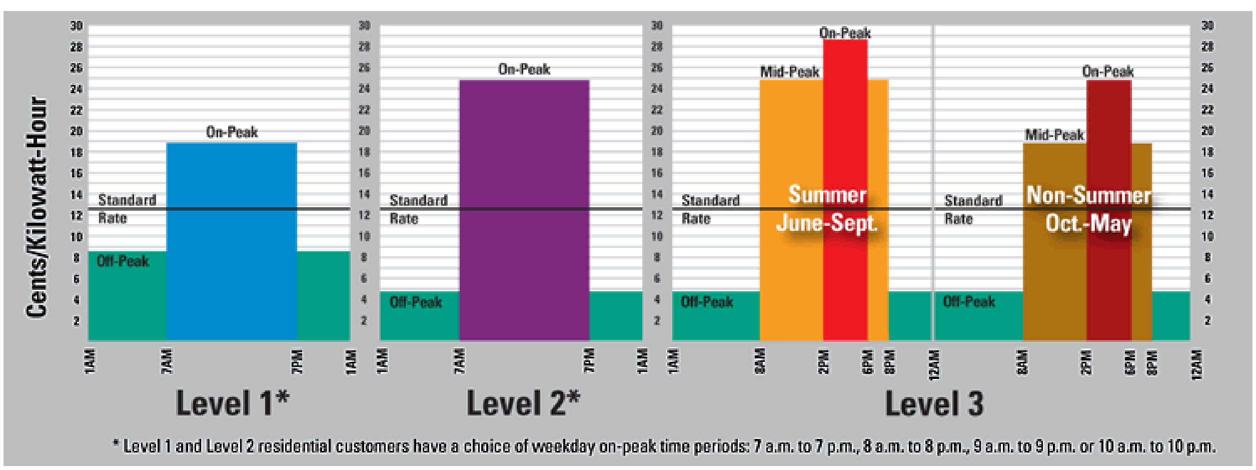


Figure 10 – WE Energy Rate Structures

Table 12 - Electricity Cost Comparison

Monthly Utility Cost Comparison								
	Museum	Annex	Retail	Actual Total	TRACE Model: WE Energy	TRACE kwh	TRACE $0.10/kwh	Standard TRACE built in Rates
January	$10,471.91	$8,814.67	$6,472.96	$25,759.54	$72,078.00	237,312.00	$ 23,731.20	-
February	$9,139.90	$7,631.74	$5,369.61	$22,141.25	$65,763.00	212,336.00	$ 21,233.60	-
March	$10,135.52	$6,851.84	$5,502.33	$22,489.69	$73,075.00	236,644.00	$ 23,664.40	-
April	$13,077.00	$5,894.36	$5,747.06	$24,718.42	$74,113.00	239,000.00	$ 23,900.00	-
May	$14,538.80	$5,684.21	$5,842.70	$26,065.71	$84,401.00	268,109.00	$ 26,810.90	-
June	$18,488.35	$5,429.63	$6,077.33	$29,995.31	$119,612.00	363,430.00	$ 36,343.00	-
July	$24,193.01	$4,756.08	$5,839.81	$34,788.90	$132,494.00	406,823.00	$ 40,682.30	-
August	$26,438.25	$4,586.95	$6,238.63	$37,263.83	$126,447.00	383,074.00	$ 38,307.40	-
September	$28,070.69	$5,133.51	$6,668.10	$39,872.30	$104,643.00	314,100.00	$ 31,410.00	-
October	$18,543.28	$4,773.60	$5,994.65	$29,311.53	$84,199.00	301,769.00	$ 30,176.90	-
November	$15,504.32	$4,900.71	$5,823.11	$26,228.14	$61,927.00	227,332.00	$ 22,733.20	-
December	$13,594.81	$6,769.54	$6,626.98	$26,991.33	$62,696.00	235,909.00	$ 23,590.90	-
			Total:	$345,625.95	$1,061,448.00		$342,583.80	$ 242,463.00

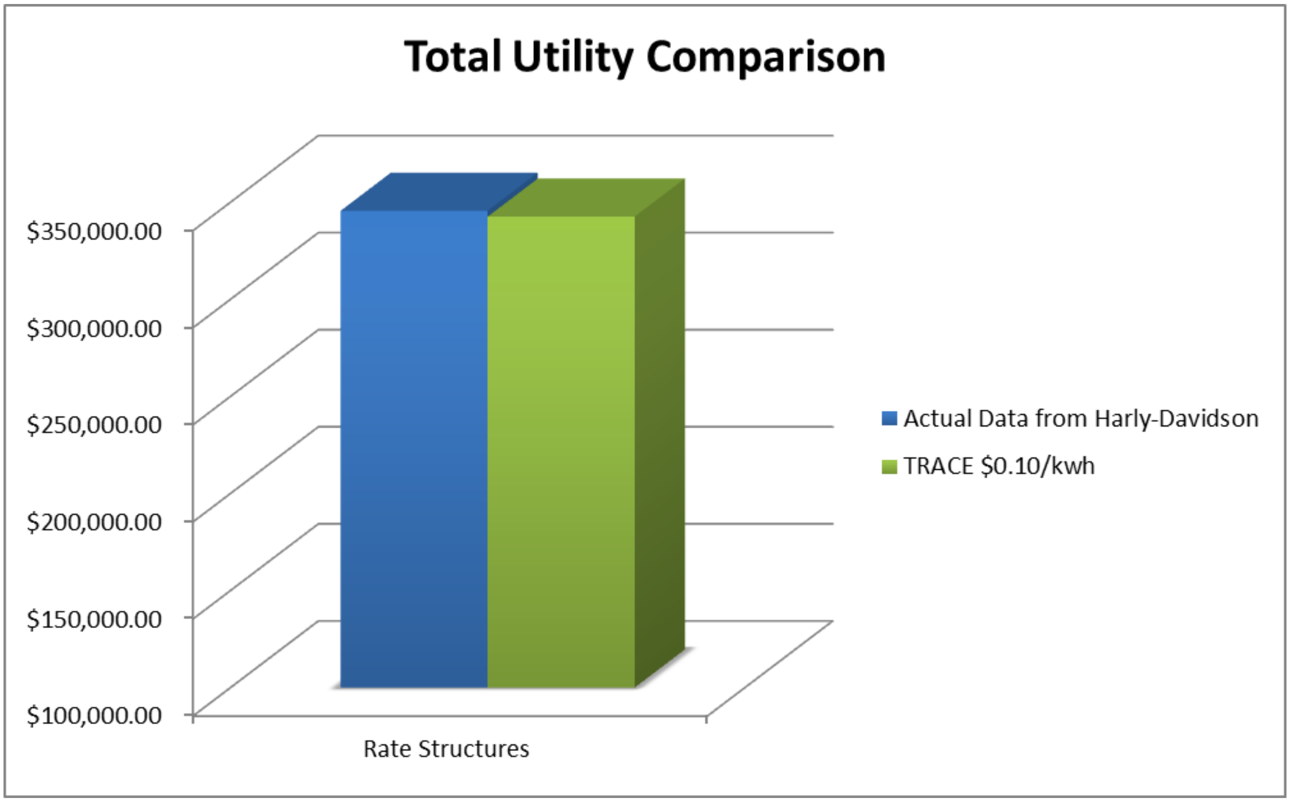


Figure 11 – Electricity Utility Rate Comparison

Table 13 - Natural Gas

Cost of Natural Gas			
Month	Model Therms	Price $/ Therm	$
1/11/2010	7540.00	0.80	$ 6,032.00
2/8/2010	5077.00	0.80	$ 4,061.60
3/9/2010	2212.00	0.80	$ 1,769.60
4/9/2010	1223.00	0.80	$ 978.40
5/10/2010	489.00	0.80	$ 391.20
6/10/2010	108.00	0.80	$ 86.40
7/8/2010	9.00	0.80	$ 7.20
8/6/2010	26.00	0.80	$ 20.80
9/8/2010	191.00	0.80	$ 152.80
10/6/2010	347.00	0.80	$ 277.60
11/5/2010	1481.00	0.80	$ 1,184.80
12/8/2010	6612.00	0.80	$ 5,289.60
Total:	25315.00	0.80	$ 20,252.00

The overall utility cost per area was calculated to be $2.14 per square foot and is broken down in Table 14 and Figure 12. 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 2. This is largely due to the fact that primary heating is only 10% when converted to source energy.

Table 14 – Cost Breakdown

Cost Breakdown	
	Cost
Primary Heating	$ 20,252.00
Primary Cooling	$ 62,223.50
Auxiliary	$ 63,184.80
Lighting	$ 150,907.60
Receptacle	$ 65,906.60

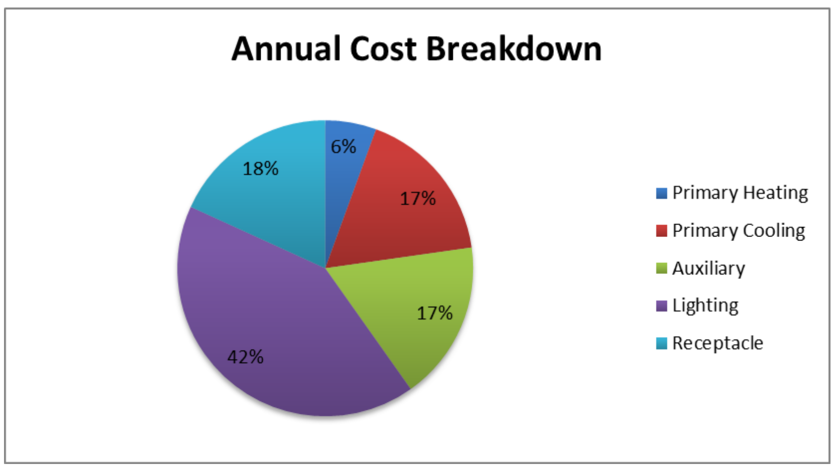


Figure 12 – Percentage Cost Breakdown

1.3.4 Existing Facility Emissions

Emissions from the energy use within the Harley-Davidson Museum were calculated using emission factors from the Regional Grid Emissions Factors 2007 database and are listed in Table 15 and Table 16. Actual natural gas data from Harley-Davidson was used along with the modeled natural gas values because the modeled natural gas was considerably lower than actually used by the building.

Total CO_2 equivalent is a quantity that defines the amount of CO_2 that would have the same global warming potential for a given mixture of pollutants. The CO_2 equivalent was calculated to be over 9 million pounds annually. 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.

Figures 15 and 16 illustrates the amount of each pollutant produced by electricity production, on-site natural gas combustion, and precombustion activities, such as extracting and transportation of fuel. It is clear that the greatest pollutant produced is CO_2 and is mostly emitted through the process of generating electricity. This is because most of the energy demand in the building is serviced by electricity and most of the electricity is from subbituminous and bituminous coal burning power plants shown in Figure 13.

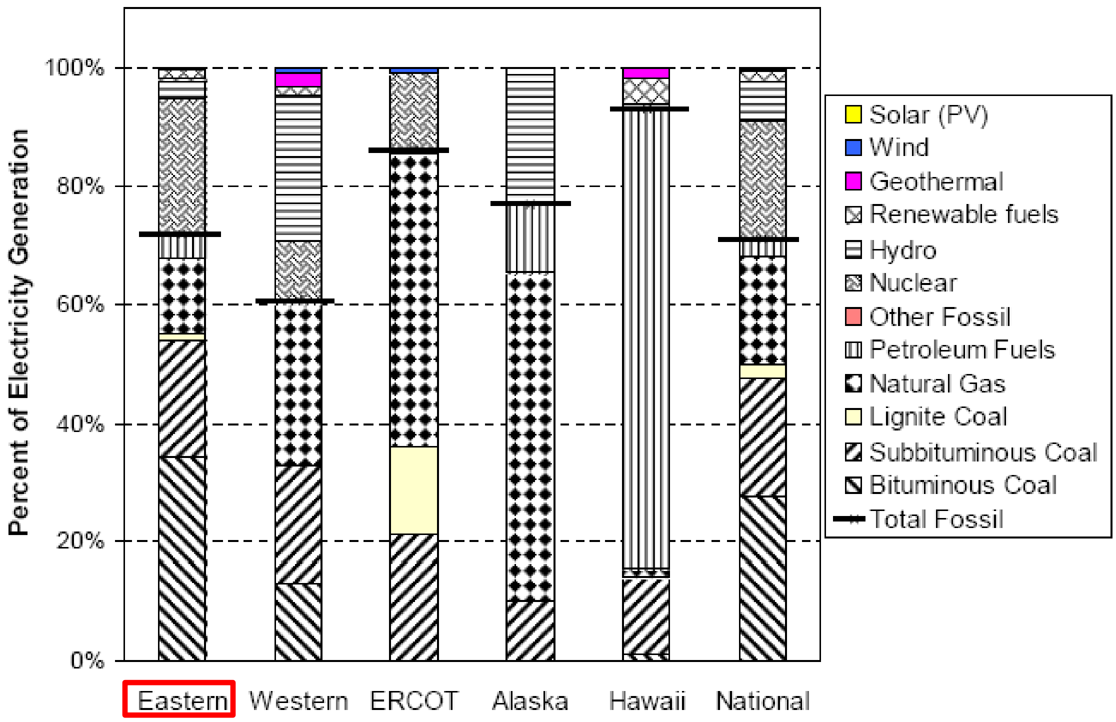


Figure 13 - – Electricity generation fuel mix for the continental United States from the Regional Grid Emission Factors 2007 database.

Table 15 - Emissions

Harley-Davidson Museum Emission Table												
	Electric			On-Site Combustion- Modeled Natural Gas				On-Site Combustion- Actual Natural Gas			Total	
	Factor	Elec.	Mass of Pollutant	Factor	Gas	Gas	Mass of Pollutant	Gas	Gas	Mass of Pollutant	Model	**w/ Actual Gas Usage
Pollutant	lb / kWh	kWh	lb	lb / 1000 ft^3	therms	1000 ft^3	lb	therms	1000 ft^3	lb	lb	lb
CO^2e	2.03E+00	3,438,613.00	6.98E+06	1.23E+02	37,736.00	3,773.60	4.6E+05	164,933.00	16,493.30	2,028,675.90	7.44E+06	9.01E+06
CO^2	1.92E+00	3,438,613.00	6.60E+06	1.22E+02	37,736.00	3,773.60	4.6E+05	164,933.00	16,493.30	2,012,182.60	7.06E+06	8.61E+06
CH4	4.13E-03	3,438,613.00	1.42E+04	2.50E-03	37,736.00	3,773.60	9.4E+00	164,933.00	16,493.30	41.23	1.42E+04	1.42E+04
N2O	5.32E-05	3,438,613.00	1.83E+02	2.50E-03	37,736.00	3,773.60	9.4E+00	164,933.00	16,493.30	41.23	1.92E+02	2.24E+02
NOx	3.51E-03	3,438,613.00	1.21E+04	1.11E-01	37,736.00	3,773.60	4.2E+02	164,933.00	16,493.30	1,830.76	1.25E+04	1.39E+04
SOx	6.60E-03	3,438,613.00	2.27E+04	6.32E-04	37,736.00	3,773.60	2.4E+00	164,933.00	16,493.30	10.42	2.27E+04	2.27E+04
CO	7.13E-04	3,438,613.00	2.45E+03	9.33E-02	37,736.00	3,773.60	3.5E+02	164,933.00	16,493.30	1,538.82	2.80E+03	3.99E+03
TNMOC	8.26E-05	3,438,613.00	2.84E+02	-	37,736.00	3,773.60	-	164,933.00	16,493.30	-	2.84E+02	2.84E+02
Lead	1.97E-07	3,438,613.00	6.77E-01	5.00E-07	37,736.00	3,773.60	1.9E-03	164,933.00	16,493.30	0.01	6.79E-01	6.86E-01
Mercury	4.01E-08	3,438,613.00	1.38E-01	2.60E-07	37,736.00	3,773.60	9.8E-04	164,933.00	16,493.30	0.00	1.39E-01	1.42E-01
PM10	1.11E-04	3,438,613.00	3.82E+02	8.40E-03	37,736.00	3,773.60	3.2E+01	164,933.00	16,493.30	138.54	4.13E+02	5.20E+02
Solid Waste	3.03E-01	3,438,613.00	1.04E+06	-	37,736.00	3,773.60	-	164,933.00	16,493.30	-	1.04E+06	1.04E+06
VOC	-	-	-	6.13E-03	37,736.00	3,773.60	2.3E+01	164,933.00	16,493.30	101.10	2.31E+01	1.01E+02
		Model	**w/ Actual Gas Usage									
	*Total CO2e (lb):	7.44E+06	9.01E+06				Factors taken from the Regional Grid Emission Factors 2007, Table B-10					

* used to evaluate global warming potential

** Actual Gas used because gas calculations were lower than actual data

Table 16 – Precombustion Emissions

Precombustion Emission							
	Modeled Natural Gas			Actual Natural Gas		Electic + Gas	
	Factor	Gas	Mass of Pollutant	Gas	Mass of Pollutant	Model	**w/ Actual Gas Usage
Pollutant	lb / 1000 ft^3	1000 ft^3	lb	1000 ft^3	lb	lb	lb
CO^2e	2.78E+01	3,773.60	1.05E+05	1.65E+04	4.59E+05	7.09E+06	7.44E+06
CO^2	1.16E+01	3,773.60	4.38E+04	1.65E+04	1.91E+05	6.65E+06	6.79E+06
CH4	7.04E-01	3,773.60	2.66E+03	1.65E+04	1.16E+04	1.69E+04	2.58E+04
N2O	2.35E-04	3,773.60	8.87E-01	1.65E+04	3.88E+00	1.84E+02	1.87E+02
NOx	1.64E-02	3,773.60	6.19E+01	1.65E+04	2.70E+02	1.21E+04	1.23E+04
SOx	1.22E+00	3,773.60	4.60E+03	1.65E+04	2.01E+04	2.73E+04	4.28E+04
CO	1.36E-02	3,773.60	5.13E+01	1.65E+04	2.24E+02	2.50E+03	2.68E+03
TNMOC	4.56E-05	3,773.60	1.72E-01	1.65E+04	7.52E-01	2.84E+02	2.85E+02
Lead	2.41E-07	3,773.60	9.09E-04	1.65E+04	3.97E-03	6.78E-01	6.81E-01
Mercury	5.51E-08	3,773.60	2.08E-04	1.65E+04	9.09E-04	1.38E-01	1.39E-01
PM10	8.17E-04	3,773.60	3.08E+00	1.65E+04	1.35E+01	3.85E+02	3.95E+02
Solid Waste	1.60E+00	3,773.60	6.04E+03	1.65E+04	2.64E+04	1.05E+06	1.07E+06
VOC	-	-	-	-	-	-	-
	Factors taken from the regional Grid Emission factors 2007, Table 6						

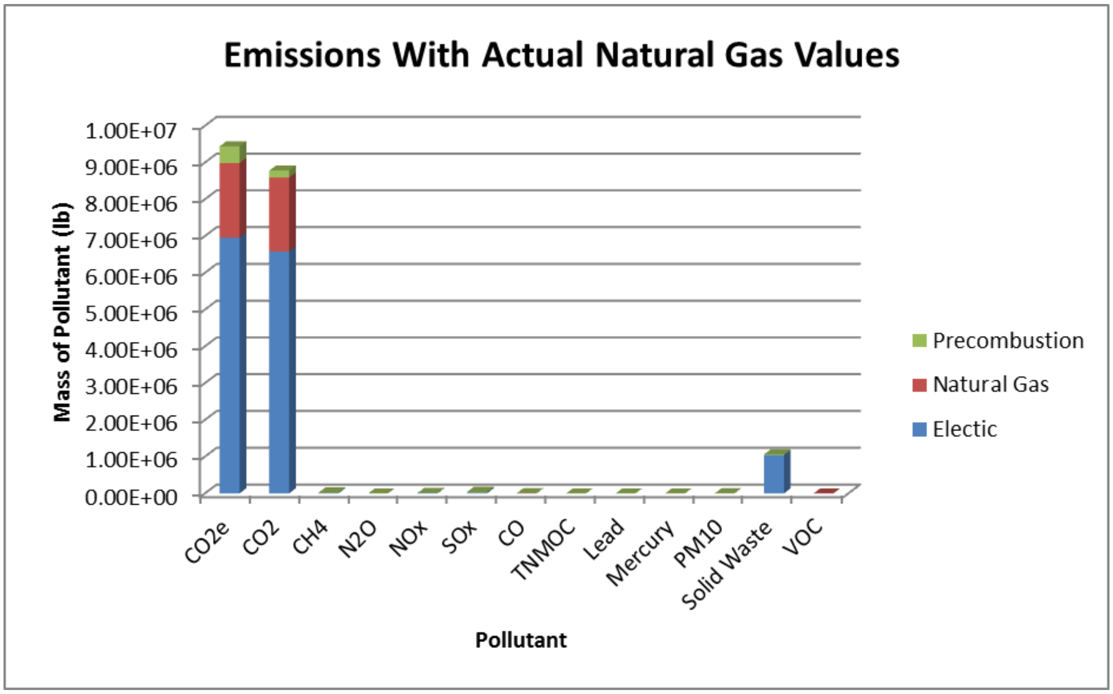


Figure 14 - Emissions without CO_2

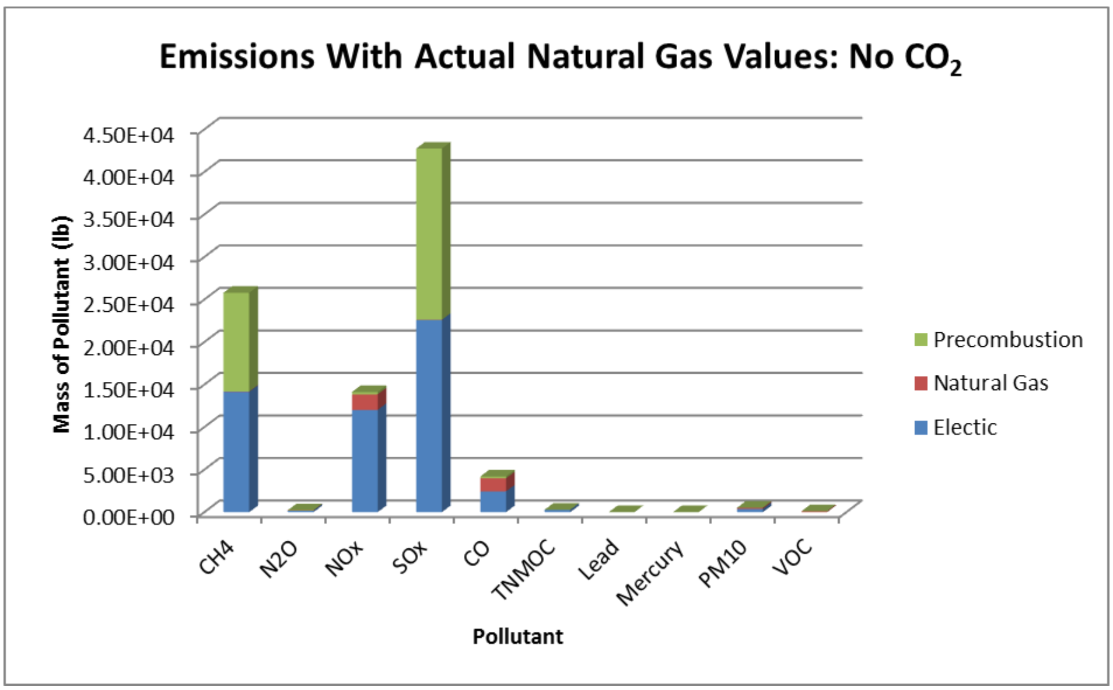


Figure 15 – Emissions with CO_2

1.4 LEED Evaluation

The U.S. Green Building Council developed LEED, or Leadership in Energy and Environmental Design, in 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 and is outlined in Figure 16 and detailed in Appendix B. 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.

LEED 2009 for New Construction and Major Renovations

Project Checklist

HARLEY-DAVIDSON MUSEUM

NOV, 2012

Y	?	N		Sustainable Sites	Possible Points: 26
15		11			
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

Y	?	N		Water Efficiency	Possible Points: 10
		12			
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

Y	?	N		Energy and Atmosphere	Possible Points: 35
5	2	28			
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

Y	?	N		Materials and Resources	Possible Points: 14
	2	13			
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

Y	?	N		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

Y	?	N		Indoor Environmental Quality	Possible Points: 15
6	3	6			
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

Y	?	N		Innovation and Design Process	Possible Points: 6
		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

Y	?	N		Regional Priority Credits	Possible Points: 4
		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

Y	?	N		Total	Possible Points: 110
26	7	80			

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

Figure 16 – LEED Checklist

1.5 Life Cycle Cost Economics

A 30 year life cycle cost (LCC) study was conducted on the existing chiller and boiler plant as a base for comparison of design alternatives. Discount rate and escalation factors were taken from the U.S. Department of Commerce technology administration, National Institute of Standards and Technology (NIST) Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis Annual Supplement. Capital Cost information was taken from RSMeans Mechanical Cost Date 2010 and consulted with design engineers at HGA and manufactures data. The capital cost used in the LCC study only includes variables which will change in the separate alternatives studied. The study detailed in Table 17 concluded over the span of 30 years, the net present value (NPV) of the expense to run and operate the HVAC system is $4,046,288.09.

Table 17 – LCC Analysis for Air-Cooled System

Alternative 1: Air-Cooled

	Elec	Water	Gas
	kWh	1000gal	therms
		-	-
Air Side	569,425.50	-	-
Water Side	683,862.00	-	-
Hot water	12,833.20	74.90	37,736.30
total	1,266,120.70	74.90	37,736.30
Price per unit	$ 0.10	$ 2.20	$ 0.80
Cost	**$ 126,612.07**	**$ 164.78**	**$ 30,189.04**

Capital **$ 550,000.00**

Economic Life	30	years
Overhaul	$ 15,000.00	every 7 years up tp 21
Maintenance	$ 5,000.00	per year
Discount Rate	2.3%	DR

Air Side = AHUs
Water Side = Chiller and CHW pump
Hot Water = Boiler and HW pump

Equipment	Price
AC Chiller 1	$ 215,000.00
AC Chiller 2	$ 215,000.00
4 Boilers	$ 120,000.00
Capital	$ 550,000.00

					Escalation			Cost			
Date	Year #	Capital	Maintenance	Overhaul	Electric	Natural Gas	Water	Electric	Natural Gas	Water	Total
2011	1	$ 550,000.00	$ 5,000.00	$ -	1	1	1	$ 126,612.07	$ 30,189.04	$ 164.78	$ 156,965.89
2012	2	$ -	$ 5,000.00	$ -	0.98	0.98	1	$ 124,079.83	$ 29,585.26	$ 164.78	$ 153,829.87
2013	3	$ -	$ 5,000.00	$ -	0.97	0.95	1	$ 122,813.71	$ 28,679.59	$ 164.78	$ 151,658.08
2014	4	$ -	$ 5,000.00	$ -	0.97	0.92	1	$ 122,813.71	$ 27,773.92	$ 164.78	$ 150,752.40
2015	5	$ -	$ 5,000.00	$ -	0.97	0.92	1	$ 122,813.71	$ 27,773.92	$ 164.78	$ 150,752.40
2016	6	$ -	$ 5,000.00	$ -	0.96	0.93	1	$ 121,547.59	$ 28,075.81	$ 164.78	$ 149,788.17
2017	7	$ -	$ 5,000.00	$ 15,000.00	0.95	0.94	1	$ 120,281.47	$ 28,377.70	$ 164.78	$ 148,823.94
2018	8	$ -	$ 5,000.00	$ -	0.94	0.95	1	$ 119,015.35	$ 28,679.59	$ 164.78	$ 147,859.71
2019	9	$ -	$ 5,000.00	$ -	0.94	0.97	1	$ 119,015.35	$ 29,283.37	$ 164.78	$ 148,463.49
2020	10	$ -	$ 5,000.00	$ -	0.93	1	1	$ 117,749.23	$ 30,189.04	$ 164.78	$ 148,103.05
2021	11	$ -	$ 5,000.00	$ -	0.93	1.02	1	$ 117,749.23	$ 30,792.82	$ 164.78	$ 148,706.83
2022	12	$ -	$ 5,000.00	$ -	0.92	1.04	1	$ 116,483.10	$ 31,396.60	$ 164.78	$ 148,044.49
2023	13	$ -	$ 5,000.00	$ -	0.92	1.06	1	$ 116,483.10	$ 32,000.38	$ 164.78	$ 148,648.27
2024	14	$ -	$ 5,000.00	$ 15,000.00	0.92	1.08	1	$ 116,483.10	$ 32,604.16	$ 164.78	$ 149,252.05
2025	15	$ -	$ 5,000.00	$ -	0.92	1.1	1	$ 116,483.10	$ 33,207.94	$ 164.78	$ 149,855.83
2026	16	$ -	$ 5,000.00	$ -	0.92	1.11	1	$ 116,483.10	$ 33,509.83	$ 164.78	$ 150,157.72
2027	17	$ -	$ 5,000.00	$ -	0.92	1.13	1	$ 116,483.10	$ 34,113.62	$ 164.78	$ 150,761.50
2028	18	$ -	$ 5,000.00	$ -	0.92	1.14	1	$ 116,483.10	$ 34,415.51	$ 164.78	$ 151,063.39
2029	19	$ -	$ 5,000.00	$ -	0.93	1.15	1	$ 117,749.23	$ 34,717.40	$ 164.78	$ 152,631.40
2030	20	$ -	$ 5,000.00	$ -	0.93	1.16	1	$ 117,749.23	$ 35,019.29	$ 164.78	$ 152,933.29
2031	21	$ -	$ 5,000.00	$ 15,000.00	0.93	1.17	1	$ 117,749.23	$ 35,321.18	$ 164.78	$ 153,235.18
2032	22	$ -	$ 5,000.00	$ -	0.93	1.18	1	$ 117,749.23	$ 35,623.07	$ 164.78	$ 153,537.07
2033	23	$ -	$ 5,000.00	$ -	0.94	1.2	1	$ 119,015.35	$ 36,226.85	$ 164.78	$ 155,406.97
2034	24	$ -	$ 5,000.00	$ -	0.94	1.22	1	$ 119,015.35	$ 36,830.63	$ 164.78	$ 156,010.75
2035	25	$ -	$ 5,000.00	$ -	0.94	1.25	1	$ 119,015.35	$ 37,736.30	$ 164.78	$ 156,916.43
2036	26	$ -	$ 5,000.00	$ -	0.95	1.26	1	$ 120,281.47	$ 38,038.19	$ 164.78	$ 158,484.44
2037	27	$ -	$ 5,000.00	$ -	0.95	1.28	1	$ 120,281.47	$ 38,641.97	$ 164.78	$ 159,088.22
2038	28	$ -	$ 5,000.00	$ -	0.95	1.3	1	$ 120,281.47	$ 39,245.75	$ 164.78	$ 159,692.00
2039	29	$ -	$ 5,000.00	$ -	0.95	1.32	1	$ 120,281.47	$ 39,849.53	$ 164.78	$ 160,295.78
2040	30	$ -	$ 5,000.00	$ -	0.95	1.34	1	$ 120,281.47	$ 40,453.31	$ 164.78	$ 160,899.56
2041	31	$ -	$ 5,000.00	$ -	0.95	1.35	1	$ 120,281.47	$ 40,755.20	$ 164.78	$ 161,201.45
NPV		$ 550,000.00	$109,968.24	$33,007.59				$2,629,729.73	$719,958.41	$3,624.11	$3,353,312.25
Total NPV											**$4,046,288.09**

1.6 Overall Evaluation

The mechanical design of the Harley-Davidson was 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, 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's ventilation was not designed to comply with ASHRAE 62.1.2007 because the Museum owner wanted the buildings to be designed for high occupancy and low frequency of when maximum occupancy would actually be seen. The engineers at HGA used ventilation rates to meet the ventilation recommendation 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. An in-depth ASHRAE standard 62.1 and standard 90.1 analyses are in Appendix A.

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 TRACE model, detailed in Tech Report Two, 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 energy consumption 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 is 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. Details on mechanical system operation and cost can be found in Technical Report Three. Proposed areas for improvement focus on efficiency rather than reducing space or overall first cost; however, these components were still investigated. 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 and lower operational costs.

The LEED analysis conducted in Tech Report Three concluded that only 26 points would have been achieved if that building was rated before completion. There were 80 points 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.

1.7 Project Methods

Three alternative mechanical designs have been developed along with two breadth topics in the electrical and structural areas of study for the proposal. In the time span of four months, the mechanical proposal was carefully examined first by researching product designs, publications, and published research. After the research phase, a thorough analysis on the water-cooled system alternatives were pursued by hand calculations and the aid of Trane Trace, an energy modeling software. Once the mechanical redesign was developed and written, a careful study of the breadth topics were reviewed. Using the same approach as with the mechanical redesign, the breadth topics first involve researching product designs, publications, and published research related to the topics. The energy model used for the mechanical redesign was also utilized in the electrical breadth to determine the size of the combined heat and power system. The economic analysis examined the simple payback and the rate of return of the combined heat and power system and was equated to the existing purchased energy economics. Emissions from the on-site energy production were also equated to emissions from the off-site power plant. Most of the emission calculations were done by hand and with the aid of Microsoft Excel. For the structural breadth, all of the thermal bridging calculations were done by hand along with all of the structural calculations.

Throughout both the mechanical depth and breadth proposal analyses, a faculty consultant was advising to ensure that the design analysis is as accurate as possible and also provide helpful feedback to the redesign. Once the designs were complete a comprehensive analysis connecting all investigations was performed and a final design was determined based on economics, environment, and feasibility.

1.8 MAE Course Relation

The requirement for the Master of Architectural Engineering is to directly relate investigations to material studied in 500-level courses. AE 557, centralized Cooling Production and Distribution Systems will be related to the alternative design of the current air-cooled chiller. AE 551, Combined Heat and Power was used in the investigation of combined heat and power. AE 559, Computational Fluid Dynamics was used to analyze the effects of thermal bridging.

Section Two Thesis Mechanical Depth

This section is an investigation into an air-cooled chilled water plant vs. a water-cooled chilled water plant. Three alternatives were studied. The first alternative is the baseline existing case discussed in the preceding sections. Alternative Two is a water-cooled system utilizing a cooling tower for heat rejection. Alternative Three is a water-cooled system utilizing the adjacent river for heat rejection.

2.1 Proposed Mechanical Redesign

The design of the Harley-Davidson Museum's mechanical system achieves all design objectives and provides a healthy comfortable environment for all occupants. The redesign of the mechanical system will focus on reducing emissions, reducing energy consumption, and cost effectiveness. The goal is to reduce the spread of contaminants that could be harmful to the environment, and reduce operating cost as much as necessary to have a satisfactory rate of return. The proposed redesign is to replace the existing air-cooled chillers with a water-cooled system and investigating different water-cooled systems.

The current method for heat rejection is with an air-cooled chiller. This is a common method of heat rejection for a facility of this size. Air-cooled chillers offer good performance particularly at part load. The use of cooling towers, condenser pumps, and condenser piping is not needed; therefore, mechanical space and upfront cost is less. Compared to evaporative cooled chillers, air-cooled chillers have increased lift because refrigerant temperature must be above ambient dry bulb, resulting in lower performance.

The facility is located on a unique 20 acre plot of land located adjacent to the Milwaukee River, see Figure 2 and 3. This site is appropriate for a water source system that utilizes river water for condensing and water side free cooling.

The alternatives defined below govern this study:

1. Air-cooled (existing case – discussed in preceding sections)
2. Water-cooled with cooling tower heat rejection
3. Water-cooled with river water heat rejection

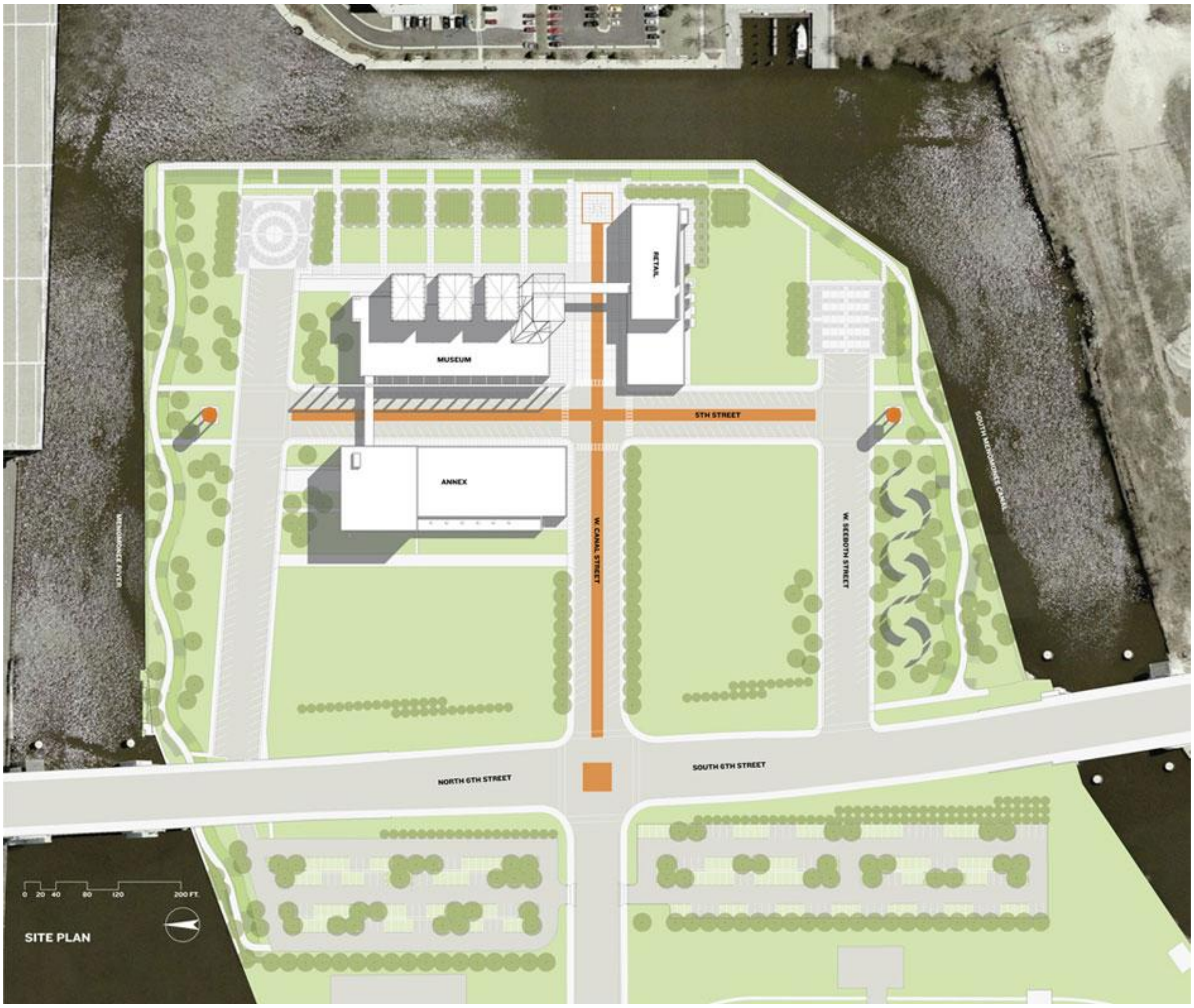


Figure 17 – Site Plan

Figure 18 – View of Milwaukee River next to the HDM

2.2.1 Alternative 2: Water-Cooled with Cooling Tower

The design of the water-cooled system was first studied with the utilization of a cooling tower system. This section reviews the design and findings of the study. Most of the current design of the chilled water plant was held constant with the limitation of switching the chillers to water-cooled. This was done to limit the variability of results and to make accurate correlations to design alternatives.

The chilled water plant was designed using recommendations from design professionals at HGA and manufacturers. The two current 9.5 EER 300 ton air-cooled screw chillers where switched to two 300 ton water-cooled screw chillers with a COP of 5.9. A two cell VFD cooling tower was selected using the Marley Cooling Tower selection software. The cooling tower was selected with a seven degree approach, a range of 10 degrees, a wet bulb of 78 degrees and a water flow rate of three gpm/ton. A constant condenser water pump was selected using the Bell and Gossett pump selection guidelines.

A second alternative was created in the TRACE energy model (section 1.3) and changes were made to the plant design to accurately model the design conditions of the new water-cooled system. Figures 19,20, and 21 illustrate the part load performance of the modeled chiller and cooling tower system.

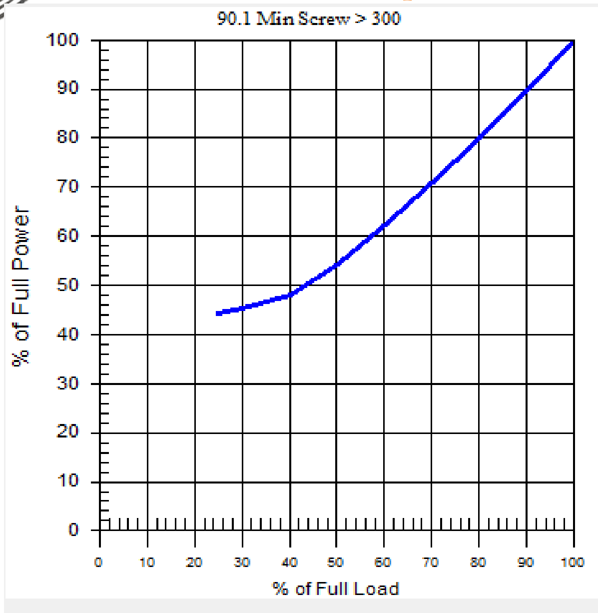


Figure 20 – Chiller Unloading Curve

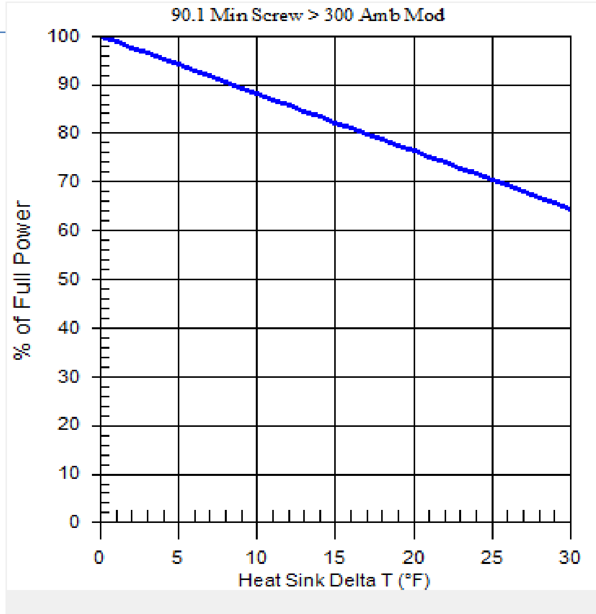


Figure 19 – Ambient Relief Curve

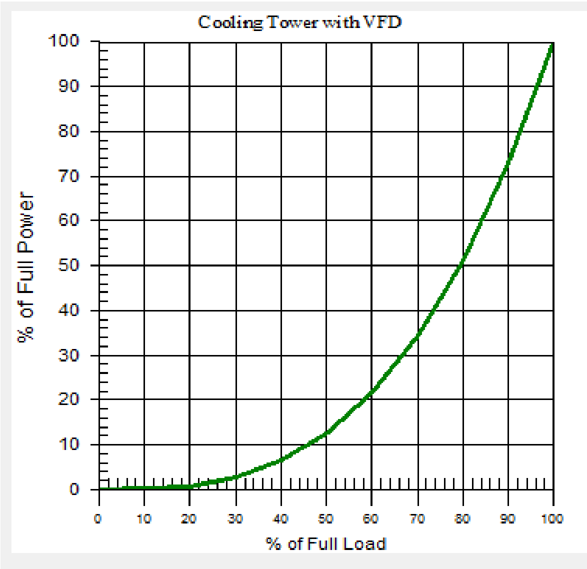


Figure 21 – Cooling Tower Unloading Curve

2.2.2 Water-Cooled with Cooling Tower Results

The calculated results illustrated in Figure 22 and Figure 23, concluded that the water-cooled chiller consumed much less energy than the air-cooled system as was expected. This is because the water-cooled system does not have the added fan energy and requires less lift from the compressor because the lift is proportional to the condensing temperature. The water-cooled system condensing temperature is related to the wet bulb temperature as opposed to the air-cooled system which is correlated to the warmer dry bulb temperature.

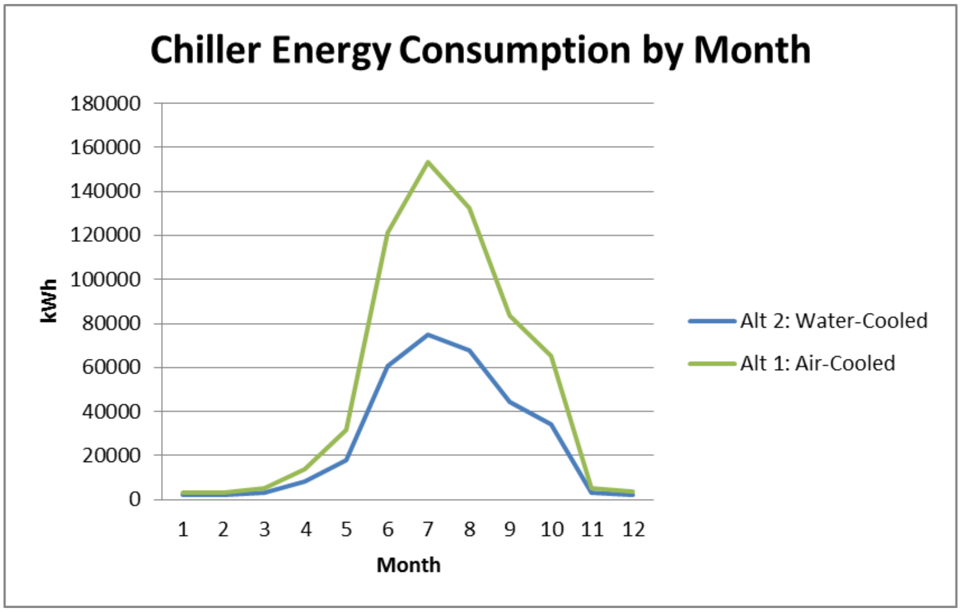


Figure 22 – Air vs. Water / Month

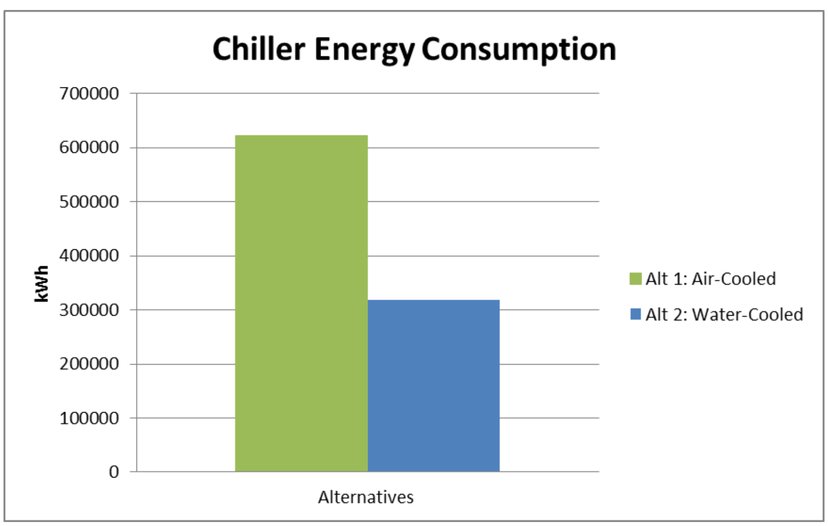


Figure 23 – Chiller Energy Consumption

Figure 24 exemplifies the power consumed by the chiller and the added energy from the cooling tower and condensing water pump. It is clear that the water-cooled system consumes less energy than the air cooled system. Figure 25 is a yearly profile of the total campus power consumption and illustrates how the majority of the savings is in the summer months when cooling is in its highest demand. The water cooled system consumes more energy in the winter months than the air-cooled system. This is because in the winter months the chiller efficiency of the air-cooled and water-cooled chiller is about equal and can be seen in Figure 22; however, the water-cooled system still has the added energy from the cooling-tower fan, freeze protection and the added energy of the condensing water circulation pump.

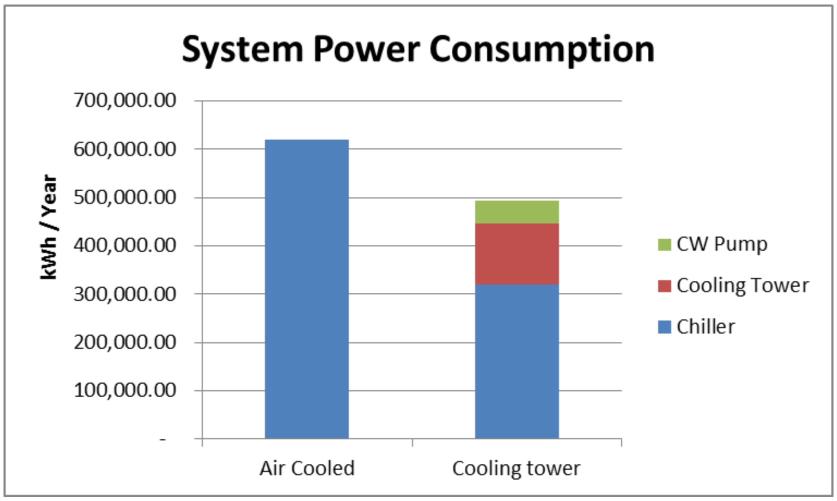


Figure 24 – System Power Consumption

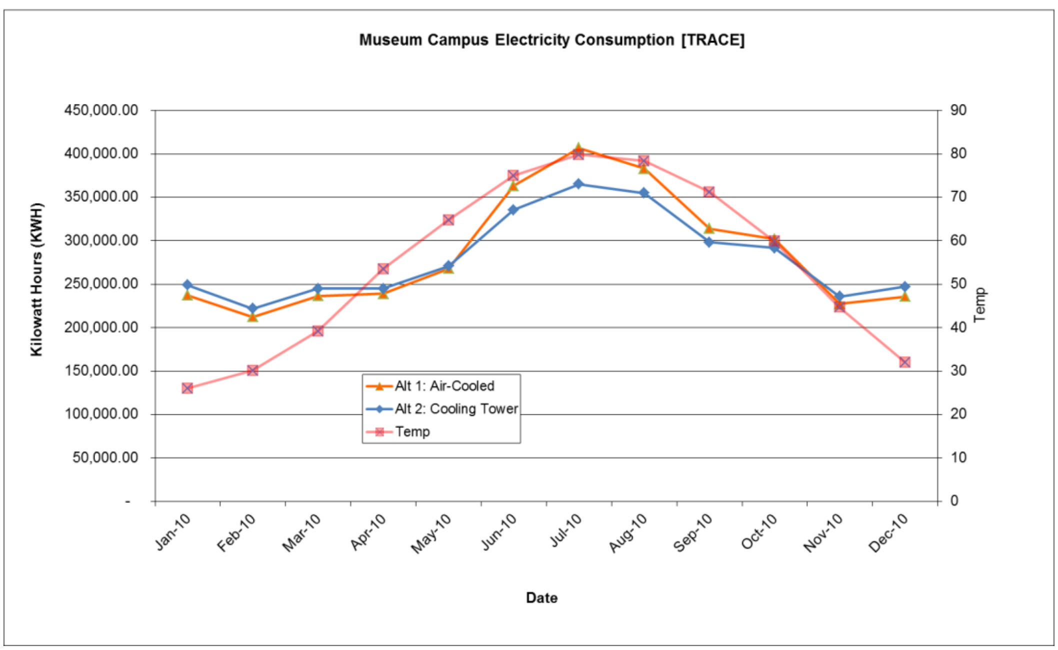


Figure 25 – Total Campus Electricity Consumption Yearly Profile

Table 18 and Table 19 are a breakdown of the electricity, water and gas consumption of the HDM campus. It is important to note the added water consumption in the water-cooled system. The added 2,505,000 gallons of water adds an additional $5,000 a year to the campus water bill. As shown in Table 20 the water-cooled system decreases the global warming potential (CO_{2eq}) by 3%.

Table 18 – Air-Cooled Consumption Breakdown

Air-Cooled				
		Elec	Water	Gas
		kWh	1000gal	therms
	Elec	2,168,082.30		
	Air Side	569,425.50		
	Water Side	683,862.00		
	Hot water	12,833.20	74.90	37,736.30
total		3,434,203.00	74.90	37,736.30

Elec	Lighting and Misc Loads
Air Side	AHU's
Water Side	Chiller, CT, CHW & CW Pumps
Hot water	Boiler, HW pumps

Table 19 – Water-Cooled Consumption Breakdown.

Water-Cooled				
		Elec	Water	Gas
		kWh	1000gal	therms
	Elec	2,168,082.30		
	Air Side	569,425.50		
	Water Side	557,153.20	2,505.10	
	Hot water	12,833.20	74.90	37,736.30
total		3,307,494.20	2,580.00	37,736.30

Table 20 - Emissions

	*Total CO2e (lb):
Air-Cooled	9.01E+06
Water-Cooled	8.77E+06
% Diff	3%

2.2.3 WATER-COOLED WITH COOLING TOWER ECONOMICS

Capital cost information was taken from RSMeans Mechanical Cost Date 2010 and consulted with design engineers at HGA and manufactures data. There is additional cost for cooling towers and condensing water pumps and piping; however, there is greater savings on the purchase of the water-cooled chillers compared to the air-cooled chillers.

Table 22 is a detail of the 30 year LCC analysis of the water-cooled system. There is an added cost of $5,511 per year for make-up water for the cooling tower; however, the reduction in energy consumption results to energy cost savings of $12,670 per year. Therefore, there is a total savings of $7,159 per year. Over the span of 30 years and including discount rate and escalation factors taken from NIST the net present value (NPV) of the expense to run and operate the HVAC system is $3,861,471.00, resulting in a 30 year NPV savings of $184,817.00.

Table 21 – Capital Cost Comparison

CAPITAL				
Alternative 1: Air- Cooled			Alternative 2: Water-Cooled	
Equipment	Price		Equipment	Price
AC Chiller 1	$215,000.00		WC Chiller 1	$ 140,500.00
AC Chiller 2	$215,000.00		WC Chiller 2	$ 140,500.00
			Cooling Tower 1	$ 37,000.00
			Cooling Tower 2	$ 37,000.00
			CW Pump 1	$ 5,575.00
			CW Pump 2	$ 5,575.00
			CW Piping	$ 21,000.00
4 Boilers	$ 120,000.00		4 Boilers	$ 120,000.00
Total	**$ 550,000.00**		**Total**	**$ 507,150.00**

Table 22 – Alternative 2: Water-Cooled LCC Analysis

Alternative 2

	Elec	Water	Gas
	kWh	1000gal	therms
		-	-
Air Side	569,425.50	-	-
Water Side	557,153.20	2,505.10	-
Hot water	12,833.20	74.90	37,736.30
total	1,139,411.90	2,580.00	37,736.30
Price per unit	$ 0.10	$ 2.20	$ 0.80
Cost	**$ 113,941.19**	**$ 5,676.00**	**$ 30,189.04**

Capital **$ 507,145.00**

Economic Life	30	years
Overhaul	$ 15,000.00	every 7 years up tp 21
Maintenance	$ 5,000.00	per year
Discount Rate	2.3%	DR

Air Side = AHUs
Water Side = Chiller ,CHW pump, CW Pump, and Cooling Tower
Hot Water = Boiler and HW pump

Date	Year #	Capital	Maintenance	Overhaul	Escalation Elec	Escalation Natural Gas	Escalation Water	Cost Elec	Cost Natural Gas	Cost Water	Cost Total
2011	1	$ 507,145.00	$ 5,000.00	$ -	1	1	1	$ 113,941.19	$ 30,189.04	$ 5,676.00	$ 149,806.23
2012	2	$ -	$ 5,000.00	$ -	0.98	0.98	1	$ 111,662.37	$ 29,585.26	$ 5,676.00	$ 146,923.63
2013	3	$ -	$ 5,000.00	$ -	0.97	0.95	1	$ 110,522.95	$ 28,679.59	$ 5,676.00	$ 144,878.54
2014	4	$ -	$ 5,000.00	$ -	0.97	0.92	1	$ 110,522.95	$ 27,773.92	$ 5,676.00	$ 143,972.87
2015	5	$ -	$ 5,000.00	$ -	0.97	0.92	1	$ 110,522.95	$ 27,773.92	$ 5,676.00	$ 143,972.87
2016	6	$ -	$ 5,000.00	$ -	0.96	0.93	1	$ 109,383.54	$ 28,075.81	$ 5,676.00	$ 143,135.35
2017	7	$ -	$ 5,000.00	$ 15,000.00	0.95	0.94	1	$ 108,244.13	$ 28,377.70	$ 5,676.00	$ 142,297.83
2018	8	$ -	$ 5,000.00	$ -	0.94	0.95	1	$ 107,104.72	$ 28,679.59	$ 5,676.00	$ 141,460.31
2019	9	$ -	$ 5,000.00	$ -	0.94	0.97	1	$ 107,104.72	$ 29,283.37	$ 5,676.00	$ 142,064.09
2020	10	$ -	$ 5,000.00	$ -	0.93	1	1	$ 105,965.31	$ 30,189.04	$ 5,676.00	$ 141,830.35
2021	11	$ -	$ 5,000.00	$ -	0.93	1.02	1	$ 105,965.31	$ 30,792.82	$ 5,676.00	$ 142,434.13
2022	12	$ -	$ 5,000.00	$ -	0.92	1.04	1	$ 104,825.89	$ 31,396.60	$ 5,676.00	$ 141,898.50
2023	13	$ -	$ 5,000.00	$ -	0.92	1.06	1	$ 104,825.89	$ 32,000.38	$ 5,676.00	$ 142,502.28
2024	14	$ -	$ 5,000.00	$ 15,000.00	0.92	1.08	1	$ 104,825.89	$ 32,604.16	$ 5,676.00	$ 143,106.06
2025	15	$ -	$ 5,000.00	$ -	0.92	1.1	1	$ 104,825.89	$ 33,207.94	$ 5,676.00	$ 143,709.84
2026	16	$ -	$ 5,000.00	$ -	0.92	1.11	1	$ 104,825.89	$ 33,509.83	$ 5,676.00	$ 144,011.73
2027	17	$ -	$ 5,000.00	$ -	0.92	1.13	1	$ 104,825.89	$ 34,113.62	$ 5,676.00	$ 144,615.51
2028	18	$ -	$ 5,000.00	$ -	0.92	1.14	1	$ 104,825.89	$ 34,415.51	$ 5,676.00	$ 144,917.40
2029	19	$ -	$ 5,000.00	$ -	0.93	1.15	1	$ 105,965.31	$ 34,717.40	$ 5,676.00	$ 146,358.70
2030	20	$ -	$ 5,000.00	$ -	0.93	1.16	1	$ 105,965.31	$ 35,019.29	$ 5,676.00	$ 146,660.59
2031	21	$ -	$ 5,000.00	$ 15,000.00	0.93	1.17	1	$ 105,965.31	$ 35,321.18	$ 5,676.00	$ 146,962.48
2032	22	$ -	$ 5,000.00	$ -	0.93	1.18	1	$ 105,965.31	$ 35,623.07	$ 5,676.00	$ 147,264.37
2033	23	$ -	$ 5,000.00	$ -	0.94	1.2	1	$ 107,104.72	$ 36,226.85	$ 5,676.00	$ 149,007.57
2034	24	$ -	$ 5,000.00	$ -	0.94	1.22	1	$ 107,104.72	$ 36,830.63	$ 5,676.00	$ 149,611.35
2035	25	$ -	$ 5,000.00	$ -	0.94	1.25	1	$ 107,104.72	$ 37,736.30	$ 5,676.00	$ 150,517.02
2036	26	$ -	$ 5,000.00	$ -	0.95	1.26	1	$ 108,244.13	$ 38,038.19	$ 5,676.00	$ 151,958.32
2037	27	$ -	$ 5,000.00	$ -	0.95	1.28	1	$ 108,244.13	$ 38,641.97	$ 5,676.00	$ 152,562.10
2038	28	$ -	$ 5,000.00	$ -	0.95	1.3	1	$ 108,244.13	$ 39,245.75	$ 5,676.00	$ 153,165.88
2039	29	$ -	$ 5,000.00	$ -	0.95	1.32	1	$ 108,244.13	$ 39,849.53	$ 5,676.00	$ 153,769.66
2040	30	$ -	$ 5,000.00	$ -	0.95	1.34	1	$ 108,244.13	$ 40,453.31	$ 5,676.00	$ 154,373.44
2041	31	$ -	$ 5,000.00	$ -	0.95	1.35	1	$ 108,244.13	$ 40,755.20	$ 5,676.00	$ 154,675.33
NPV		$ 507,145.00	$109,968.24	$33,007.59				$2,366,555.85	$719,958.41	$124,835.95	$3,211,350.21
Total NPV											**$ 3,861,471.04**

2.3.1 Alternative 3: Water-Cooled with River Water

Alternative Three is an investigation into the utilization of the adjacent Milwaukee River as condensing water for the water-cooled chillers. The same energy model was used as the previous two alternatives. All parameters were held constant except for the chiller's heat rejection system, which was switched from using a cooling tower to a river water heat rejection system. Additional pump energy was also modeled.

Milwaukee River temperatures from the U.S. Geological Survey are illustrated in Figure 26. As the entering condensing water temperature decreases the chillers efficiency increases. This happens as long as the condensing water is above approximately 55 degrees. When the temperature drops below 55 degrees the pressure in the chiller falls below optimal conditions and the efficiency drops. A comparison was made between average water temperatures leaving the cooling tower and water temperatures leaving the river plus the approach of river water heat exchanger. This was a preliminary study to investigate if chiller energy consumption would decrease by using the river water as condensing water.

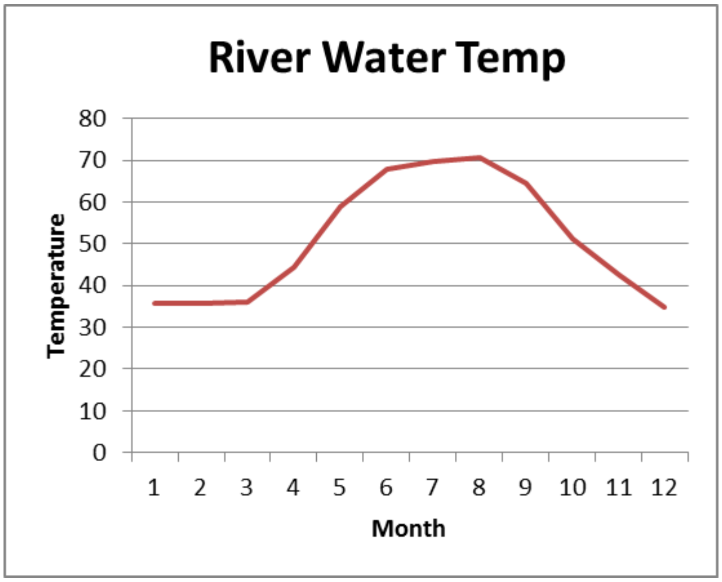


Figure 26 – Monthly River Temperature

The leaving water temperature from the cooling tower (cold water) decreases as the wet-bulb temperature decreases. Using the Marley Cooling Tower selection software, a cooling tower was selected and a cold water temperature equation was generated from the ten degree range curve shown in Figure 27. Using this equation and taking the average hourly wet-bulb for a typical day each month from ASHRAE weather data, the cold water temperature was calculated for a typical day for every month. This projection is plotted in Figure 28 along with river water temperature plus three degrees for the heat exchanger approach. It was concluded that the temperature of the river is lower than the cold water temperature leaving the cooling tower at certain times of the year, resulting in increased chiller efficiency.

Equation 1 – Cooling tower leaving water temp as a function of outside air wet-bulb

$$Cold\ Water\ Temp[°F] = .739 \times WB[°F] - 27.35$$

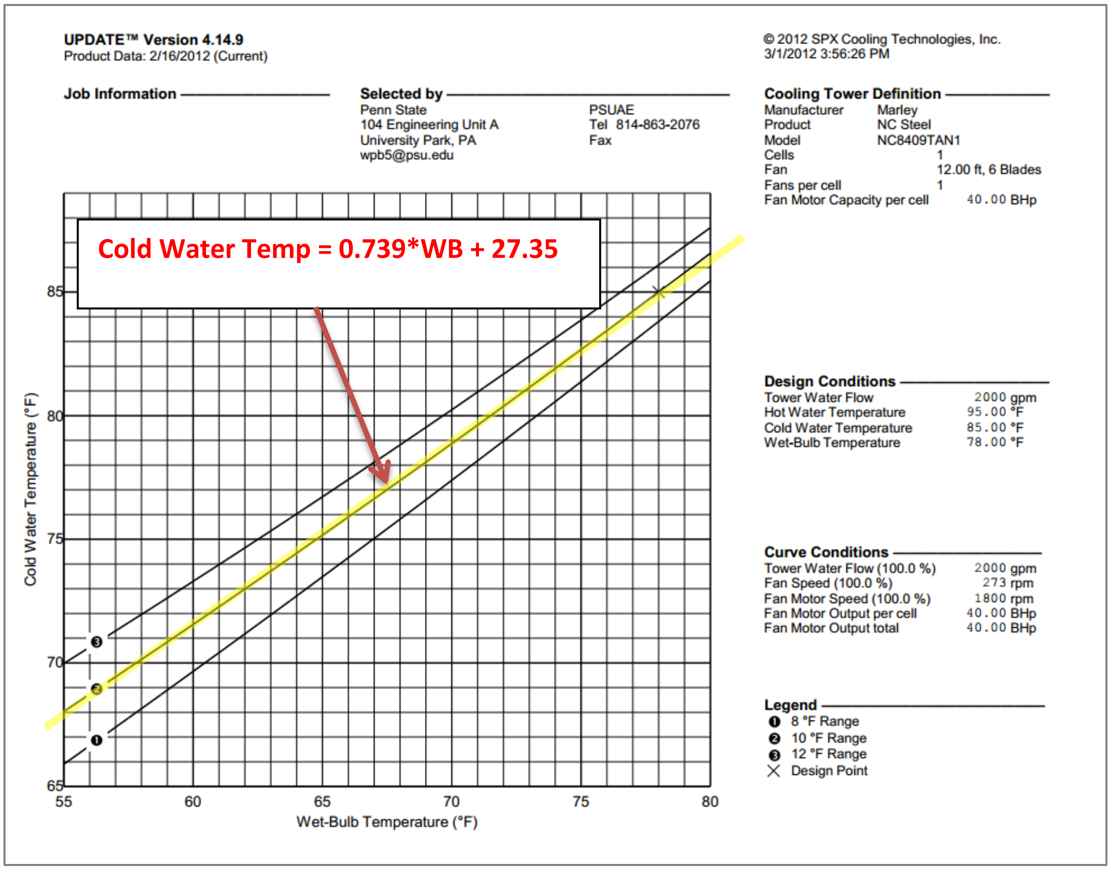


Figure 27 – Marley Cooling Tower Selection

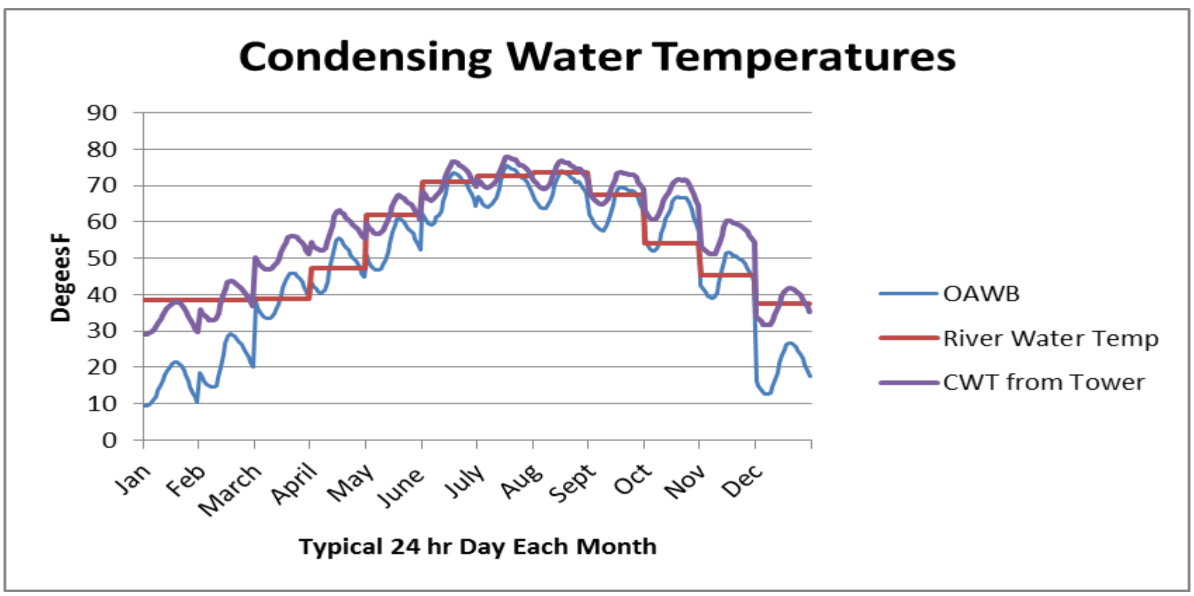


Figure 28 – Cooling Tower vs. River

2.3.2 Water-Cooled with River Water Design

The design of the river water cooling system is a two loop system. The first loop is an open loop coming off the adjacent Milwaukee River. A constant speed pump will pump water through a plate and frame heat exchanger joining with the second loop. The second loop is a closed loop constant flow system, supplying condensing water to the water-cooled chillers. This two loop system was designed to limit the opportunity for fouling within the chiller. By using a heat exchanger, heat is extracted from the closed loop and moved to the open loop without physical contact. A schematic of the heat exchange process between the two loops is in Figure 29.

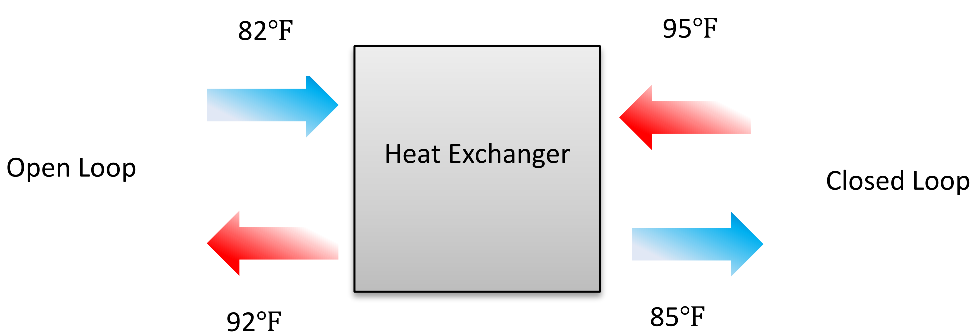


Figure 29 – Heat Exchanger

It is also important to limit fouling within the heat exchanger to maintain performance. The river water open loop provides many opportunities for foreign contaminants to enter the water stream. To limit the potential of foreign contaminants entering the heat exchanger, proper filtration is required. Figure 30 is a schematic of the filtration design. Water from the river enters through a large 24 inch diameter opening in the seawall that contains an inlet screen preventing large contaminants, like fish

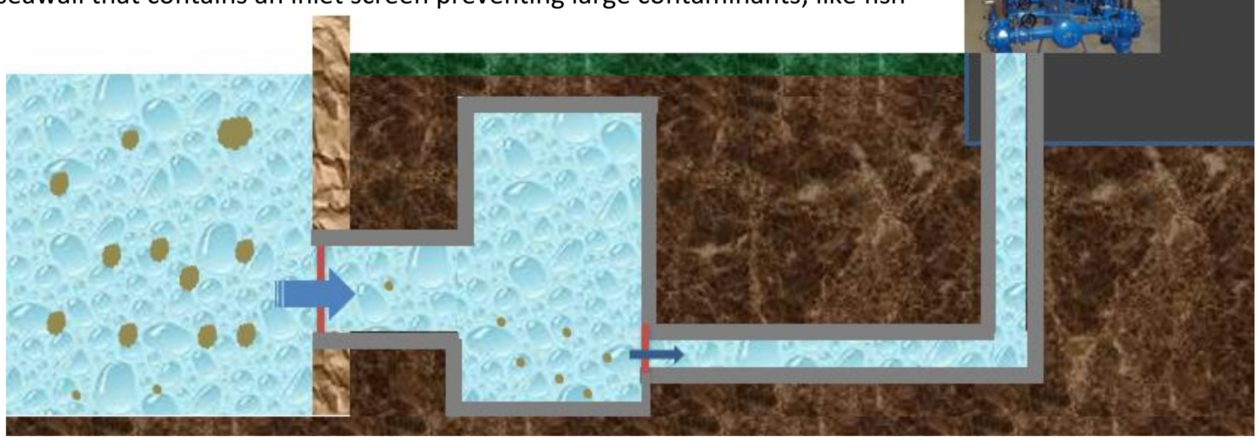
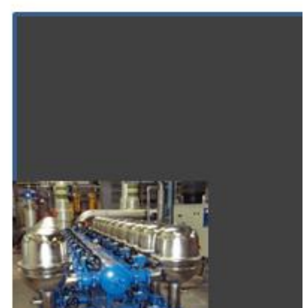



Figure 30 – Filtration Schematic

from entering. The large opening maintains a low velocity of 1.28 feet per second preventing contaminates from being drawn into the water stream. The water then enters a transition well. Here the contaminants have a chance to fall to the bottom of the well and the water transitions from low velocity to a higher velocity of 11.5 feet per second by entering a smaller eight inch diameter pipe. At the entrance to the eight inch pipe there is an inlet screen that will block smaller contaminants than the upstream screen. Once the water reaches the mechanical room it will then be filtered through a SpinClean water filtration devise from Industrial Purification Systems capable of filtration from 10-100 microns. After the filtration process, the river water will be free of harmful contaminates that have potential to create fouling and thus decrease the performance of the heat exchanger.

Equation 2 – velocity of water as a function of pipe diameter

$$v = 0.4085\frac{q}{d^2}$$

$$v = velocity\left(\frac{ft}{s}\right),\ q = volume\ flow\ rate\ \left(US\frac{gal}{min}\right),\ d = pipe\ inside\ diameter\ (inches)$$

Supply water will be drawn from the east river channel and returned in the north channel to insure no short circuiting between streams, as shown in Figure 31. Figure 32 is a flow diagram illustrating the river heat rejection system. A more detailed flow diagram can be found in Appendix C. Redundancy is designed into the pumping arrangement to allow the system to run while maintenance is performed. The chiller is designed to operate with a maximum condensing water temperature of 85 °F. This means that the river must not exceed 82 °F. Looking back at Figure 26, the river temperature will never rise above this point. Furthermore, if the river water temperature did rise to 82 °F the discharged water temperature would only be 92 °F. The city of Milwaukee states that water discharged into the river may not be greater than 120°F, concluding that the design is well within the city ordinances. This is discussed more in the next section.

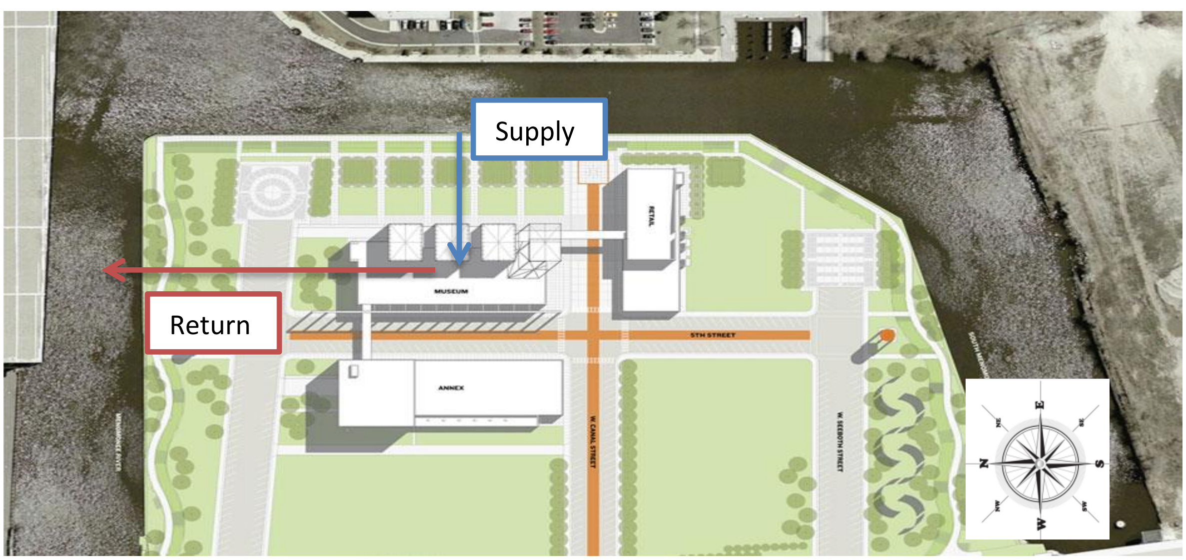


Figure 31 – Supply and Return Schematic

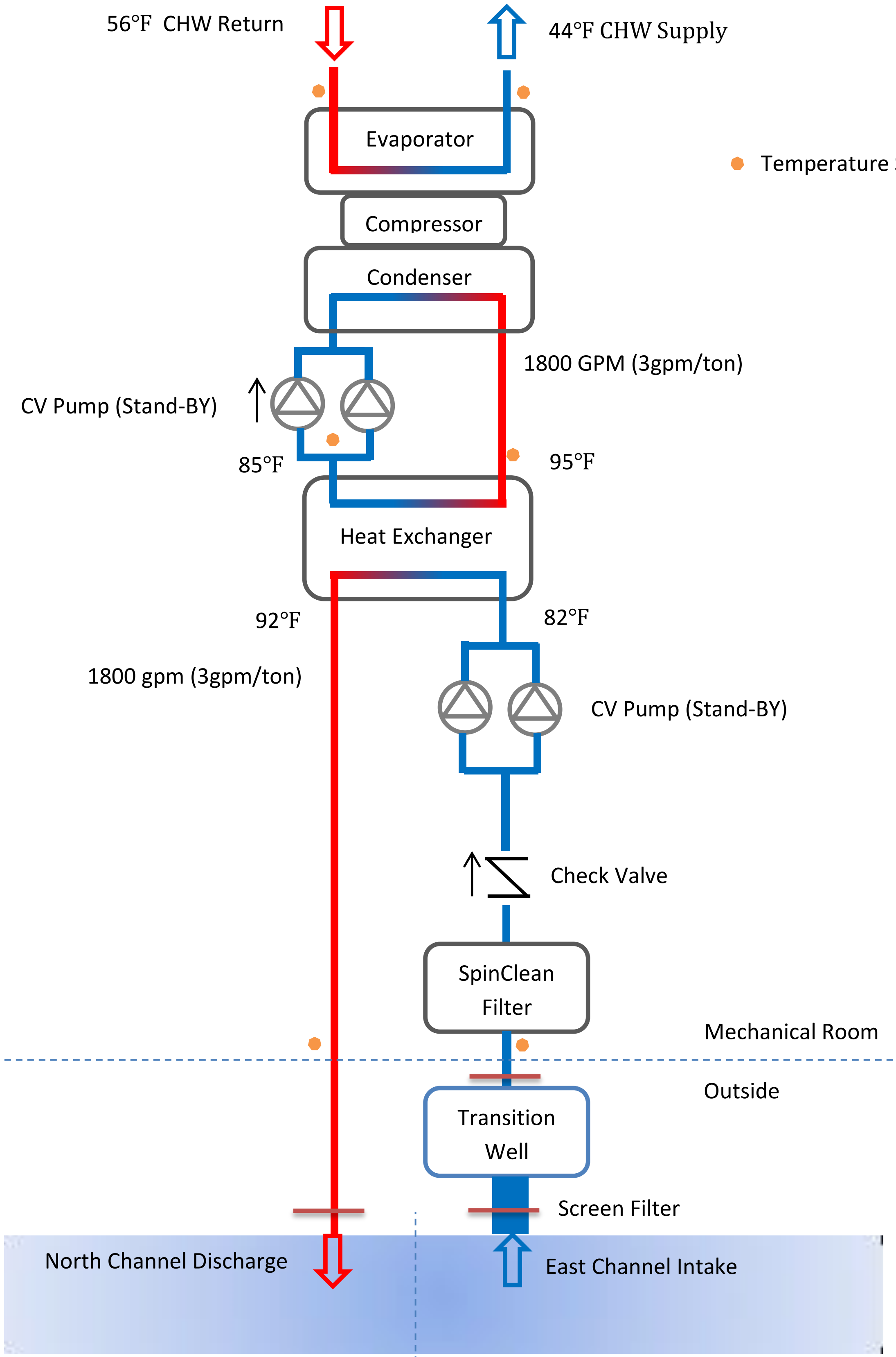


Figure 32 – River Heat Rejection Flow Diagram

2.3.3 Water-Cooled with River Water Constraints and Considerations

According to the Wisconsin's Water Law, the discharge of pollutants to surface waters is governed by federal and state law. The clean water act prohibits the discharge of pollutants without a permit. Discharge permits are required for the discharge of any pollutant from a point source to water of the state. In Wisconsin, these permits are called Wisconsin Pollutant Discharge Elimination System permits. The term "point source" is defined as *a discernible, confined and discrete conveyance of water pollutants which includes among other things any ditch or channel*. The term "pollutant" is broadly defined and not only includes sewage, chemical wastes, and biological materials but also dirt, and heat [Wisconsin Water Law].

According to Kevin Pope[1], engineer at HGA, there are several other permits required for approval from Wisconsin Department of Natural Resources (DNR), Army Corp of Engineers and the Milwaukee Harbor Commission. To obtain the necessary permits the major constraint is that the temperature of discharged water must be less than 120 °F. As mentioned in section 2.3.2 the discharged water temperature will never approach 120 °F. Located 1.5 miles away from the Harley-Davidson Museum, Pier Wisconsin is the latest building in Milwaukee that uses Lake Michigan for cooling.

It is also important to consider the dependence on river water temperature. A sensitivity analysis was conducted on the fluctuation of river water temperature and how it effects the overall energy consumption of the facility. The study concluded that an increase in water temperature by 5 degrees would increase energy consumption by 0.23% or about $700 a year.

Figure 33 – Pier Wisconsin, Photo consent of Robert Powers

[1] **Kevin Pope** is the Associate Vice President of HGA Mechanical Engineering and principal mechanical engineer of Discovery World, Pier Wisconsin .

2.3.4 Water-Cooled With River Water Results

Figure 28 shows how as the WB temperature increases the difference between the WB temperature and the cold water temperature from the cooling tower decreases. Furthermore, the plot shows how the river water temperature is lower than the cold water temperature from the tower during the warmer hours of the warmer months when cooling is in high demand. The lower temperature leads to increase efficiency of the water-cooled chiller, illustrated in Figure 34 and Figure 35.

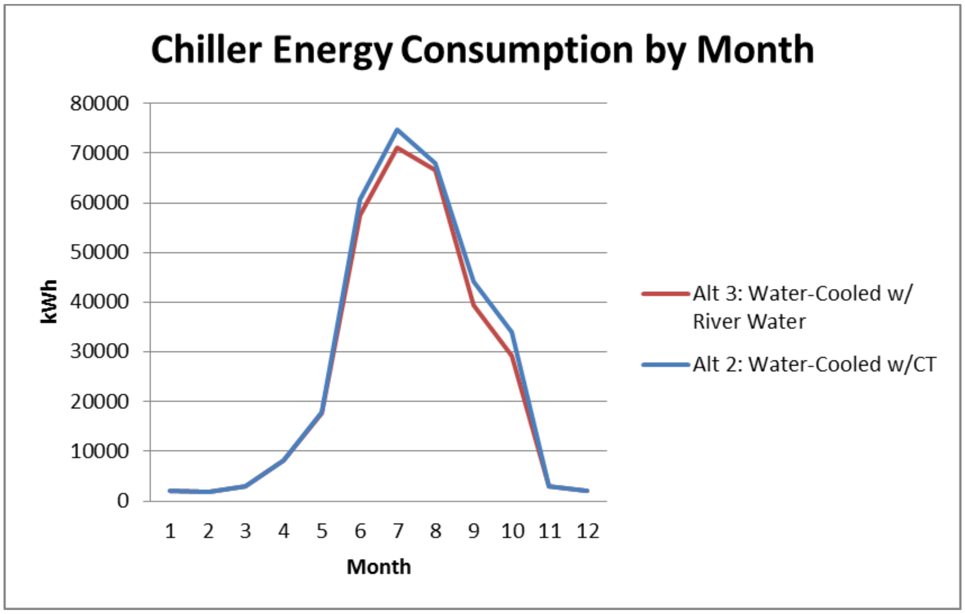


Figure 34 – Monthly Projection of Chiller Energy Consumption

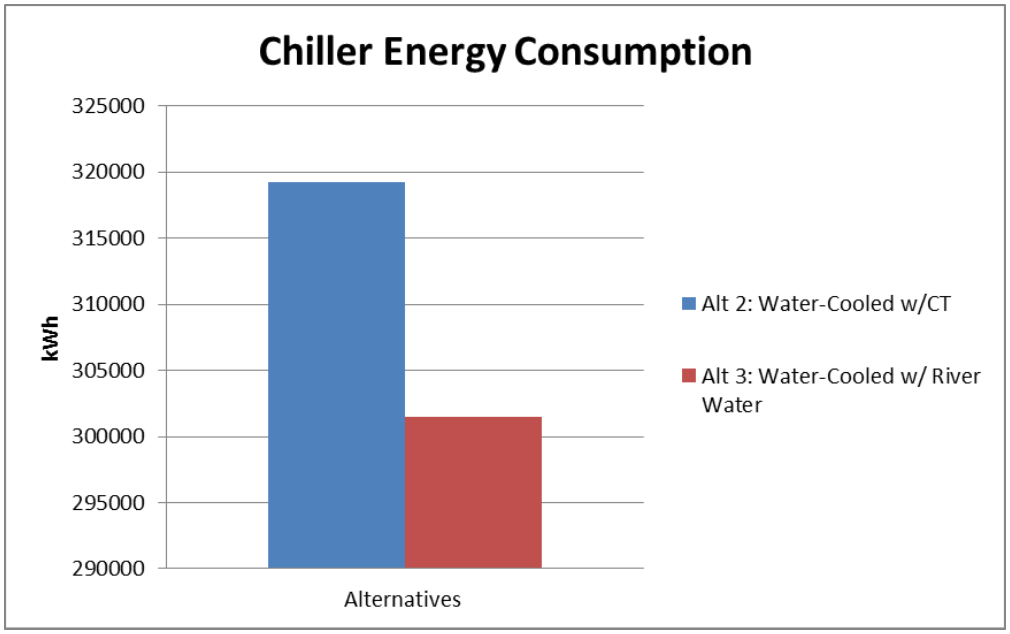


Figure 35 – Total Chiller Energy Consumption for One Year

Energy consumed by pumps was modeled with the calculated head loss based on the piping layout. An example of the river water pump curve is shown in Figure 36. This curve was generated using the Bell and Gossett selection software. Figure 37 illustrates the additional power consumption from distribution pumps and fan power from the cooling tower on top of the chiller's consumption. The condensing water (CW) pump in both alternatives consumes approximately the same amount of energy; however, the CW pump in the cooling tower system uses slightly more energy to compensate for the added elevation head. Furthermore, the river water pump consumes less energy than the cooling tower. Therefore, the river water cooling system uses less energy than the cooling tower cooling system. Figure 38 illustrates the total energy consumption for the Harley-Davidson Museum for both alternatives.

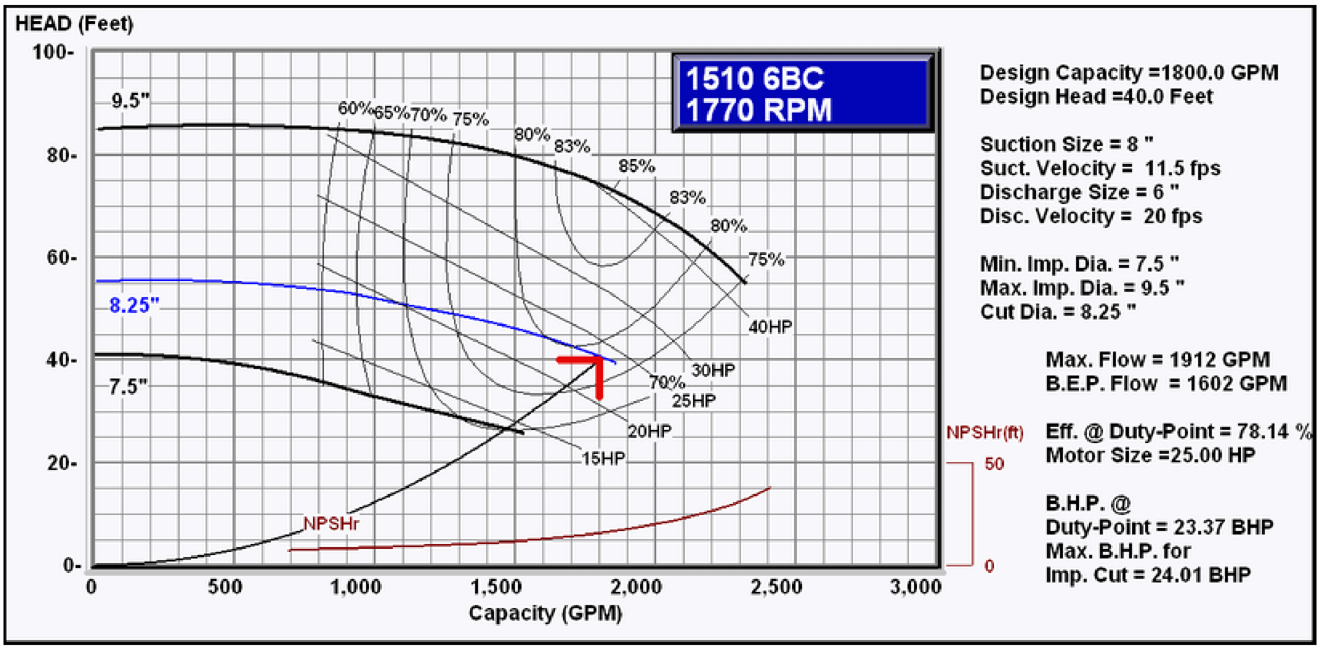


Figure 36 – River Water Pump Curve: Bell & Gossett

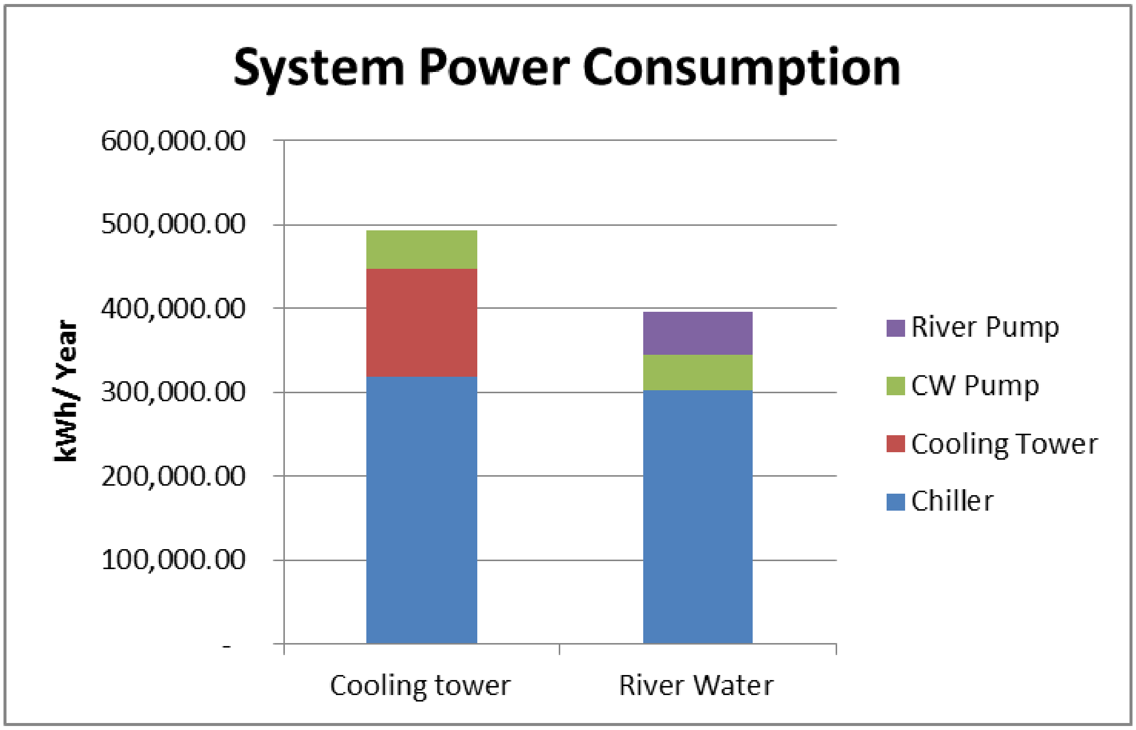


Figure 37 – System Power Consumption: Cooling Tower vs. River water

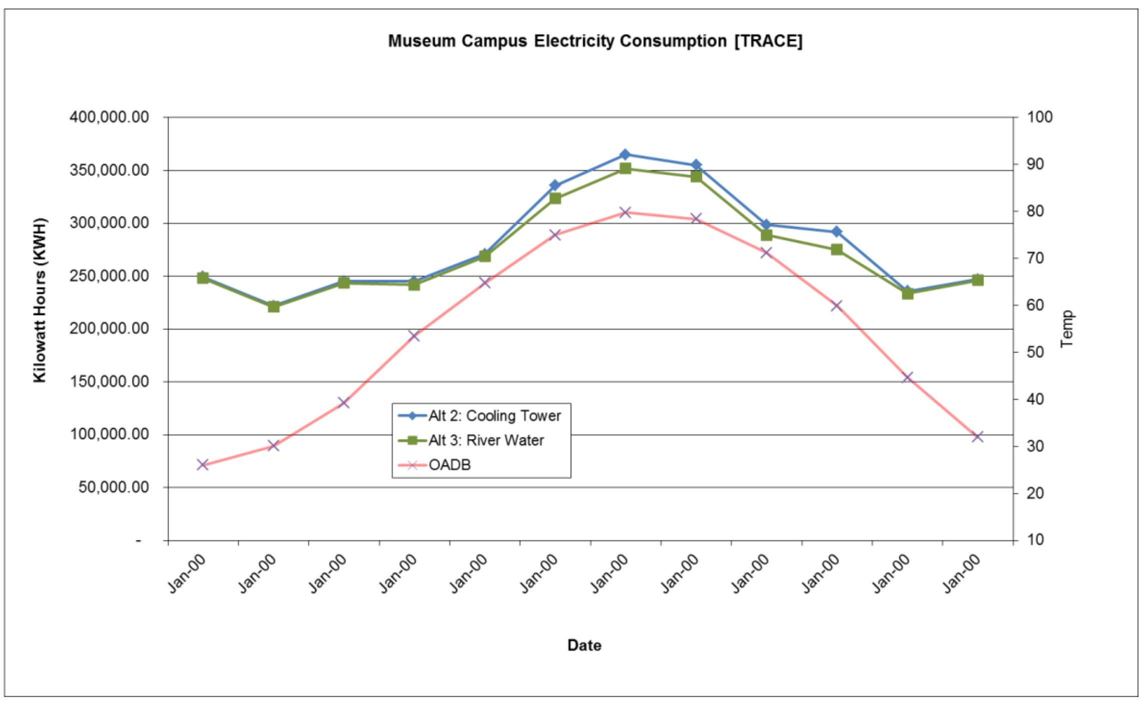


Figure 38 – Annual Campus Energy Consumption, River Water vs. Cooling Tower.

Table 23 and Table 24 are a breakdown of the electricity, water and gas consumption of the HDM campus. The water-cooled system using river water consumes 97,857.4 kWh and 25 million gallons of water less than the water-cooled cooling tower system. As shown in Table 25 the river water system decreases the global warming potential (CO_{2eq}) by 2%.

Table 23

Water-Cooled with Cooling Tower				
		Elec	Water	Gas
		kWh	1000gal	therms
	Elec	2,168,082.30		
	Air Side	569,425.50		
	Water Side	557,153.20	2,505.10	
	Hot water	12,833.20	74.90	37,736.30
total		3,307,494.20	2,580.00	37,736.30

Elec	Lighting and Misc Loads
Air Side	AHU's
Water Side	Chiller, CT, CHW & CW Pumps
Hot water	Boiler, HW pumps

Table 24

Water Cooled with River				
		Elec	Water	Gas
		kWh	1000gal	therms
	Elec	2,168,082.30		
	Air Side	569,425.50		
	Water Side	459,295.80		
	Hot water	12,833.20	74.90	37,736.30
total		3,209,636.80	74.90	37,736.30

Table 25

	*Total CO2e (lb):
Alt 2: Cooling Tower	8.77E+06
Alt 3: River Water	8.57E+06
% Diff	2%

2.3.5 Water-Cooled with River Water Economics

Capital Cost information was taken from RSMeans Mechanical Cost Date 2010 and consulted with design engineers at HGA and manufactures data. Table 26 is a summary of the piping calculations completed for sizing and estimating cost. Most of the piping is concealed and does not run near occupied areas; therefore, noise due to high velocity water streams was not a concern. Piping sizes were selected to limit head loss to 4 ft per 100 ft. Sizing a pipe for a lower head loss would result in less pump energy, but would have more capital cost.

Table 26 – Pipe Selection

Piping								
	Flow	size	Velocity	Head Loss	length	Head loss	Price	Price
	GPM	Inches	ft/s	ft/100 ft	ft	ft	$/ft	$
CW piping CT	1800	8	11.5	4	221	8.84	$ 95.00	$20,995.00
CW piping RW		8	11.5	4	50	2	$ 95.00	$ 4,750.00
River Piping		8	11.5	4	500	20	$ 95.00	$47,500.00
		24	1.28	-	10	-	$500.00	$ 5,000.00

Table 27 is a breakdown comparing the capital cost of a water-cooled system with a cooling tower and a water-cooled system using river water. The river water system has a capital cost of $611,400.00 which is $104,255.00 more than the cooling tower system. The increase in capital cost is from additional piping, the filtration system, additional pumps, and the heat exchanger. The increase in capital leads to a yearly energy savings of $9,785.74 and water savings of $5,511.22, resulting in an annual savings of $15,296.96. Over the span of 30 years and including discount rate and escalation factors taken from NIST, the net present value (NPV) of the expense to run and operate the HVAC system is $3,641,264.61, resulting in a 30 year NPV savings of $220,206.43 compared to the water-cooled system with cooling tower heat rejection.

Table 27 - Capital: Cooling Tower vs. River Water

CAPITAL				
Alternative 2: Water-Cooled Cooling Tower			Alternative 3: Water-Cooled River Water	
Equipment	Price		Equipment	Price
WC Chiller 1	$ 140,500.00		WC Chiller 1	$ 140,500.00
WC Chiller 2	$ 140,500.00		WC Chiller 2	$ 140,500.00
			River Pump 1	$ 12,000.00
Cooling Tower 1	$ 37,000.00		River Pump 2	$ 12,000.00
Cooling Tower 2	$ 37,000.00		River Piping	$ 52,500.00
			Heat Exchanger	$ 18,000.00
			Filtration System	$ 100,000.00
CW Pump 1	$ 5,575.00		CW Pump 1	$ 5,575.00
CW Pump 2	$ 5,575.00		CW Pump 2	$ 5,575.00
CW Piping	$ 20,995.00		CW Piping	$ 4,750.00
4 Boilers	$ 120,000.00		4 Boilers	$ 120,000.00
Total	$ 507,145.00			$ 611,400.00

Table 28 - 30 Year LCC: River Water System

Alternative 3

	Elec	Water	Gas
	kWh	1000gal	therms
		-	-
Air Side	569,425.50	-	-
Water Side	459,295.80		-
Hot water	12,833.20	74.90	37,736.30
total	1,041,554.50	74.90	37,736.30
Price per unit	$ 0.10	$ 2.20	$ 0.80
Cost	**$ 104,155.45**	**$ 164.78**	**$ 30,189.04**

Economic Life	30	years
Overhaul	$ 15,000.00	every 7 years up tp 21
Maintenance	$ 5,000.00	per year
Discount Rate	2.3%	DR

Air Side = AHUs
Water Side = Chiller ,CHW pump, CW Pump, and Cooling Tower
Hot Water = Boiler and HW pump

Capital **$ 611,400.00**

Date	Year #	Capital	Maintenance	Overhaul	Escalation Elec	Escalation Natural Gas	Escalation Water	Cost Elec	Cost Natural Gas	Cost Water	Cost Total
2011	1	$ 611,400.00	$ 5,000.00	$ -	1	1	1	$ 104,155.45	$ 30,189.04	$ 164.78	$ 134,509.27
2012	2	$ -	$ 5,000.00	$ -	0.98	0.98	1	$ 102,072.34	$ 29,585.26	$ 164.78	$ 131,822.38
2013	3	$ -	$ 5,000.00	$ -	0.97	0.95	1	$ 101,030.79	$ 28,679.59	$ 164.78	$ 129,875.15
2014	4	$ -	$ 5,000.00	$ -	0.97	0.92	1	$ 101,030.79	$ 27,773.92	$ 164.78	$ 128,969.48
2015	5	$ -	$ 5,000.00	$ -	0.97	0.92	1	$ 101,030.79	$ 27,773.92	$ 164.78	$ 128,969.48
2016	6	$ -	$ 5,000.00	$ -	0.96	0.93	1	$ 99,989.23	$ 28,075.81	$ 164.78	$ 128,229.82
2017	7	$ -	$ 5,000.00	$ 15,000.00	0.95	0.94	1	$ 98,947.68	$ 28,377.70	$ 164.78	$ 127,490.16
2018	8	$ -	$ 5,000.00	$ -	0.94	0.95	1	$ 97,906.12	$ 28,679.59	$ 164.78	$ 126,750.49
2019	9	$ -	$ 5,000.00	$ -	0.94	0.97	1	$ 97,906.12	$ 29,283.37	$ 164.78	$ 127,354.27
2020	10	$ -	$ 5,000.00	$ -	0.93	1	1	$ 96,864.57	$ 30,189.04	$ 164.78	$ 127,218.39
2021	11	$ -	$ 5,000.00	$ -	0.93	1.02	1	$ 96,864.57	$ 30,792.82	$ 164.78	$ 127,822.17
2022	12	$ -	$ 5,000.00	$ -	0.92	1.04	1	$ 95,823.01	$ 31,396.60	$ 164.78	$ 127,384.40
2023	13	$ -	$ 5,000.00	$ -	0.92	1.06	1	$ 95,823.01	$ 32,000.38	$ 164.78	$ 127,988.18
2024	14	$ -	$ 5,000.00	$ 15,000.00	0.92	1.08	1	$ 95,823.01	$ 32,604.16	$ 164.78	$ 128,591.96
2025	15	$ -	$ 5,000.00	$ -	0.92	1.1	1	$ 95,823.01	$ 33,207.94	$ 164.78	$ 129,195.74
2026	16	$ -	$ 5,000.00	$ -	0.92	1.11	1	$ 95,823.01	$ 33,509.83	$ 164.78	$ 129,497.63
2027	17	$ -	$ 5,000.00	$ -	0.92	1.13	1	$ 95,823.01	$ 34,113.62	$ 164.78	$ 130,101.41
2028	18	$ -	$ 5,000.00	$ -	0.92	1.14	1	$ 95,823.01	$ 34,415.51	$ 164.78	$ 130,403.30
2029	19	$ -	$ 5,000.00	$ -	0.93	1.15	1	$ 96,864.57	$ 34,717.40	$ 164.78	$ 131,746.74
2030	20	$ -	$ 5,000.00	$ -	0.93	1.16	1	$ 96,864.57	$ 35,019.29	$ 164.78	$ 132,048.63
2031	21	$ -	$ 5,000.00	$ 15,000.00	0.93	1.17	1	$ 96,864.57	$ 35,321.18	$ 164.78	$ 132,350.53
2032	22	$ -	$ 5,000.00	$ -	0.93	1.18	1	$ 96,864.57	$ 35,623.07	$ 164.78	$ 132,652.42
2033	23	$ -	$ 5,000.00	$ -	0.94	1.2	1	$ 97,906.12	$ 36,226.85	$ 164.78	$ 134,297.75
2034	24	$ -	$ 5,000.00	$ -	0.94	1.22	1	$ 97,906.12	$ 36,830.63	$ 164.78	$ 134,901.53
2035	25	$ -	$ 5,000.00	$ -	0.94	1.25	1	$ 97,906.12	$ 37,736.30	$ 164.78	$ 135,807.20
2036	26	$ -	$ 5,000.00	$ -	0.95	1.26	1	$ 98,947.68	$ 38,038.19	$ 164.78	$ 137,150.65
2037	27	$ -	$ 5,000.00	$ -	0.95	1.28	1	$ 98,947.68	$ 38,641.97	$ 164.78	$ 137,754.43
2038	28	$ -	$ 5,000.00	$ -	0.95	1.3	1	$ 98,947.68	$ 39,245.75	$ 164.78	$ 138,358.21
2039	29	$ -	$ 5,000.00	$ -	0.95	1.32	1	$ 98,947.68	$ 39,849.53	$ 164.78	$ 138,961.99
2040	30	$ -	$ 5,000.00	$ -	0.95	1.34	1	$ 98,947.68	$ 40,453.31	$ 164.78	$ 139,565.77
2041	31	$ -	$ 5,000.00	$ -	0.95	1.35	1	$ 98,947.68	$ 40,755.20	$ 164.78	$ 139,867.66
NPV		$ 611,400.00	$109,968.24	$33,007.59				$2,163,306.26	$719,958.41	$3,624.11	$2,886,888.78
Total NPV											**$ 3,641,264.61**

2.3.6 Water-Cooled with River Water Other Considerations

Water-side free cooling was investigated, but was found to be unbeneficial. For free cooling to be successful the condensing water would have to be 44 degrees, meaning the river must be 41 degrees. When the river is 41 degrees little cooling in required and the outside air dry bulb temperature encourages air-side free cooling though the use of economizers. Therefore, air-side economizers in the Milwaukee climate are encouraged more so than water-side free cooling. In a climate like Atlanta, Georgia where there is more latent load, water-side free cooling would be more encouraged if river water temperatures ever dropped below 44 degrees.

The location of water cooled chillers, the heat exchanger, additional pumps, and the SpinClean filter within the building was investigated. It was concluded that the rentable space next to the main mechanical room on the third floor of the Harley-Davidson Museum building would be the best location for several reasons. Placing the additional mechanical equipment next to the majority of the existing mechanical equipment allows for easier maintenance and less construction expense. This location was also determined to be the best because of the existing architecture. The rentable space is an open room constructed the same way as the adjacent mechanical room. This room is also not used on a day-to-day bases and there is not an important reason the room must be located in the area it is currently designed to be in. It is recommended that the room be relocated within the existing footprint of the building; however, if the architect decided to expand the building by an equal amount of area displaced by the additional mechanical room, it would result in approximately $200,000.00 more to the overall construction cost. This cost was not considered in the life cycle cost analysis.

2.4 Air-Cooled vs. Water-Cooled Assessment

When comparing all three alternatives it is important to look not only at how much energy is saved, but also environmental impact and capital cost. Figure 39 and Figure 40 illustrates the energy consumption of the three alternatives. With the decrease in chiller energy consumption and less energy used to pump river water relative to what a cooling tower consumes, it is clear that Alternative Three uses the least amount of energy.

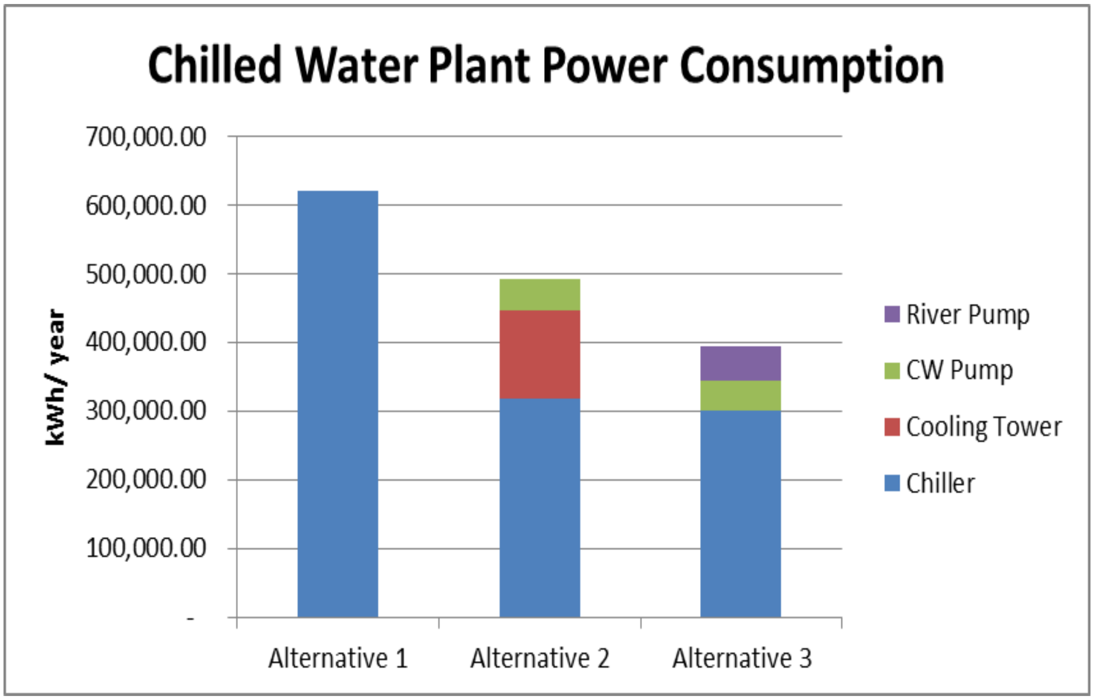


Figure 39 – Chilled Water Plant Power Consumption

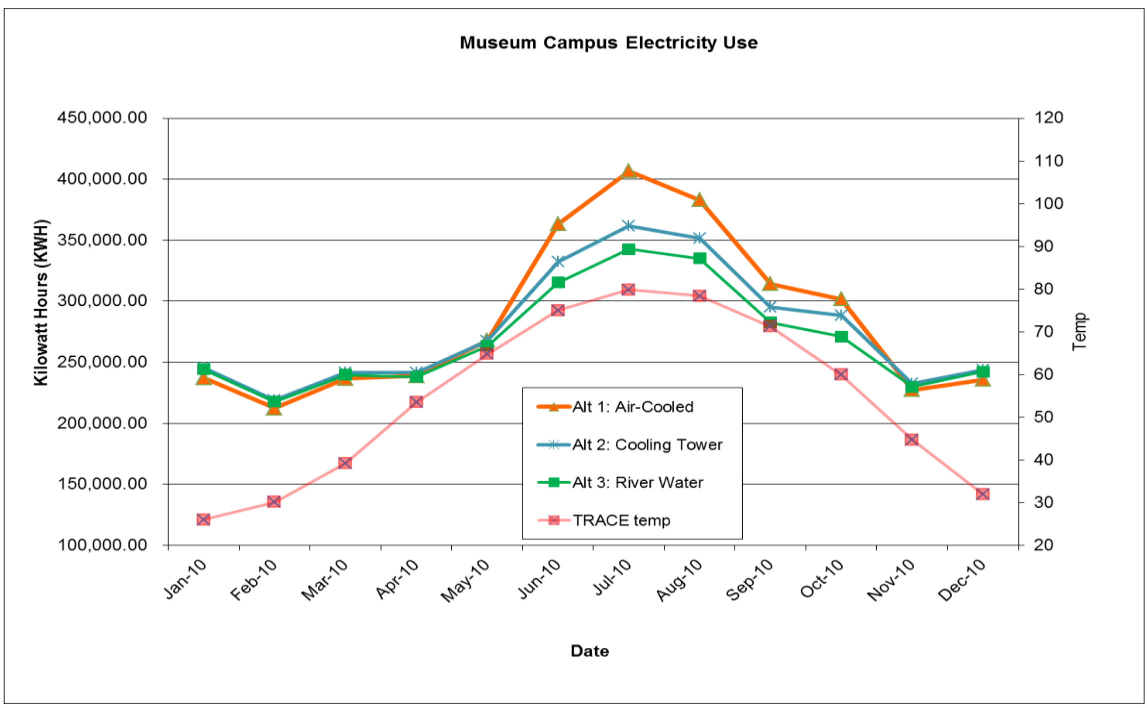


Figure 40 – Yearly Profile of Campus Electricity Use

Not only does Alternative Three consume the least amount of energy, it also does not consume any more purchased water than the existing air-cooled system. Alternative Three has the least amount of global warming potential with only 8.57E6 lbs of Co_{2eq}. This reduction of $Co_{2eq,}$ relative to the existing case, would be equal to planting 42 acres of forests. Alternative Three does however have the highest capital cost. The additional capital cost has a simple payback period of 2.8 years, which is typically acceptable by most building owners.

Table 29 – Total Facility Consumption Comparison

Consumption Comparison			
	Elec	Water	Gas
	kWh	1000gal	therms
Alternative 1	3,438,613.00	74.90	37,736.30
Alternative 2	3,320,478.00	2,580.00	37,736.30
Alternative 3	3,222,622.00	74.90	37,736.30
Best Alternative	3	1,3	1,2,3

Table 30 – Alternative Comparison

Alternative Comparison								
		Capital	First Year Expense	Simple Payback (Years)	Discount Payback (Years)	30 year LCC	30 Year Savings	*Total CO2e (lb):
Base Case	Alternative 1	$550,000.00	$ 156,965.89	-	-	$4,046,288.09	0	9.01E+06
	Alternative 2	**$507,145.00**	$ 149,806.23	-	-	$ 3,861,471.04	$184,817.04	8.77E+06
	Alternative 3	$611,400.00	**$ 135,233.23**	2.8	3.0	**$ 3,656,301.16**	**$389,986.93**	**8.57E+06**

2.5 Air-Cooled vs. Water-Cooled Depth Conclusion

The water-cooled system using that adjacent river for heat rejection has proven to be the best system overall for the Harley-Davidson Museum. The increased capital expense of $61,400.00 has a short payback of 3 years and over the span of 30 years could save the building owner $389,986.93. This system does however have its weaknesses. Alternative Three is the most complex and unconventional system, meaning the predictability of future performance and maintenance is low. If this design was to be implemented, future work of this project should focus on obtaining appropriate licenses and a more in-depth onsite study should be conducted on the variability of river water temperatures.

Section Three Electrical Breadth

The Harley-Davidson Museum was modeled to use 3.4 million kWh of purchased electricity and 3.6 million kBtu of natural gas every year. This is equivalent to emitting 9 million pounds of CO_2 into the atmosphere every year. There are several factors to consider when using power from the grid. Only about 33 percent of the electricity produced by the power plant is usable energy, the remaining 66 percent is lost through production and transmission. Relying on the grid exposes the facility to potential surges, brownouts, and unexpected service interruptions, and requires investments in backup solutions, such as an on-site gas generator that sits idle most of the time. With increasing energy costs and growing concern on the environment, on-site generation is becoming a valued alternative to the grid. The design of the combined heat and power system is diagramed in Figure 41. Waste heat from energy production will be supplied to a boiler which will add the extra heat, if needed, to heating loads and an absorbtion chiller for cooling loads. Generating power on-site, rather than centrally, eliminates cost, complexity, interdependencies, and inefficiencies associated with transmission and distribution, and shifts control to the consumer. Utilizing the waste heat is essentially free energy; therefore, the CHP system will be designed to maximize thermal utilization.

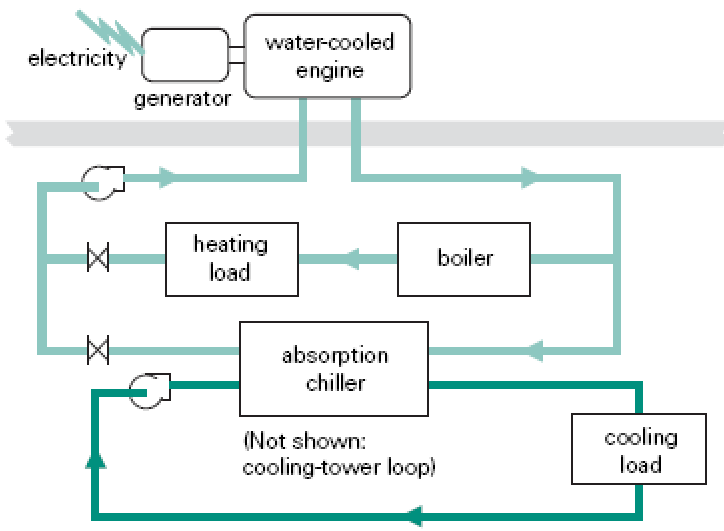


Figure 41 – CHP diagram from TRANE

This electrical breadth will study the valued alternative of on-site generation. An investigation of the feasibility of cogeneration will first be conducted based on economics and practicality. An in-depth design of the cogeneration system will not by deliberate in this electrical breadth. An analysis on the electrical design characteristics and the codes governed by the National Electric Code will be analyzed and is the focus of this electrical breadth.

3.1 Tri-generation – Combined Heat & Power Development Process

The U.S. Environmental Protection Agency (EPA) Combined Heat and Power (CHP) Partnership is a voluntary program that seeks to reduce the environmental impact of power generation by promoting the use of CHP. The feasibility study for this thesis follows stage 1 and stage 2 guidelines from the EPA CHP Partnership outlined in Figure 42.

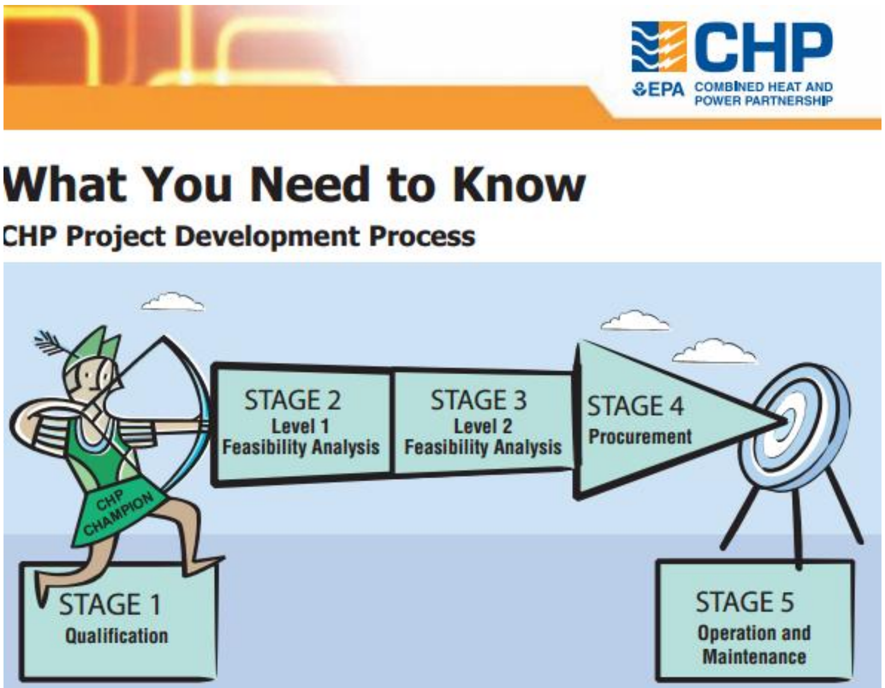


Figure 42 – EPA CHP Design Process

3.2 Tri-generation – Combined Heat & Power Qualification

Stage 1 determines whether CHP is worth considering at the facility. The purpose of qualification is to eliminate sites where CHP does not make technical or economic sense. Preliminary questions are provided by the EPA for a base of qualification. If three of more of the questions listed in Figure 43 are answered "yes" then the facility might be a good candidate for CHP. Eight of the questions were answered "yes"; therefore, the facility should be investigated further and stage 2, level 1 feasibility analysis should be conducted.

Another qualification is consideration of the "spark gap" which is the price difference between electricity and fuel used by the CHP system. With electric cost at $0.10/kWh and gas prices at $0.80/therm and converting to the common unit of MMBTU the price of power equals $29.30/MMBTU and $8.00/MMBTU respectively. This means that the spark gap is $21/MMBTU and is well above the minimum general rule of $12/MMBTU.

Is My Facility a Good Candidate for CHP?

STEP 1

Please check the boxes that apply to you:

- [x] Do you pay more than $.07/ kilowatt-hours on average for electricity (including generation, transmission, and distribution)?
- [x] Are you concerned about the impact of current or future energy costs on your business?
- [x] Is your facility located in a deregulated electricity market?
- [x] Are you concerned about power reliability? Is there a substantial financial impact to your business if the power goes out for 1 hour? For 5 minutes?
- [x] Does your facility operate for more than 5,000 hours/year?
- [x] Do you have thermal loads throughout the year (including steam, hot water, chilled water, hot air, etc.)?
- [ ] Does your facility have an existing central plant?
- [ ] Do you expect to replace, upgrade, or retrofit central plant equipment within the next 3-5 years?
- [ ] Do you anticipate a facility expansion or new construction project within the next 3-5 years?
- [x] Have you already implemented energy efficiency measures and still have high energy costs?
- [x] Are you interested in reducing your facility's impact on the environment?

Figure 43 – CHP Qualification Checklist

3.3 Tri-generation – Combined Heat & Power Feasibility

A Level 1 Feasibility Analysis is the first step in determining the economic viability of CHP at a site. This analysis is characteristically to provide information on project economics to allow an end user to make decisions regarding further investment. In this study the feasibility analysis is used to appropriately size and select a prime mover, analyze preliminary economic benefits, and to study the environmental impact of the CHP system. System sizing is based on estimated loads and schedules for thermal and electrical demand. These loads we calculated based on the energy model used in the depth analysis of this thesis. The economic analysis is a simple payback calculation that takes into account the amount of power and heat produced by the CHP system and the estimated amount of each to be used on-site; the offset costs of utility purchased power and heat; the amount and cost of fuel associated with running the CHP system; and the budgetary cost to install and maintain the system.

Typical separate production of electricity and heat has an efficiency around 56.5%, while combined production of electricity and heat has an total efficiency around 85%. This is illustrated in Figure 44 and was the basis for feasibility calculations. Calculations were conducted through an excel file used in AE551 "Combined Heat and Power." The following figures summarize the feasibility analysis.

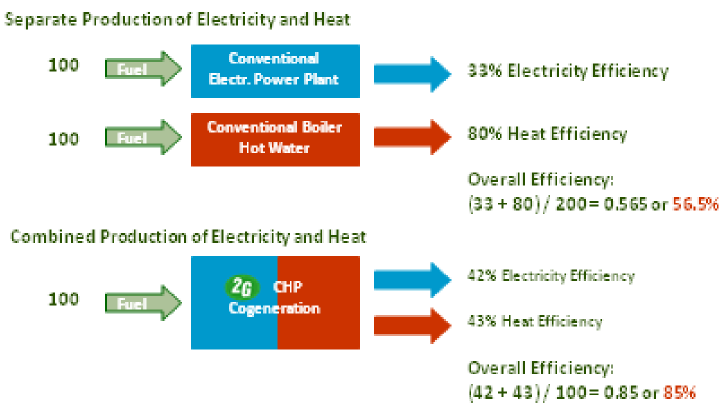


Figure 44 –SHP vs. CHP [Cenergy]

Table 31 – Input Baseline Electric Energy Usage

	Electricity				Fuels	
					Gas	
	Energy	Peak Demand	% of Total Cost from Peak Demand Charges	Cost*	Energy	Cost*
	kWh	*kW*		*$*	*Therms*	*$*
Jan-03	252,717	611	10%	$25,272	12,113	$9,690
Feb-03	225,119	626	10%	$22,512	8,256	$6,605
Mar-03	247,492	631	10%	$24,749	4,217	$3,374
Apr-03	241,526	671	10%	$24,153	3,102	$2,482
May-02	255,900	704	10%	$25,590	3,848	$3,078
Jun-02	281,412	900	10%	$28,141	11,795	$9,436
Jul-02	299,775	932	10%	$29,978	14,495	$11,596
Aug-02	294,522	898	10%	$29,452	13,080	$10,464
Sep-02	257,444	847	10%	$25,744	8,969	$7,175
Oct-02	261,155	799	10%	$26,116	6,960	$5,568
Nov-02	237,578	631	10%	$23,758	3,040	$2,432
Dec-02	250,657	618	10%	$25,066	10,303	$8,242

Table 32 – Input Baseline Rates

Electric Sell Back Desired	No	
Peak Electric Rates Apply	Yes	
Standby Demand Charge	$1.50	$/kw/month
Electric Sell Back Price	1.500	¢/kWh
Cogen Fuel Cost	$8.00	$/MMBTU
W/O Cogen Fuel Cost	$8.00	$/MMBTU
Existing Boiler Efficiency	86	%

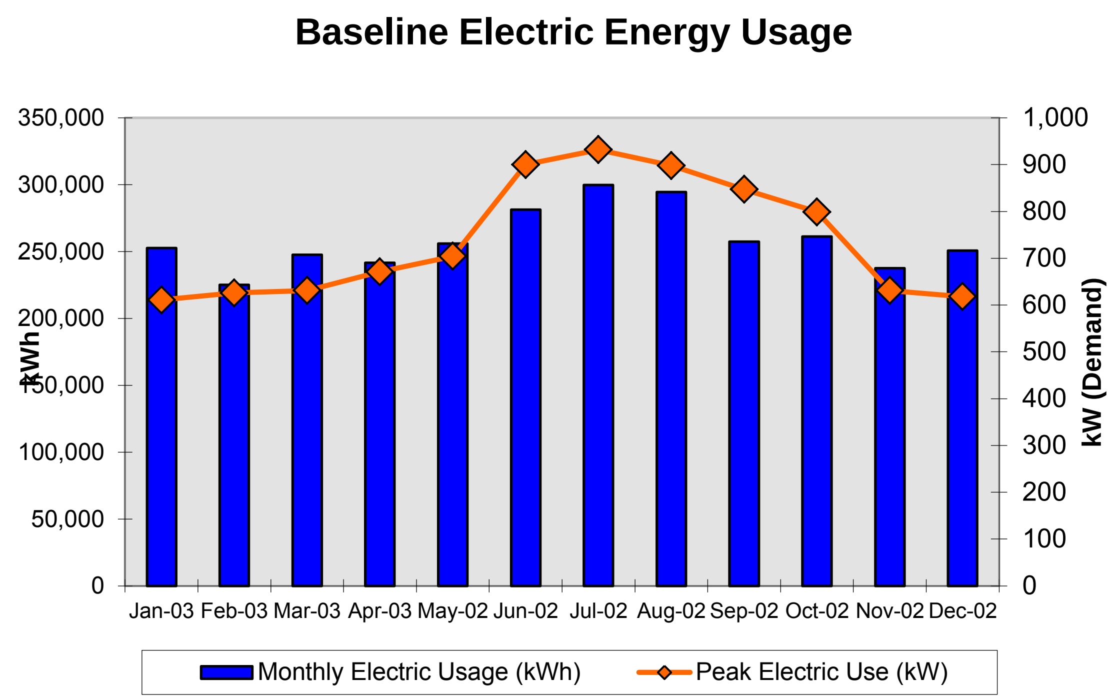


Figure 45 - Baseline Electric Energy Usage

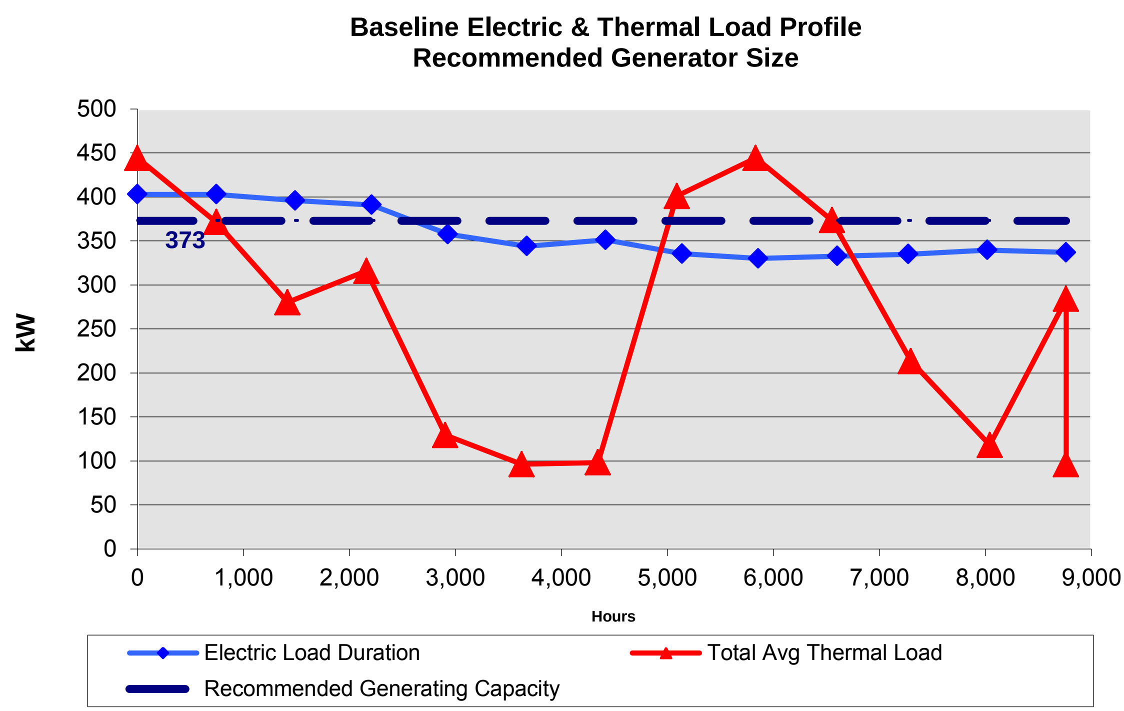


Figure 46 – Baseline Electric & Thermal Load Profile

Table 33 – CHP Economic Results

SITE			
MN Hospital			
1234 W. Main St			
Milwakee		**WI**	
ASSUMPTIONS			
Average Electric Cost		10.000	¢/kWh
Peak Averge Electric Cost		N/A	¢/kWh
Initial Electric Sell Back		1.500	¢/kWh
Supplemental Elect Cost		10.000	¢/kWh
Cogen Initial Fuel Cost		8.00	$/MMBTU
W/O Cogen Fuel Cost		8.00	$/MMBTU
Existing Boiler Efficiency		86.0	%
Standby Demand Charge		$1.50	$/kw/month
Standby Capacity Required		373	kW
O&M Charge		$4,943	$/yr
Annual Electric Load		3,105	MWh
Annual Heat Load		7,795	MMBTU
PURPA	(Assuming Gas or Liquid Fuel Fired)		
Efficiency		55.4	%
Qualified Facility		Yes	
Sell Back		0	kWh
Sell Back Desired		No	
FINANCIAL RESULTS			
COSTS WITHOUT COGENERATION $(1000)			
Electricity Costs			$311
Thermal Energy Costs			$80
		TOTAL	$391
COSTS WITH COGENERATION $(1000)			
Supplemental Electric Purchase			$1
Peak Electric Charge Adjustment			($31)
Fuel			$269
Electricity Sold			$0
O&M			$5
Standby Charges			$7
		TOTAL	$251
	SAVINGS		**$140**
	SIMPLE PAYBACK	**4.04**	**Years**

RESULTS		
CHP RESULTS		
Prime Mover		
Total ECP Cost	$564	$(1000)
Prime Mover	Gas Engine	
Parasitic Load	2.7	kW
Total Generation Capacity	373	kW
Electrical Output	3,035	MWh
Absorption Chiller Credit	60	MWh
Net Total Generation Effect	3,095	MWh
Elecectric Capacity Factor	93	%
Gross Heat Rate (LHV)	10,038	BTU/kWh
Recoverable Heat	4,305	BTU/kWh
Thermal Loads		
TAT Thermal Loads (June, July, August)		
Absorption Chiller	1,795	MMBTU
Desiccant	0	MMBTU
Total Thermal Load with TAT	9,590	MMBTU
Thermal Capacity Factor	78	%
Thermal Energy Output		
From Generator	13,065	MMBTU
From Auxiliary Boiler	0	MMBTU
Fuel Requirements:		
For Generator (HHV)	33,669	MMBTU
For Auxiliary Boiler (HHV)	0	MMBTU
Generation Costs	**8.88**	**¢/kWh**

3.4 Tri-Generation – Combined Heat & Power Emissions

The Excel program file developed by the U.S. Department of Energy's Distributed Energy Program and Oak Ridge National Laboratory was used to conduct an analysis on the emissions of the CHP alternative. The program compares separate heat and power (SHP) emissions to CHP emissions. It was concluded that the SHP emissions for CO_2 is 4212 tons/year from electricity production and 898 tons/year from thermal production. The program calculated CHP emissions to be 1,924 tons/year. This is a CO_2 reduction of 62% or an equivalent reduction of 342 cars or 372 acres of pine forest. Figure 47 illustrates the energy consumption, production, and emissions for both SHP and CHP.

CHP Results

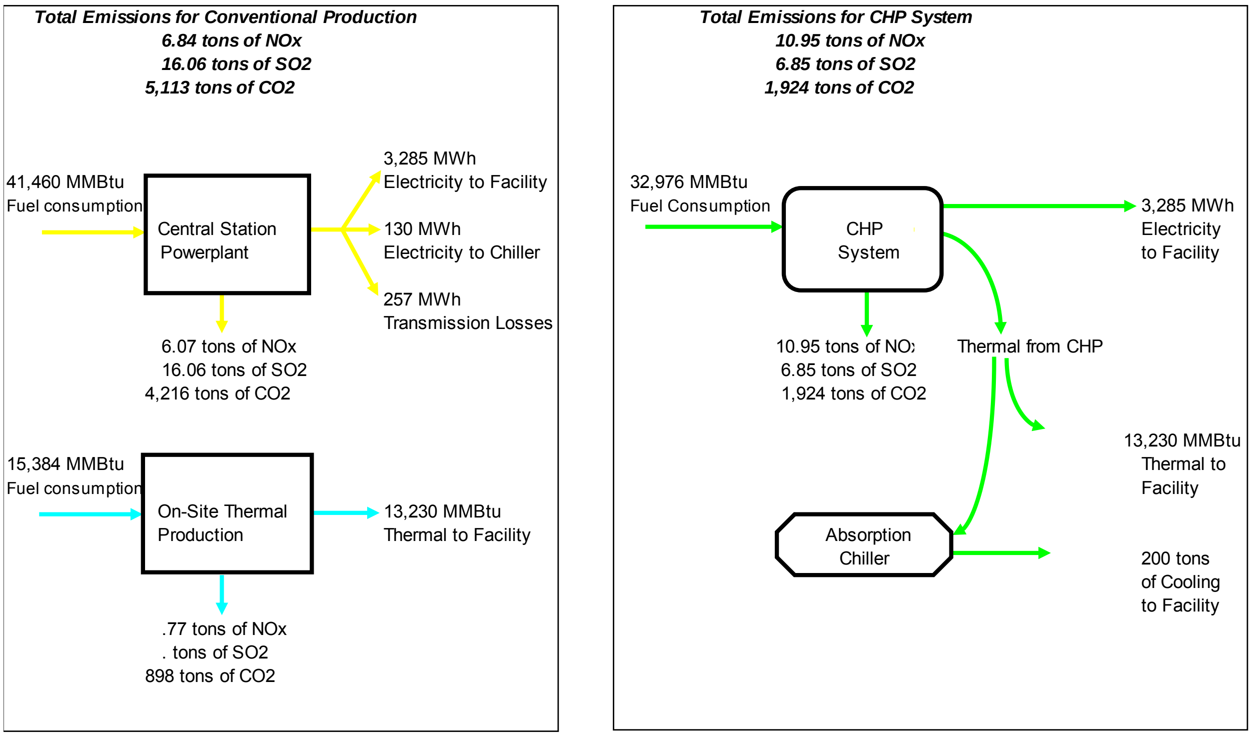


Figure 47 – SHP and CHP Energy Diagram

3.5 Tri-Generation – Combined Heat & Power Feasibility Conclusion

Based on the feasibility analysis it was determined that a 373 kW Gas Engine will produce 100% of the thermal load while producing nearly 100% of the electric load. Generation cost is 8.88 cents per kWh. This is 1.12 cents per kWh less than purchased electricity. With the added savings of thermal energy production, the annual savings is $140,000.00. Additional savings can be accrued if the river water heat rejection system is used in conjunction with absorption chilled water production. The CHP tri-generation system has a capital cost of $563,785.00 which accounts for the generator, heat recovery unit, absorption chiller, and installation, while subtracting the displaced electric chiller cost and backup generator cost. Thus, there is an acceptable 4.04 year payback on the system, concluding that a CHP system would be feasible at the Harley-Davidson Museum facility.

3.6 Tri-generation – Combined Heat & Power Equipment Selection

The *2G 380 NG* modular combined heat and power generator was selected from Cenergy Advanced Clean Energy Technologies, detailed in Appendix D. This generator has a rating of 380 ekW at 60Hz, thermal BTU usable of 1,835,732 , electrical efficiency of 37.2%, thermal efficiency of 52.60%, and a total system efficiency of 89.90%. This generator is more efficient than assumptions made during the feasibility analysis. The generator should be placed in the generator room where the existing backup generator was designed to be installed.

3.7 Tri-generation – Combined Heat & Power Electrical considerations

There are many electrical design conditions that must be considered when designing a CHP system. Risks in poorly designing electrical interconnection to the main utility could include failure of life safety power and security systems failure. It is important to have a design with high redundancy and reliability to allow the building's owner to feel secure and confident in their CHP system.

The interconnection between the CHP facility and the local utility is critical. Where two generator sets are in parallel, they must have the same voltage, phase sequence frequencies, and their output voltages must be in phase, see Figure 48. This is a concern in the Harley-Davidson Museum CHP system because the onsite generator will be paralleled with the main utility and will act as a supplement to the power purchased from the serving utility.

The CHP design for the Harley-Davidson Museum is a base load design, meaning the facility will use the energy generated by the CHP plant up to its maximum capability and will only use a separate utility source when its needs exceed the capacity of the CHP system. In this case the main switchgear must be capable of being fed by both a utility source and the CHP source. Because the CHP system is in parallel with the utility and for reasons stated earlier, the switchgear must have a synchronizing system which ensures that all electric power generated is operating together at the same rated voltage, frequency, and phase. A prime mover load controller is needed to ensure that power from all sources are balanced and efficient. This is accomplished with a frequency relay, which is a high-speed relay that separates the utility and generator sources whenever the frequency drops below the designed 60Hz. Then, the engine governor will vary the speed of the engine to match the bus frequency of the utility.

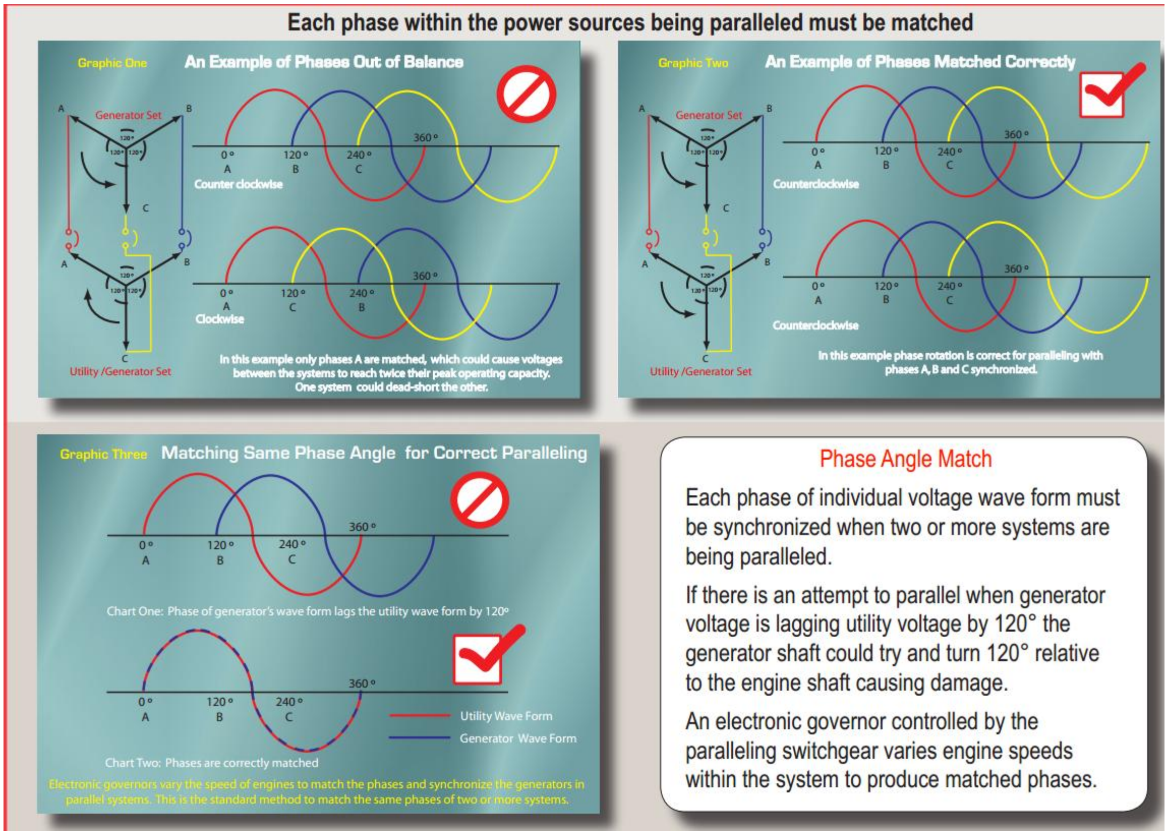


Figure 48 – Phase Angle Match from Kraft Power

Figure 49 and Figure 50 illustrate the existing utility connection to building loads and how the generator and utility should be connected in a paralleling CHP system.

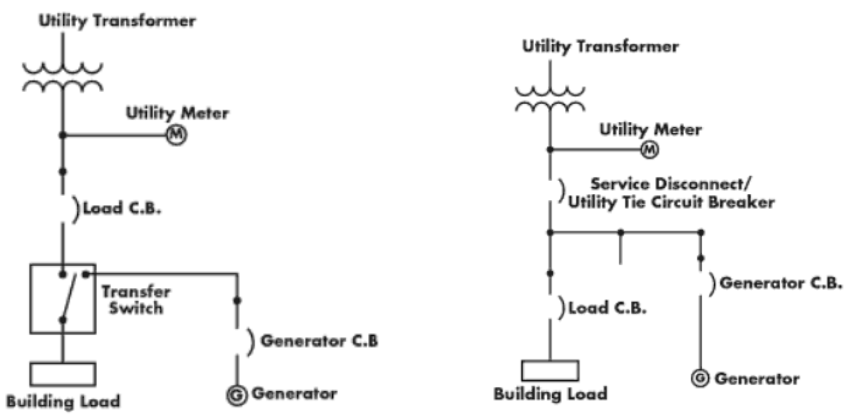


Figure 49 – Existing Single Line and CHP Parallel Connection - Single Line Diagrams by: Author Neil Petchers

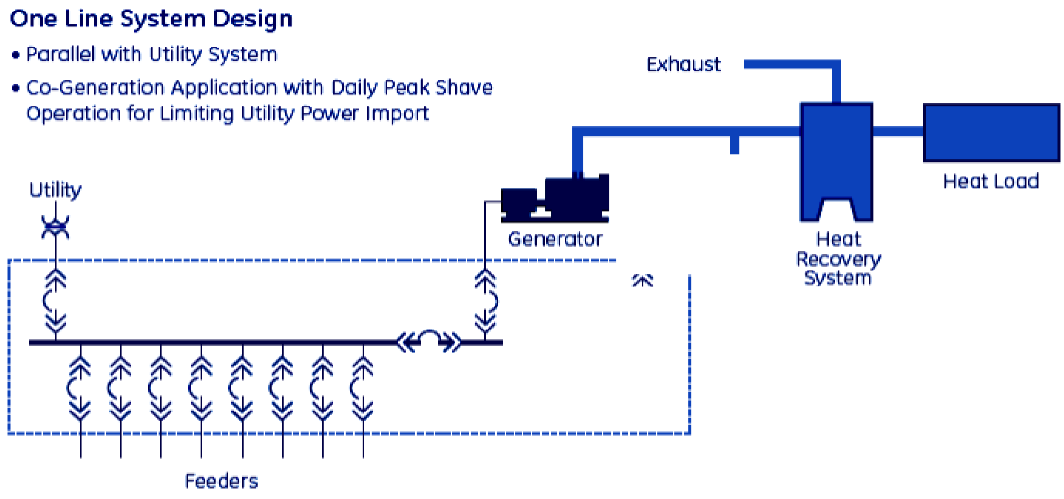


Figure 50 – One Line System Design GE diagram

According to the National Electric Code (NEC) section 445.13, the ampacity of conductors coming from the generator terminals to the first distribution device(s) containing overcurrent protection shall not be less than 115 percent of the nameplate current rating of the generator. It shall be permitted to size the neutral conductors in accordance with NEC 220.61.

$$Amps = \frac{kW * Power\ factor}{\sqrt{3} * Volts} \rightarrow \frac{380 * 0.9}{\sqrt{3} * 480} = 411.36\ amps$$

$$1.15 * 411.36 = 473.064\ amps$$

Using THHN - thermoplastic high heat resistant nylon coated conductors it is determined from table 310.16 in the NEC that the size of each current carrying conductor should be 600kcmil. Therefore, there should be three 600kcmil current carrying conductors and a neutral from the generator terminal to the first distribution device(s). An alternate solution could be six 4/0 AWG CC conductors and one neutral.

The NEC defines a CHP generator as a separately derived system, meaning the generator serves a facility with energy separate from the utility. Because of this, there are codes governed by the NEC for grounding and bonding the CHP generator and plant with the facility electrical distribution system. According to ProSpex, grounding means connected to the earth and is the process of joining all non-current-carrying conductors in the electrical system and making a low-resistance connection between them and the earth or some conducting body that serves in place of the earth. Bonding means connected to establish electrical continuity and conductivity. It is the permanent joining of metallic parts to form an electrically conductive path that ensures both electrical continuity and the capacity to safely conduct any current likely to be imposed on such metallic parts. Bonded systems are neither designed nor intended to carry current as part of the electrical system but they must be able to safely do so in the event that current is imposed on them. A system bonding jumper is a connection between the grounding conductors of the CHP generator and the grounded neutral conductor in the main switchgear, and is a vital connection necessary so that ground fault current can return to the utility source.

A separately derived system must be grounded and bonded as per NEC section 250.30 and NEC table 250.66. A grounding electrode conductor should be sized based on the largest ungrounded service-entrance conductor or equivalent area for parallel conductors; therefore, the conductor for the generator should be sized as copper 1/0 AWG.

3.8 Tri-generation – Combined Heat & Power Electrical Breadth Conclusion

This study has concluded that combined heat and power is feasible and would save the building owner approximately 140 thousand dollars every year with a simple payback of 4.04 years. The CHP system would also reduce emissions by 62 percent, which is equivalent to planting 373 acres of forest. It should be noted that this study is only a preliminary study and is intended to only determine if CHP is feasible at the facility and to investigate the electrical design considerations.

There are many important design considerations of the electrical system. A CHP system runs parallel to the utility. For this reason, there are many other complex requirements. The protection and safety of equipment and building occupants is of high concern when designing electrical systems. It is important that the utility and generator are operating together at the same rated voltage, frequency, and phase.

There are many other requirements and regulations that govern the interconnection of the CHP system and utility that are not discussed in this study. The design considerations analyzed in this study were based on information covered in AE 467 - Advanced Building Electrical System Design and AE 551 - Combined Heat and Power.

The Harley-Davidson Museum is a good candidate for CHP because of its occupancy profile and energy consumption profile. The facility has a fairly flat daily electrical profile because of the need for high security 24/7 and the need for lighting at night. The thermal load is also fairly flat. Climate variation could harm objects on display and in the archives; therefore, the Harley-Davidson Museum needs to be kept at constant climate conditions, meaning the temperature and humidity should not vary.

Combined heat and power can be a large cost savings for the building owner in the long run. By utilizing “free” energy for heating and cooling, the facility consumes less primary energy, reduces electrical consumption for utility, reduces peak demand on the utility, and reduces emissions. According to a study conducted by Sycom Energy Corporation on CHP utilization for 20 different building sectors, museums utilize CHP the least out of the 20 different sectors of buildings studied; the highest was hospitals. However, this breadth has proven that CHP should be implemented in museums similar to the Harley-Davidson Museum.

Section Four Structural Breadth

The structural system of the Harley-Davidson Museum presents many areas of thermal bridging through the exterior façade. Thermal bridging occurs when there is a conductive path between two separate zones at different temperatures. ASHRAE 189.1 and 90.1 contains tables that list maximum U-values for various envelope assemblies and minimum R-values for insulation. ASHRAE 1365-RP, "thermal performance of Building Envelope Details for Mid- and High-Rise buildings" addresses the issues of thermal bridging by providing thermal transmittance for 40 common building envelope details. This publication does not incorporate thermal transmittance requirements of steel elements that bridge the building envelope; however, according to AISC "American Institute of Steel Construction" recent meetings of the ASHRAE Standing Standards Project Committee 90.1 (SSPC90.1), the Envelope Subcommittee identified several topics for further consideration and development; among them is thermal bridging.

In the Harley-Davidson Museum there are many areas where thermal bridging is present. The most observable conductive thermal bridging path is from structural steel that is fully exposed inside and outside and can be visualized by the infrared image in Figure 51. The relatively high conductivity of steel permits heat to travel in and out of the building, this not only wastes energy, but can also cause condensation when the beam's temperature is below the dew point. When condensation forms there is a potential for corrosion, mold, and other indoor air quality problems. Also, colder interior surfaces can make people feel colder than the ambient air temperature, causing occupants to raise the temperature of the room. To combat these problems, the engineers at HGA utilized heat trace cable to heat the steel as it penetrates the façade when the outdoor temperature is below the point that would cause the steel's temperature to drop below the dew point.

Figure 51 – Infrared image

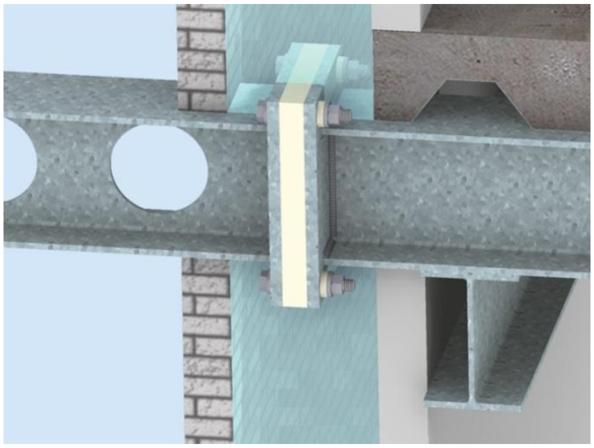


Figure 52 – Thermal Break

The utilization of heat trace is a successful solution to some of the thermal bridging problems; however, it does have its disadvantages. This solution prevents condensation inside when the temperature outside is cold, but it does not address the issue of wasted energy. By heating the beam, not only is energy going into heating the beam inside, but a percentage of the energy will be transferred to the exterior portion of the beam. Another disadvantage is when the outside temperature is hot, the beam will increase in temperature adding undesired cooling load to the space.

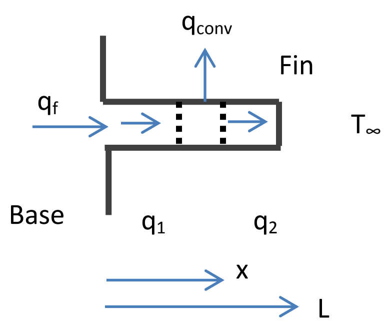
The proposed redesign to the thermal bridging concerns is to create structural thermal breaks in the steel framing where heat trace is used. An example of a potential structural thermal break is in Appendix E and shown in Figure 52. An investigation of the structural properties of the break and the existing structural system loads were investigates in this breadth study and a determination was made as to if the structural breaks will support the structural loads and prevent heat transfer through thermal bridging. The area being studied is shown in the figure below.

Figure 53 – Harley-Davidson Museum

4.1 Heat Transfer from Extended Surface Existing Calculations

Typically when we think about heat transfer from an extended surface we are thinking about the application of fins on heated surfaces to help in the cooling process, or finned-tube heat exchangers that improve the efficiency of the heat exchanger. This is just two applicable examples of heat transfer through extended surfaces. In this study, the extended surfaces in concern are the exposed steel beams that bridge the exterior façade, meaning they are exposed to outdoor climate conditions, penetrate the façade, and are exposed to indoor ambient conditions. This can be a problem for reasons expressed earlier. Before modeling the solution to thermal bridging it was important to gain an understanding of how cold the beams could actually get and how much energy they are wasting. The energy modeling program Trane TRACE uses assumptions on the overall insulation and air leakage performance of typical wall, roof, and fenestration assemblies. It does not directly consider the effect of “hot spots” such as steel bridging details that are prone to heat transfer. For this reason, heat transfer calculations were conducted by hand.

The following calculations are a derivation used to generate an equation to find heat transfer through each exposed beam and temperature distribution though the beam.



The image to the left is an energy balance for an extended surface. Variables are used in the equations below.

Figure 54 – Extended Surface Energy Balance

- Starting with the conservation of energy equation 4.1 was developed.

$q_2 = q_1 + dq$ (From Conservation of Energy) *[4.1]*

$q_x = q_{x+dx} + dq_{conv}$ *[4.2]*

$q_x = -kA_c\frac{dT}{dx}$ (From Fourier's Law) *[4.3]*

$A_c = Cross\ section\ area\ , k = conductivity\ of\ the\ material$

$dq_{conv} = h\ dA_s(T - T_\infty)$ *[4.4]*

$\frac{d}{dx}\left[-kA_c\frac{dT}{dx}\right]dx = hA_s\,(T - T_\infty)$ *[4.5]*

$A_s = P\ dx\ , (P = perimiter)$ *[4.6]*

- Creating a homogeneous equation from equation 4.5 and substituting in for A_s with equation 4.6

$\frac{d^2T}{dx^2} - \frac{hP}{kA_c}(T - T_\infty) = 0$ (Uniform Cross-Sectional Area) *[4.7]*

$\frac{d^2\theta}{dx^2} - m^2\theta = 0$ (Homogeneous Second Order ODE) *[4.8]*

$\frac{d^2\theta}{dx^2} - m^2\theta = 0 \rightarrow \theta(x) = C_1e^{mx} + C_2e^{-mx}$ (General Solution) *[4.9]*

$m^2 \equiv \left(\frac{hP}{kA_c}\right)$ *[4.10]*

$\theta = T - T_\infty$ *[4.11]*

- Conduction at the base is equal to the total convective heat transfer

$$q_f = -kA_c \frac{d\theta}{dx}\bigg|_{x=0} = \int_{A_F} h\theta(x)dA_s \Big\} \ q_{cond} \text{ at base of fin } [4.12]$$

- Apply Boundary Conditions at x = 0

$$\theta(0) = \theta(b) = T(0) - T_\infty = C_1 + C_2 \ [4.13]$$

$$C_2 = \theta_b - C_1 [4.14]$$

- Assume Adiabatic Tip Boundary Condition

$$\frac{dT}{dx}\bigg|_{x=L} = 0 = C_1 e^{mL} - C_2 e^{-mL} = C_1 e^{mL} - (\theta_b - C_1)e^{-mL} \ \text{(Adiabatic Tip)} \ [4.15]$$

$$C_1 = \frac{\theta_b e^{-mL}}{e^{mL} + e^{-mL}} \ [4.16]$$

- Substitute into general solution

$$\theta(x) = C_1 e^{mL} - C_2 e^{-mL} = \theta_b e^{mx} - \frac{(\theta_b)e^{-mx}}{e^{mL} + e^{-mL}} + \theta_b e^{-mx} \ [4.17]$$

$$\frac{\theta(x)}{\theta_b} = \frac{e^{-mL}(e^{mx} - e^{-mx})}{e^{mL} + e^{-mL}} - e^{-mx} = e^{m(L-x)} + \frac{e^{-m(L-x)}}{e^{mL} + e^{-mL}} \ [4.18]$$

- Using sinh and cosh

$$\sinh(x) = \frac{1}{2}(e^{-x} - e^x), \quad \cosh(x) = \frac{1}{2}(e^{-x} + e^x) \ [4.19]$$

- To give

$$\frac{\theta(x)}{\theta_b} = \frac{\cosh[\mathrm{m(L-x)}]}{\cosh(ml)} \ [4.20]$$

$$q_f = -kA_c \frac{dT}{dx}\bigg|_{x=0} = M\tanh(mL) \ [4.21]$$

- Where

$$m = \sqrt{\frac{hP}{kA_c}} \quad \text{and} \quad M = \sqrt{hPkA_c}\,(T_b - T_\infty) \ [4.22]$$

The below graph illustrates the tanh function and shows how as length approaches infinity the value of the function asymptotically approaches solitude. This means, as the beam's length approaches infinity or for all intensive purposes of this study is greater than 2 meters, equation 4.21 equals M, defined in equation 4.22.

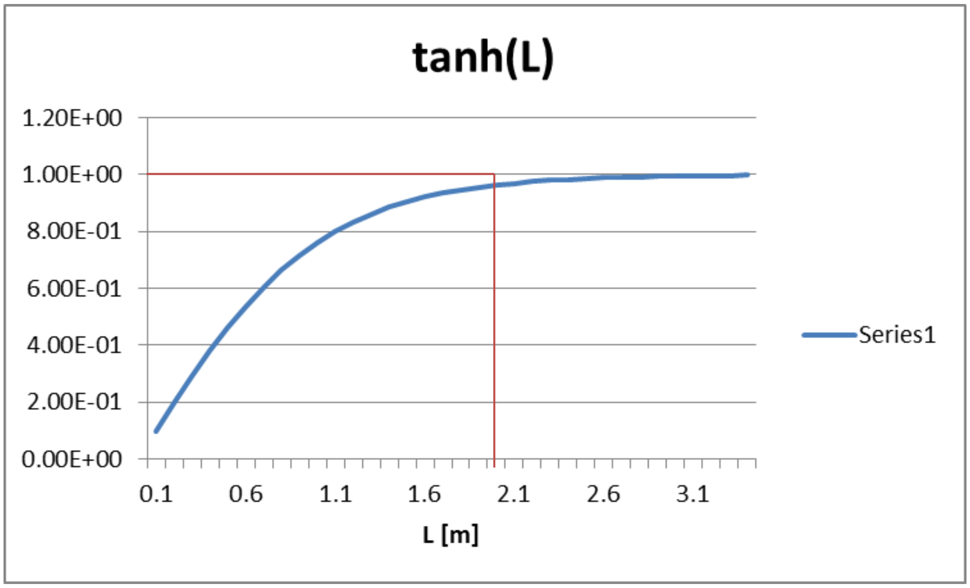


Figure 55 – tanh Function

In order to calculate$M$, T_b must be determined. T_b is the base temperature of the extended surface. In this study, T_b is the temperature of the beam when it passes through the exterior façade of the building.

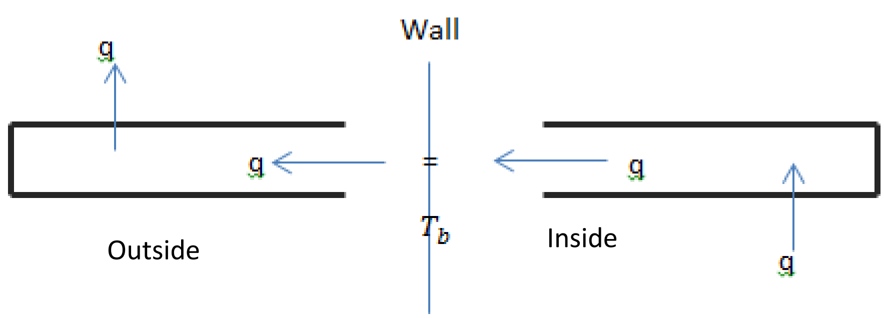


Figure 56 – Double Extended Surface Heat Transfer Energy Balance

The beam passing through the wall can be thought of as two extended surfaces joined together at the wall. All heat absorbed by the interior portion of the beam will be equal to the heat rejected by the exterior portion of the beam. This means that T_b is a common temperature point.

$$q_{outside} = -q_{inside} \rightarrow M_{ouside} = M_{inside} \quad [4.23]$$

$$\sqrt{h_o P k A_c}\left(T_b - T_{\infty_o}\right) = -\sqrt{h_i P k A_c}\left(T_b - T_{\infty_i}\right) \quad [4.24]$$

Constants:

$$k = Conductivity\ of\ steal = 43\frac{W}{m^2K}$$

$$A_c = \text{Cross section area of a W40x149} = 0.047\ \text{m}^2$$

$$h_o = Convective\ heat\ transfer\ coefficient\ of\ outside\ air = 30\frac{W}{m^2K}$$

$$h_i = Convective\ heat\ transfer\ coefficient\ of\ inside\ air = 15\frac{W}{m^2K}$$

$$T_{\infty_o} = Outside\ air\ temperature = 0\ ^0F$$

$$T_{\infty_i} = Outside\ air\ temperature = 72\ ^0F$$

Solving for T_b from equation 4.24

$$T_b = \frac{\sqrt{h_i}\,T_{\infty_i} + \sqrt{h_o}\,T_{\infty_o}}{\sqrt{h_o}+\sqrt{h_i}} = \mathbf{29.8\ ^oF} \quad [4.25]$$

Now that T_b is defined for the conservative ambient conditions defined, the total heat transferred through the beam can be calculated using equation 4.21 and remembering that the length of the beam can be thought of as infinite, thus equation 4.21 = M.

$$M = \sqrt{hPkA_c}\,(T_b - T_\infty) = \mathbf{422\ Watts} \quad [4.26]$$

4.1.2 Heat Transfer from Extended Surface Existing Calculations Conclusion

The above calculations have determined that the coldest temperature of the beam when the outside air temperature is near zero degrees will be $29.8\,^oF$. This is well below the dew point of $53\,^oF$ shown in Figure 57. It was also concluded that the amount of energy wasted is $422\frac{Watts}{beam}$. The main gallery space has 10 exposed beams corresponding to 4,220 Watts or 4.2kW of wasted energy. Calculations were done for every hour of an average day per month and then multiplied by the number of days each month to find the annual energy transfer through one beam to be 1,379.39 kWh. Table 34 summarizes the calculation for the month of January. This equals $1,379.39 for all ten exposed beam in the main gallery space. There are other areas in the building that have thermal bridging; however, the main gallery space is the focus of this study.

Table 34 – 24 hr. Energy Profile

January	Typical Weather (°F)	Tb	M	Days	W*hr*days
Hour	OADB		qf		
1	3.5	31.87363	401.4646	31	12,445.40
2	3.29	31.75061	402.6953	31	12,483.55
3	3.5	31.87363	401.4646	31	12,445.40
4	4	32.16652	398.5342	31	12,354.56
5	4.9	32.69373	393.2594	31	12,191.04
6	6	33.3381	386.8126	31	11,991.19
7	7.3	34.09962	379.1935	31	11,755.00
8	8.8	34.9783	370.4023	31	11,482.47
9	10.3	35.85698	361.6111	31	11,209.95
10	11.69	36.67122	353.4646	31	10,957.40
11	13.1	37.49718	345.2009	31	10,701.23
12	14.19	38.13569	338.8126	31	10,503.19
13	15.1	38.66875	333.4793	31	10,337.86
14	15.6	38.96164	330.5489	31	10,247.02
15	15.8	39.0788	329.3768	31	10,210.68
16	15.5	38.90307	331.135	31	10,265.18
17	14.8	38.49302	335.2376	31	10,392.36
18	13.6	37.79007	342.2705	31	10,610.39
19	12.1	36.91139	351.0617	31	10,882.91
20	10.39	35.9097	361.0837	31	11,193.59
21	8.6	34.86114	371.5745	31	11,518.81
22	6.9	33.8653	381.5378	31	11,827.67
23	5.4	32.98662	390.329	31	12,100.20
24	4.3	32.34226	396.7759	31	12,300.05
		TOTAL	**8787.326**	31	**272,407.12**

The existing solution wraps the beams in heat trace. This heats up the beam so there is no heat transfer from the inside and outside; thus, there will be no condensation leading to mold, poor indoor air quality, and occupant health problems. It is estimated that the heat trace consumes the same amount of energy which would otherwise be wasted by the exposed beam, $422\frac{Watts}{beam}$ for the condition studied.

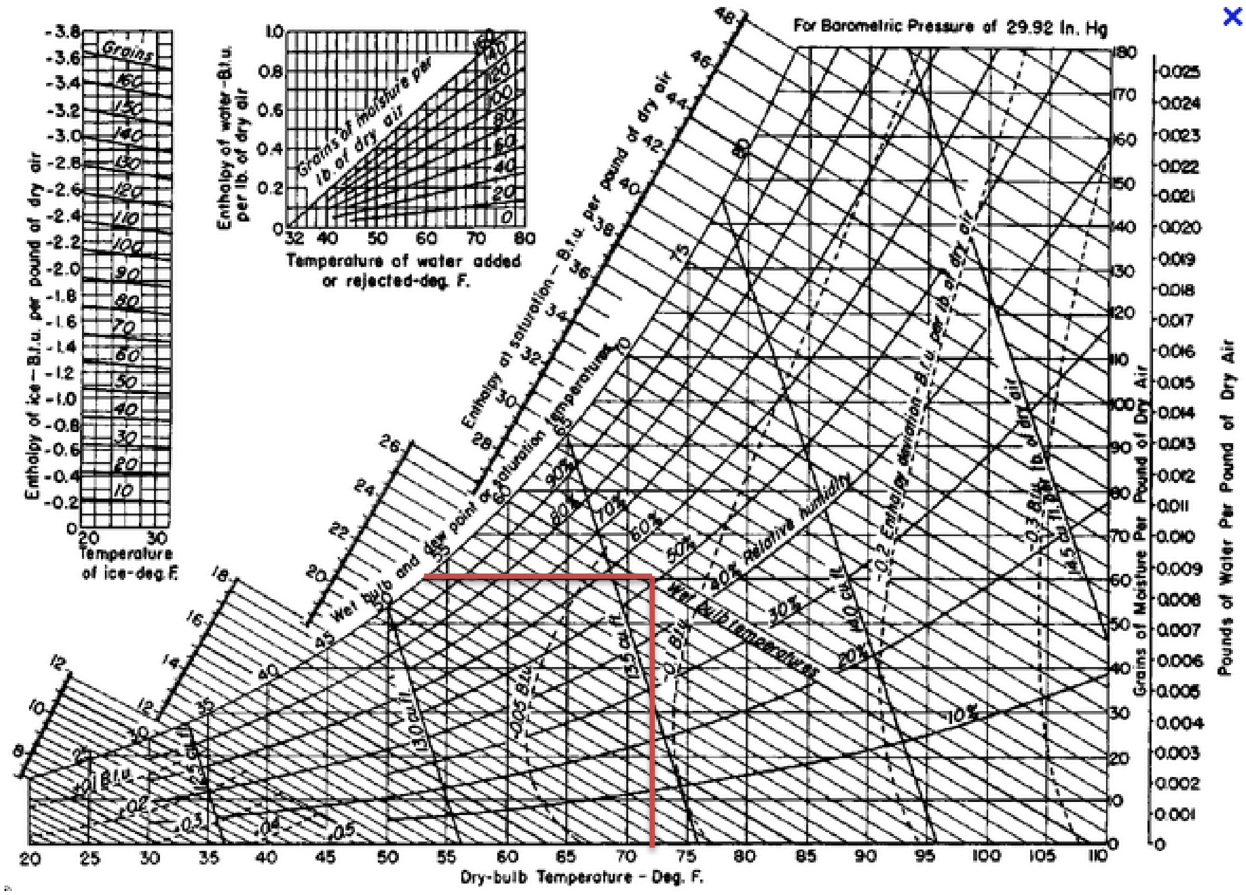


Figure 57 – Psychometric Chart

4.2.1 Heat Transfer from Extended Surface Alternative

The proposed redesign is to solve the heat transfer problem at the source, meaning to stop heat transfer from ever occurring. Fabreeka has developed a product that is manufactured from a fiberglass-reinforced laminate composite and acts as a thermal break in the structural system. In order to determine if this product is a good solution to the thermal bridging problem, several studies needed to be analyzed further involving heat transfer and structural stability.

4.2.2 Heat Transfer from Extended Surface Alternative Thermal Study

The first study conducted was an analysis on the heat transfer through the thermal break. The thermal break adds additional complexities to the equations in section 4.1, but the governing equations remain the same. Figure 58 is a diagram of the thermal circuit of the extended surface with the thermal break.

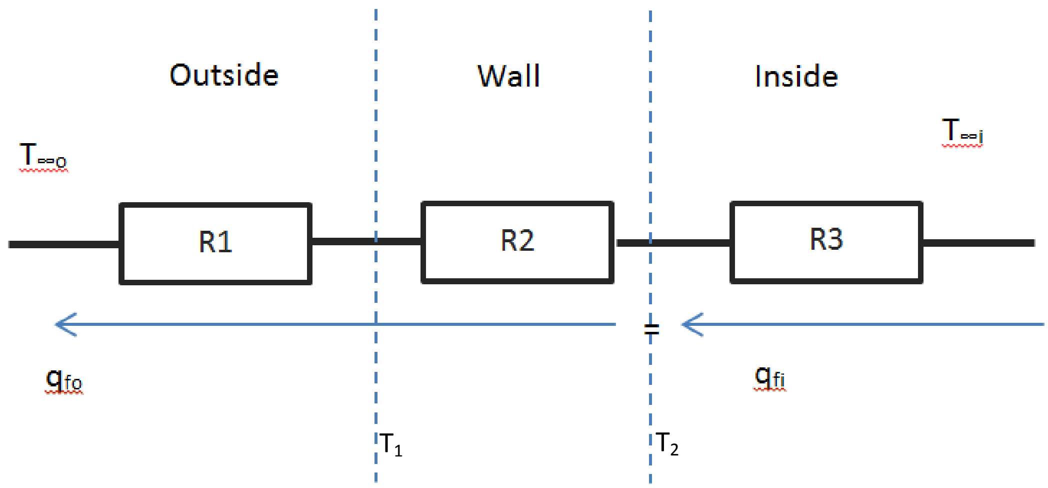


Figure 58 – Resistance circuit

$R1, R_2$ *and* R_3 is the resistance through the exterior portion of the beam, thermal break, and interior portion of the beam, respectively.

$$R1 = \frac{\Delta T}{q} \rightarrow \frac{\Delta T}{\sqrt{h_o P k A_c}\,\Delta T} \rightarrow \frac{1}{\sqrt{h_o P k A_c}} \quad [4.27]$$

$$R_2 = \frac{L_r}{k_r A_c} \quad [4.28]$$

$$R_3 = \frac{\Delta T}{q_{fi}} \rightarrow \frac{\Delta T}{\sqrt{h_i P k A_c}\,\Delta T} \rightarrow \frac{1}{\sqrt{h_i P k A_c}} \quad [4.29]$$

L_r = Length of insulation in thermal break = 1" , 0.0254m

k_r = Conductivity of insulation in thermal break = 0.259 w/m*K

The heat transfer through the exterior portion of the beam including the thermal break (q_{fo}), is equal to the difference in temperature divided by the total resistance.

$$q_{fo} = \frac{T_2 - T_{\infty_o}}{R_1 + R_2} \rightarrow \frac{T_2 - T_{\infty_o}}{\left(\frac{1}{\sqrt{h_o P k A_c}} + \frac{L_r}{k_r A_c}\right)} \quad [4.30]$$

$$q_{f_i} = \sqrt{h_i P k A_c}\,(T_2 - T_{\infty_i}) \quad [4.31]$$

$$q_{f_o} = -q_{f_i} \rightarrow \frac{T_2 - T_{\infty_o}}{\left(\frac{1}{\sqrt{h_o P k A_c}} + \frac{L_r}{k_r A_c}\right)} = -\sqrt{h_i P k A_c}\,(T_2 - T_{\infty_i}) \quad [4.32]$$

Solving to T_2

$$T_2 = \frac{\sqrt{h_i PKA_c}\left(\frac{1}{\sqrt{h_O PkA_c}}+\frac{Lr}{k_r A_c}\right)T_{\infty 2}+T_{\infty i}}{1+\sqrt{h_2 PkA_c}\left(\frac{1}{\sqrt{h_O PkA_c}}+\frac{Lr}{k_r A_c}\right)} \quad [4.33]$$

Now that T_2 is equated, heat transfer through the beam can be calculated using equation 4.30 or equation 4.31. With the same environmental conditions as the existing conditions study the heat transfer through the beam is only 31 Watts and the lowest temperature of the inside potion of the beam will be 69 degrees. This results a savings of 390 Watts and is well above the dew point temperature. The same yearly profile study that was conducted on the existing case was conducted on the design alternative and resulted in a total savings of 1,272.19 kWh equaling $1,271.19 per year in the main gallery space alone. This solution also does not have the complexity involved with controls needed for the existing design.

Cost information could not be obtained by Fabreeka for their thermal insulation material. For there to be an economical simple payback of 5 years, the thermal break must be less than $635. This does not factor in how much the heat trace system would cost.

4.2.3 Heat Transfer from Extended Surface Computational Fluid Dynamics

The above calculations determined the amount of energy transferred through thermal bridging, but they have not shown how it affects the occupied zone. Computational Fluid Dynamics (CFD) was used as a tool to create illustrations and for analysis of the affected environments. The CFD model was generated using Phoenics and uses the KE-turbulence model with a hybrid differencing scheme. **Error! eference source not found.** And Figure 59 illistate the area under study. Load information for the TRACE energy model was used to estimate heat loss through the façade.

Figure 60 – Interior zone

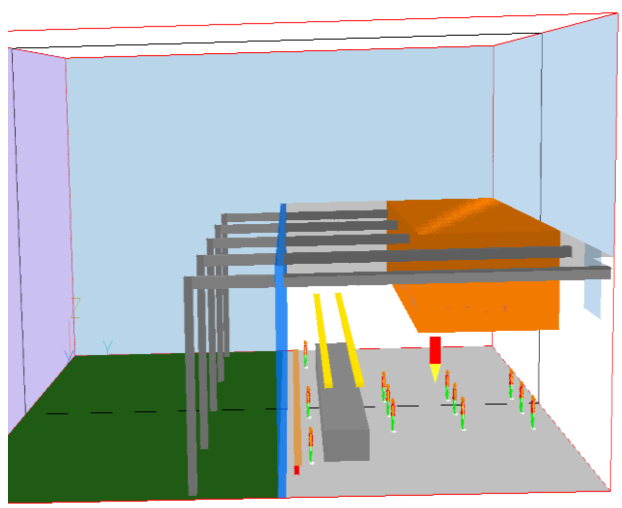


Figure 59 – Modeled Geometry

Figure 61 and Figure 62 illustrates the temperature distribution in the room when there is heat transfer through the beam and when there is no heat transfer through the beam. When looking at the temperature gradients it is hard to see a difference. This was predictable because there is -75,000 Watts of heat flux through the wall and only -400 Watts per each beam. The heat transfer through the beam is relatively minimal. To analyze the average temperature of the occupied zone, measurements were recorded every 5 square meters at head level and knee level, and then averaged. The average occupied zone temperature with heat transfer through the beam is 66.78 ^{o}F. When there is no heat transfer through the beam, the average occupied zone air temperature is 0.3 ^{o}F higher. Air temperature at the return was also noted because return air temperature is a good approximation for the average air temperature in the room. With heat transfer through the beam, the return air temperature is 69.44 ^{o}F. When there is no heat transfer through the beam, the return air temperature is 0.4 ^{o}F higher.

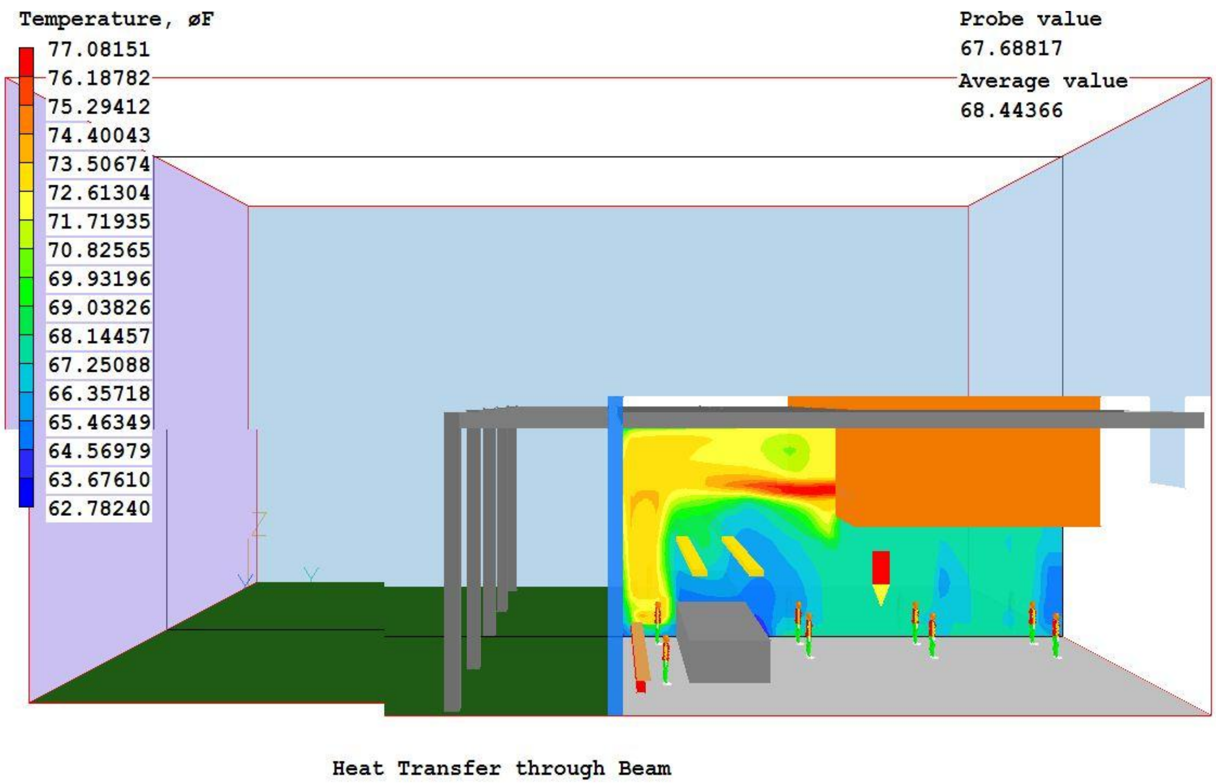


Figure 61 – Heat Transfer Through Beam

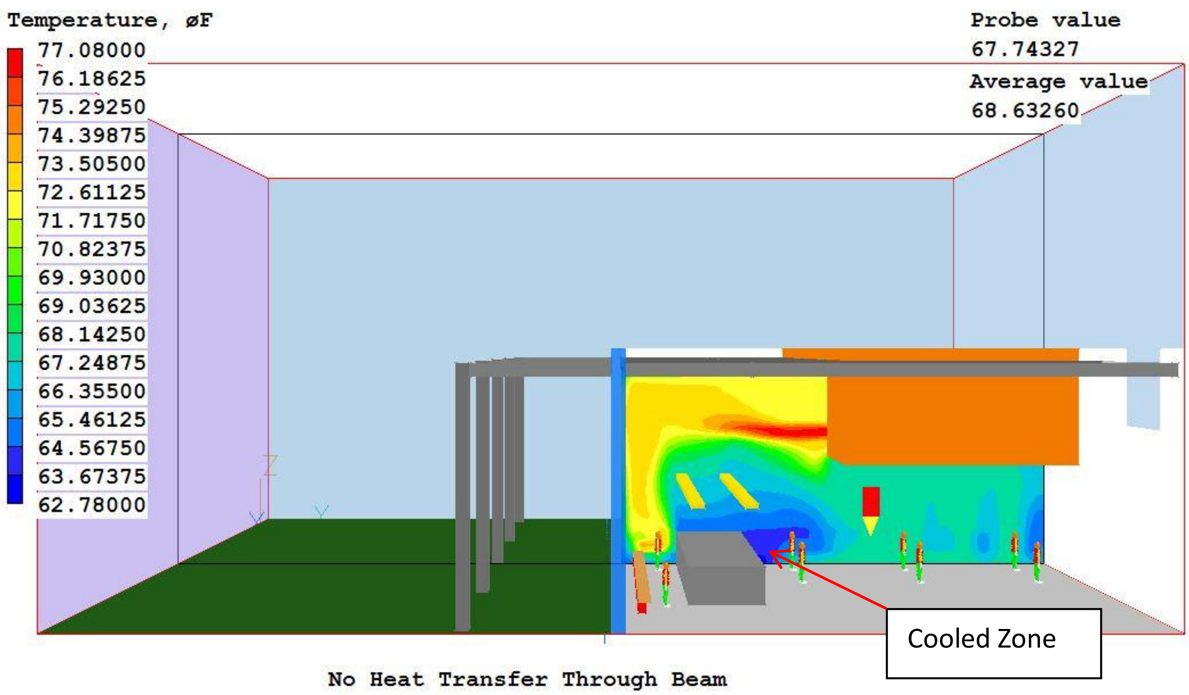


Figure 62 – Thermal Break

There is a small difference that can be seen near the gray box on the floor representing the bike rack. There is a cooled spot around 62 ^{o}F at occupied level. When looking at the velocity vectors in Figure 63 and Figure 64, there is more of an uplift and better mixing when there is heat transfer through the room. It appears that the heat transfer though the beam encourages a more unified temperature gradient at the occupied space; thus, it could be concluded that the heat transfer though the beam actually creates a more comfortable space for the occupants.

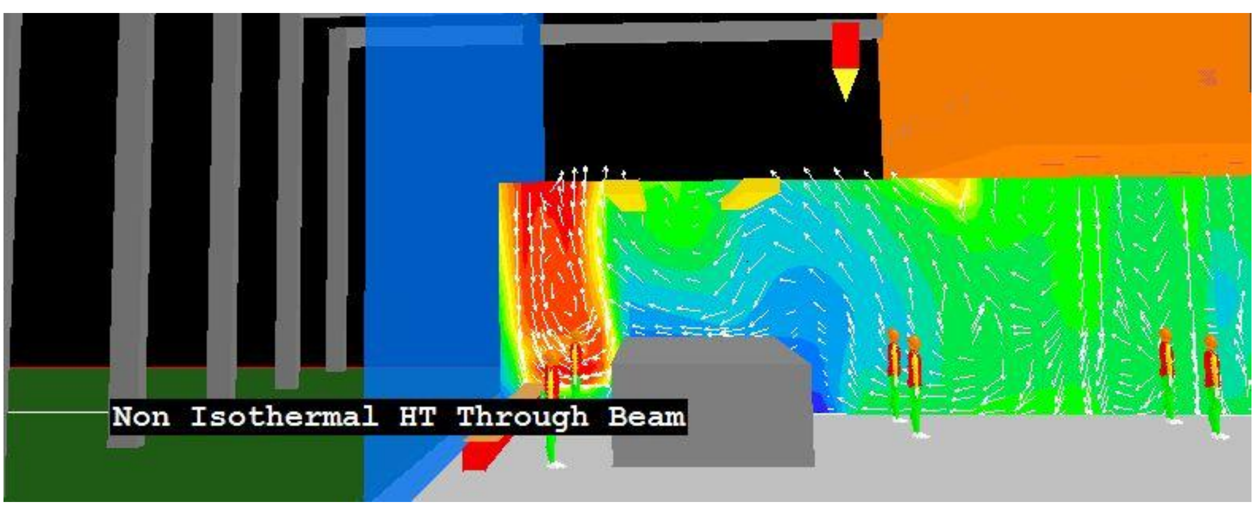


Figure 63

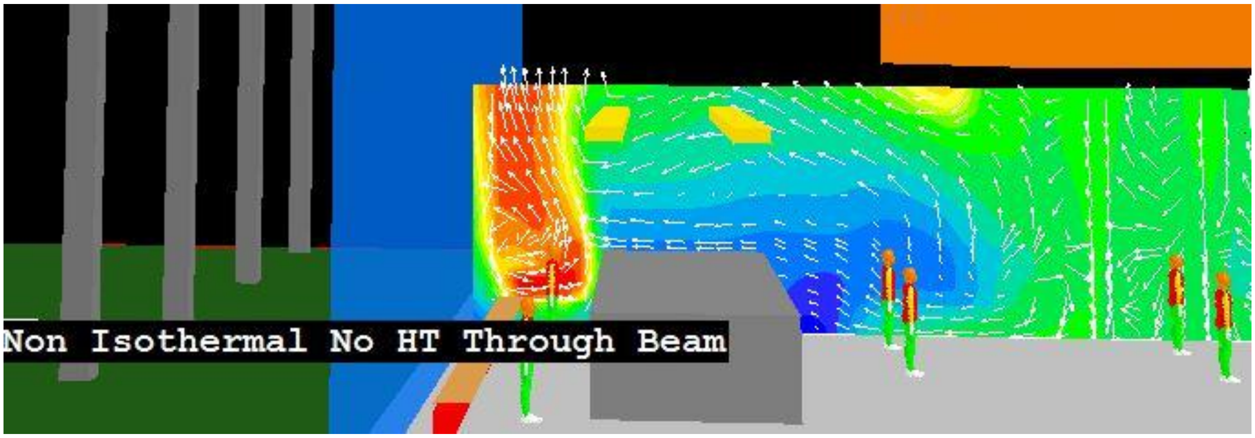


Figure 64

When looking at the temperatures around the beam, it is clear that the air temperature near the beam, when there is heat transfer though the beam, is much lower than the dew point (53 ^{o}F). Therefore, regardless of the effect on the occupied space, heat transfer through the beam must be prevented.

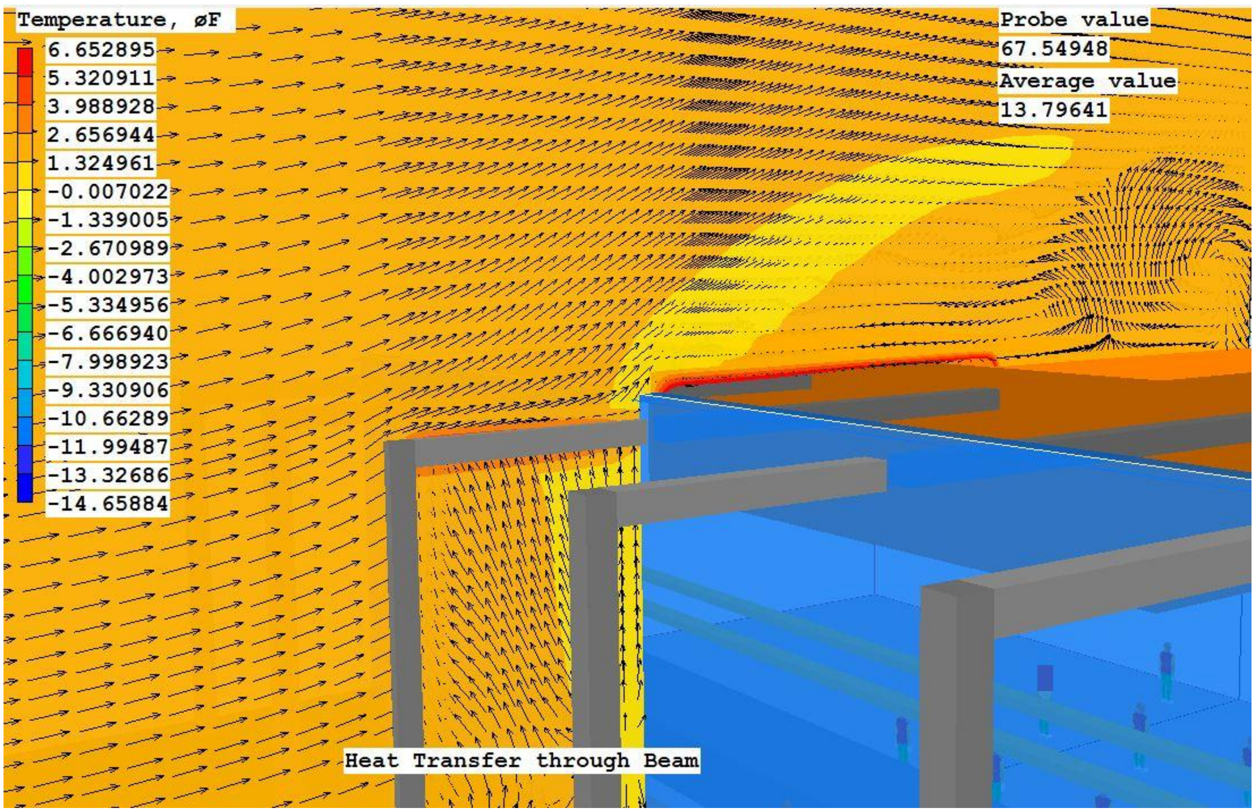


Figure 65 – Outside air temperatures around the beam when there is heat transfer through the beam

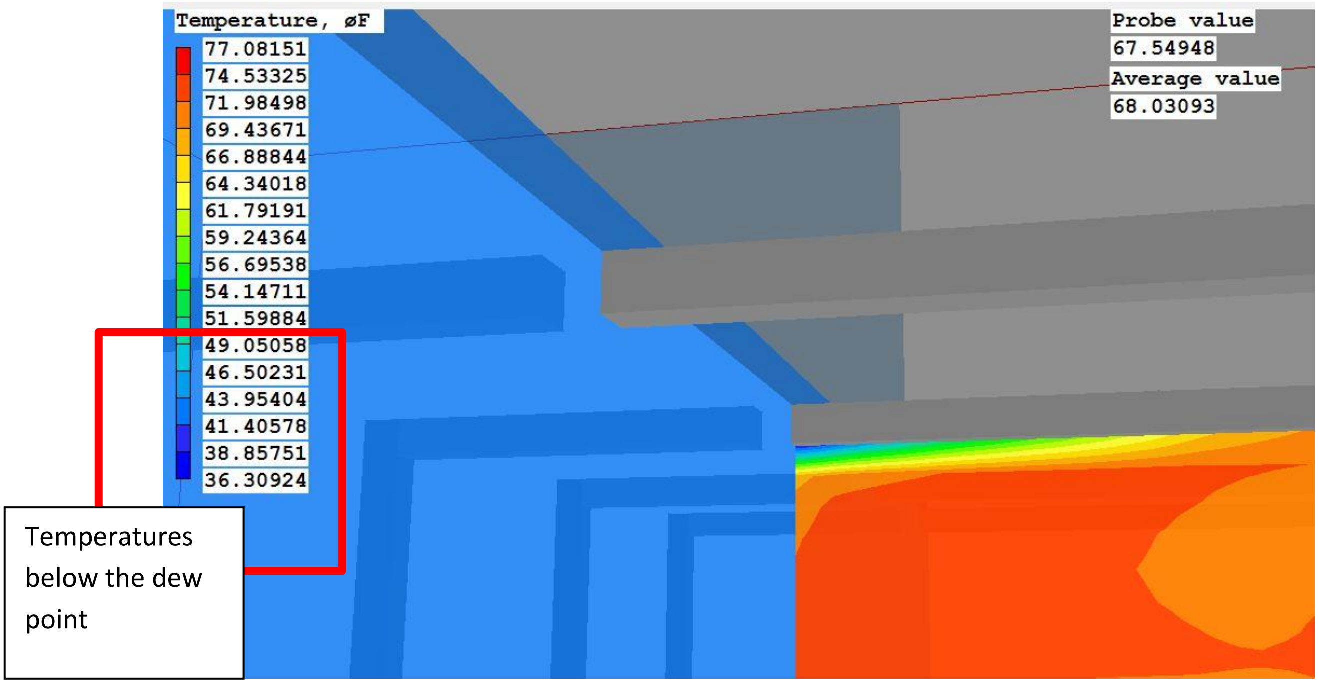


Figure 66 – Interior air temperatures around the beam when there is heat transfer through the beam

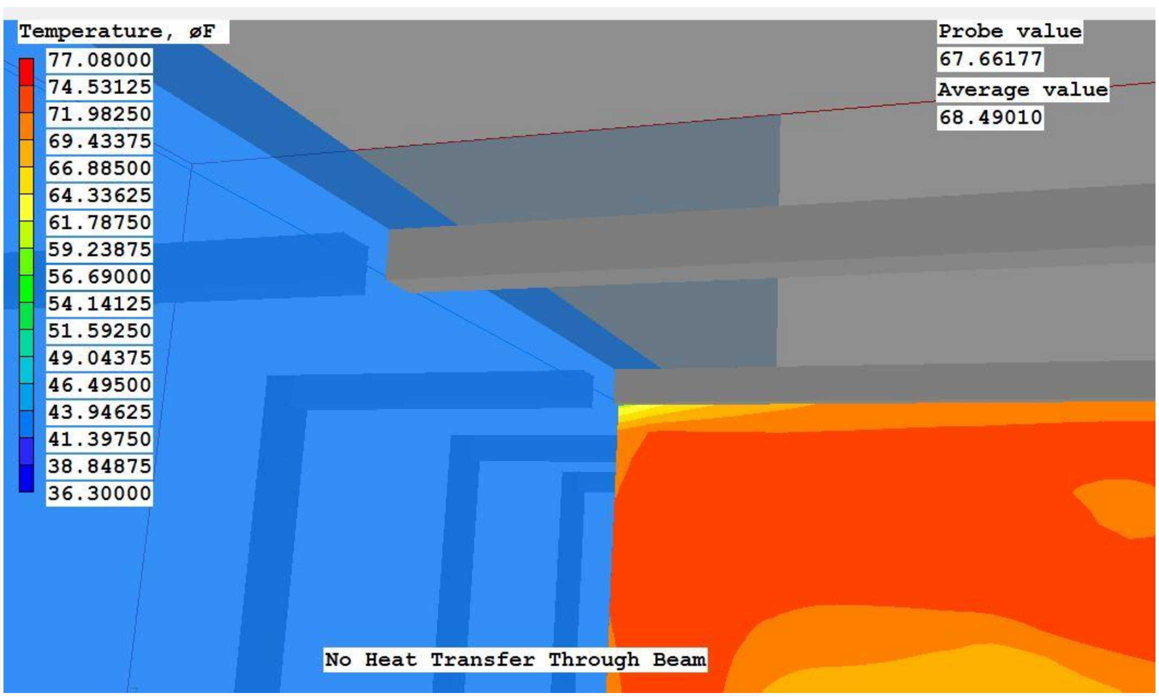


Figure 67 - Interior air temperatures around the beam when there is not heat transfer through the beam

The CFD analysis has confirmed the calculation in the first section of this report. It is not clear if the heat transfer through the beam actually contributes a noticeable heating load to the space, but it is clear that heat transfer through the beam results in air temperatures below the dew point near the beam. This would result in condensation, possible mold growth and poor indoor air quality. If a thermal break was used to separate the exterior and interior section of the beam there wouldn't be any condensation. CFD was an important tool to confirm the hand calculations. If not for CFD an experimental study would need to be conducted to confirm the calculations.

4.2.4 Heat Transfer from Extended Surface Structural Study

It has been determined in the previous section that the thermal break is an acceptable thermal solution to the thermal bridging problem in the main gallery space; however, it must also be structurally sound. Figure 68 highlights the location of the thermal break and details the connection of the thermal break to the column. A structural analysis was conducted on the girder to first analyze if the girder was structurally stable without the exterior steel "buttress" system. Then the column was analyzed for the same reason. These two studies were done to prove that the exterior "buttress" was there for only aesthetics and not for structural reasons. The thermal break was then analyzed for shear strength.

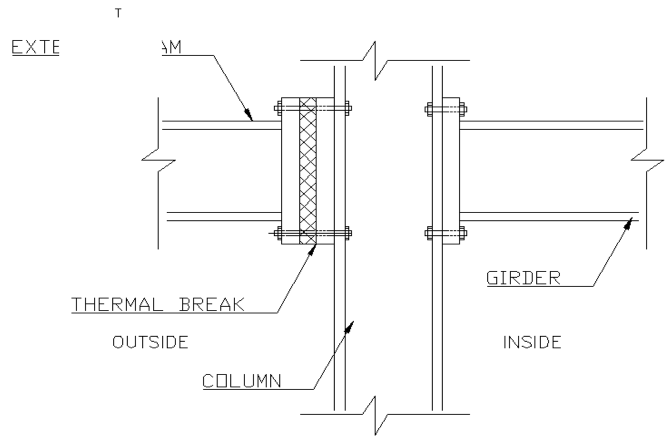


Figure 68 – Thermal Break Connection

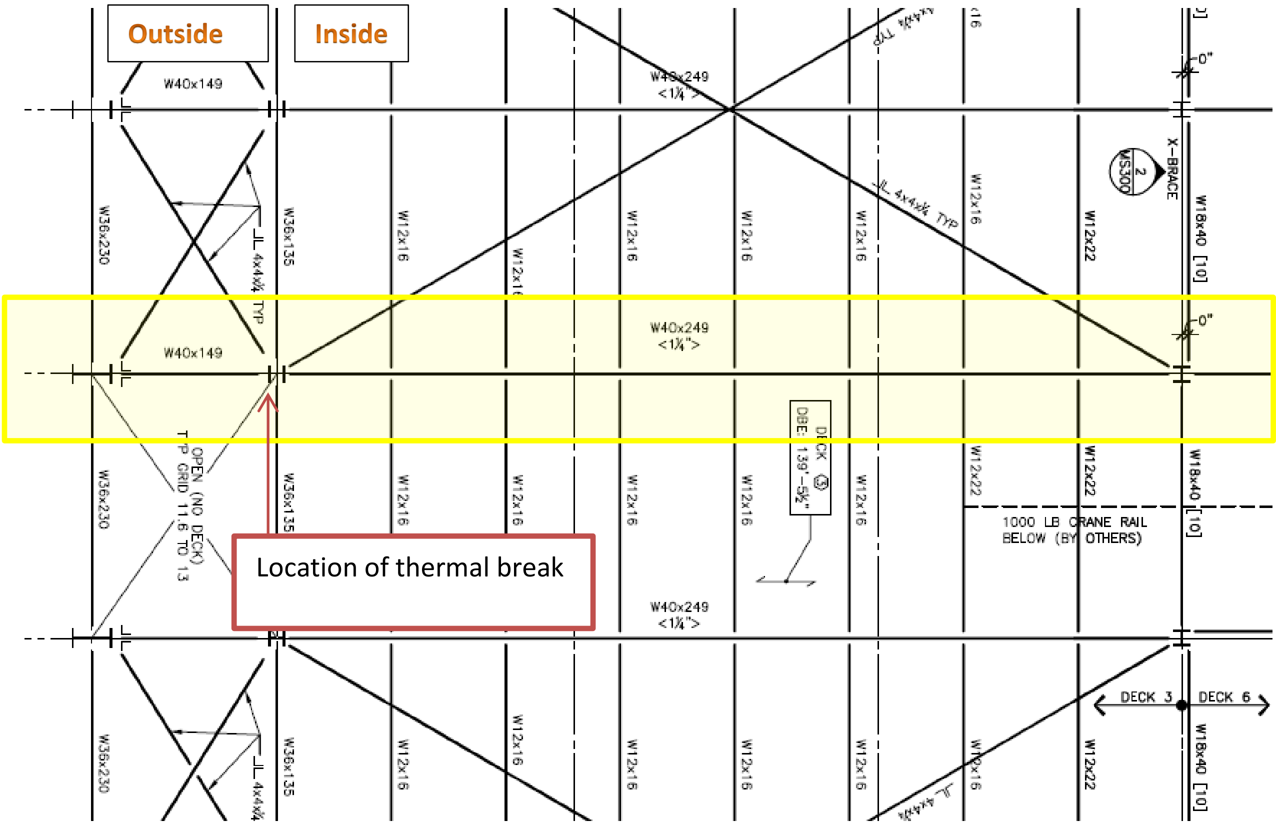


Figure 69 – Structural Plan

4.2.5 Heat Transfer from Extended Surface Structural Study Calculations

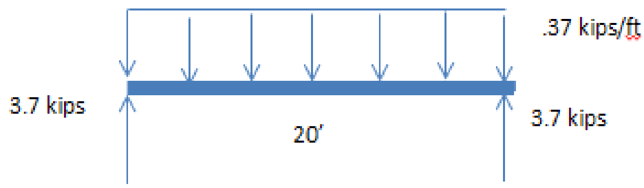
The span of the W12x16 girder is 68.5 feet with W12x16 beam connections every 8.5 feet. From the structural plans and shown in Figure 69, 3" galvanized decking is used. Using the Vulcraft deck catalog a 3N20 10ft three span condition has an allowable load of 90 psf on the un-factored table and has a self-weight of 2.71 psf. The beam is simply supported with a span of 20ft. The beam was checked for bending strength by first finding the factored loading.

$$Factored\ Load = 1.2\ (Dead) + 1.6(Live)$$

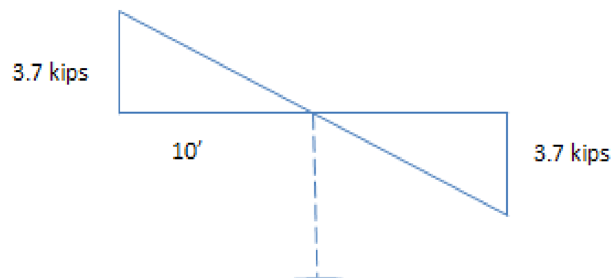
$$1.2(super\ impossed + deck\ weight)(Tributary\ Width) + 1.2(Self\ Weight) + 1.6(Live\ Load)(Tributary\ Width)$$

$$1.2(5 + 2.71)(8.5) + 1.2(16) + 1.6(20)(8.5) = 370\text{ lbs/ft} = .37\text{ kips}$$

Beam Loading Diagram



Shear Diagram



$$3.7 * \frac{10}{2} = 18.5$$

Moment Diagram

$$\emptyset M_n = \frac{0.9 * F_y * Z_x}{12} \rightarrow \frac{0.9 * 50 * 17.1}{12} = 64.125\ allowable\ ft\ kips$$

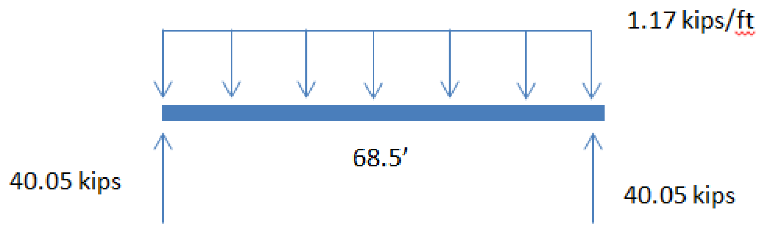
$$18.5 < 64.125\ therefore\ OK$$

$$\emptyset V_n = 79.1\ [table\ 3.1\ steel\ manual] > 3.7\ therefore\ OK$$

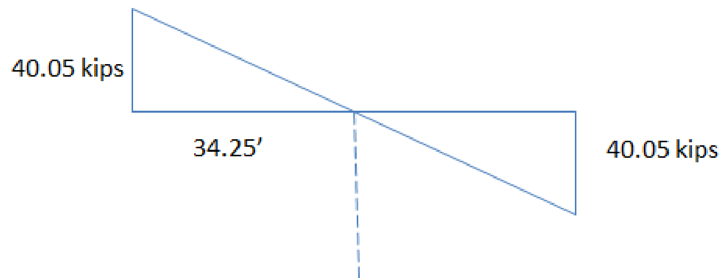
- Girder Strength
    - The girder has more than five point loads; therefore, uniform distribution of load

$$2 * \frac{3.7}{8.5} = .87\ kips \rightarrow .87 + 1.2 * (.249[self\ weight]) = 1.17\frac{kips}{ft}$$

Girder Loading Diagram



Shear Diagram



$$40.05 * \frac{34.25}{2} = 686$$

Moment Diagram

$$\emptyset M_n = \frac{0.9 * F_y * Z_x}{12} \rightarrow \frac{0.9 * 50 * 993}{12} = 3723\ allowable\ ft\ kips$$

$$686 < 3723\ therefore\ OK$$

$$\emptyset V_n = 886\ [\ steel\ manual] > 40.05\ therefore\ OK$$

- Girder Deflection

$$Allowable\ Live\ Load\ Defection = \frac{L}{240} = 3.4"$$

$$WL = \frac{20psf * 20ft}{1000} = 0.4\ kips/ft$$

$$Live\ Load\ Deflection = \frac{5W*L^4*convertion}{384EI} = \frac{5*0.4*68.5^4*1728}{384*2900*19600} = 3.5\text{” [Table 3-23 fig. 1: Steel Manual]}$$

$$3.5"\text{-}\ 0.75"\ chamber = 2.75"$$

$$2.75<3.5\ therefore\ OK$$

$$Allowable\ Total\ Deflection = \frac{L}{180} = 6.85"$$

$$Load\ Deflection = \frac{5W*L^4}{384EI} = \frac{5*0.84*68.5^4*1728}{384*2900*19600} = 7.35$$

$$7.35" - .75" = 6.6"$$

$$6.6<6.85\ therefore\ OK$$

- Column Strength

$$\begin{aligned} Load\ on\ Column \\ &= 40.05kips \\ &+ \frac{\{208[1.2(5+2.71)(4.25)+1.2(55)+1.2(5*40)+1.6(20)(4.25)]\}}{1000} \\ &= 50\ kips \end{aligned}$$

$$Allowable\ \emptyset P_n[steel\ Manual] = 355\ kips$$

$$50 < 355kips\ therefore\ OK$$

- Shear Strength In Thermal Break
  - The allowable shear strength of the thermal break is 13,400 psi
  - The only shear force comes from the weight of the exterior W40x149 beam
  - There is no moment at the connection

$$Weight\ of\ Beam * \frac{Length}{2} = \vartheta$$

$$149 * \frac{14}{2} = 1{,}043$$

$$\sigma_v = \frac{3}{2}\frac{\vartheta}{A} = 1.5\left(\frac{1043}{42 * 16}\right) = 2.24\, psi$$

$$2.24\, psi \ll 13{,}400\, psi\ therefore\ OK$$

4.3 Heat Transfer from Extended Surface Structural Breadth Conclusion

The preceding calculations have proven that the thermal break will not fail under the load from the exterior beam. They have also proven that the exterior steel is not needed structurally and are only aesthetic. Determined by the thermal study, the thermal break must cost less than $635 each, if this qualification can be met, this alternative is a solution to the thermal bridging problem and will save the building owner money in the long run.

SECTION FIVE THESIS CONCLUSION

The goals for this thesis were to provide alternative solutions to the existing design of the Harley-Davidson Museum with the objective to reduce energy consumption, pollution, and operating cost with a healthy and economical approach. Through investigation of thermal bridging, chilled water production, and combined heat and power, it has been determined that the thesis goals have been met conceptually and analytically. Lessons learned in thesis findings are intended to encourage abstract thinking in designing buildings and illustrate potential alternatives leading to sustainably enhanced, progressive designs.

5.1 CONCLUSION MECHANICAL DEPTH

The Harley-Davidson Museum energy consumption is 24% due to heating and 14% due to cooling; however, when looking at total source energy, heating drops to 14% and cooling increases to 16%. Total source energy is a better estimate when analyzing emissions and utility cost. Furthermore, heating contributes only 6% to the utility cost and cooling is 17% of the utility cost. This is one of the reasons chilled water production was the main focus in the mechanical depth of this thesis. The facility is also on a unique plot of land, which creates a unique opportunity for unconventional progressive design for chilled water production.

The existing chilled water production utilizes an air-cooled system. Air-cooled systems can be efficient at smaller loads, takes up less room, and doesn't need extra mechanical equipment such as condensing water pumps, piping, and cooling towers; however, the compressor must have a great enough lift to allow the condenser to reject heat at outside air dry bulb temperature. The proposed alternative is to use a water cooled system to create chilled water. The compressor in a water-cooled system does less work than a compressor in an air-cooled system because the condenser rejects heat at the lower outside air wet bulb temperature, thus reducing chiller energy consumption. Furthermore, a water-cooled system consumes energy in ways an air-cooled system does not, such as condensing water pumps and cooling tower fans.

The water-cooled study investigated two alternatives. The first alternative is a conventional cooling tower system. The second alternative uses the adjacent river as condensing water. **Error! eference source not found.** summarizes all three cases. It is apparent that the river water system saves the most money over the lifetime of the system and has an acceptable payback. This system adds complexity to the operation of the mechanical systems and should be taken under consideration when selecting alternatives.

Table 35 – Mechanical Depth Summary

	Air-Cooled	Cooling Tower	River Water
Capital	$550,000.00	$507,145.00	$611,400.00
Simple Payback	-	-	2.8 years
30 Year LCC Savings	-	$184,817.00	$389,986.93

Statistical Monte Carlo simulation were conducted on the 30 year life cycle cost analyses to investigate the results under 5% varying capital cost, fuel escalation cost, utility rates, and discount rate with a 90% confidence range output. The results are illustrated in Figure 70. The river water system has the lowest maximum and the lowest minimum, futhering the conclusion that the river water system is the most efficent system.

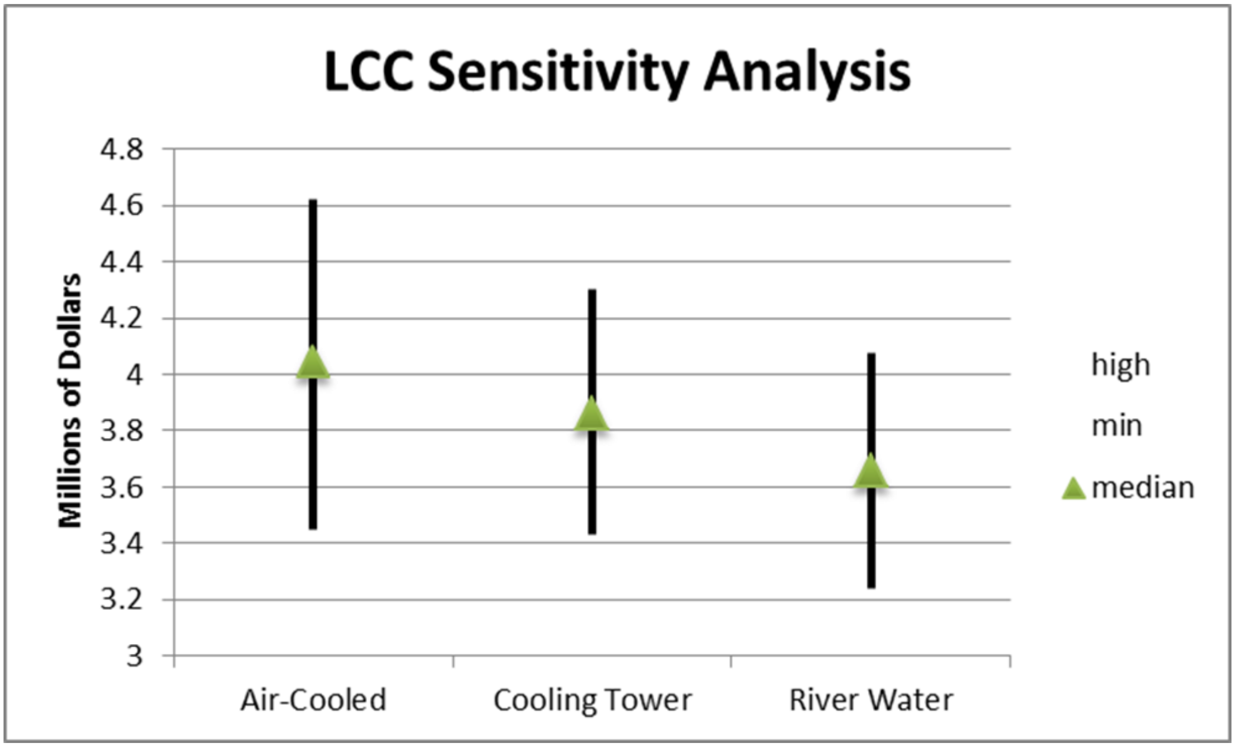


Figure 70 – LCC Sensitivity Analysis

5.2 Conclusion Electrical Breadth

Combined heat and power is typically not associated with museums because of the varying occupancy loads. This however does not mean that thermal loading on the building is uneven over a 24 hour period. The goal of this study was to prove that CHP is feasible in a facility similar to the Harley-Davidson Museum and also a study of the added electrical challenges of a CHP system.

It is imperative to maintain constant climatic indoor condition, such as humidity and temperature to insure exhibits and items on display or in archive are not harmed or damaged. The Harley-Davidson Museum and facilities similar to it should be considered as good candidates for CHP because of the importance of a flat thermal load profile which is also desired for CHP.

The combined Heat and Power Partnership was consulted to analyze the feasibility of CHP for the facility. It was determined that the onsite generation cost is 1.2 cents/kWh cheaper than purchased electricity. With added thermal savings from absorption refrigeration using recovered heat and displaced boiler heat production with recovered waste heat from generation, the total annual savings is

$140,000 a year and has an acceptable simple payback of 4.04 years. There is also a significant 62% reduction of CO_2. Additional savings can be accrued if the river water heat rejection system is used in conjunction with absorption chilled water production.

There are many important design considerations of the electrical system. A CHP system runs parallel to the utility. For this reason, there are many other complex requirements. The protection and safety of equipment and building occupants is of high concern when designing electrical systems. It is important that the utility and generator are operating together at the same rated voltage, frequency, and phase. The National Electric Code was consulted to evaluate the necessary considerations when paralleling generators and sizing conductors and grounding.

5.3 Conclusion Structural Breadth

Thermal loads in a building are mostly due to conduction, infiltration, and radiation through the exterior façade. By reducing the effectiveness of these heat transfer methods, thermal loads in the building are reduced; thus, reducing energy consumption, and utility costs. This thesis investigated conduction through thermal bridging of the steel structure because of the additional consequences of mold growth and poor indoor air quality along with increasing thermal loads. The existing solution to combat thermal bridging was to heat the beam with electric heat trace. This is a successful solution to the consequences of thermal bridging, but it does not prevent thermal bridging. The proposed alternative is to use structural thermal breaks on the exterior of the building to prevent thermal bridging from ever occurring in the first place.

The main gallery zone in the Harley-Davidson Museum was selected to be the area studied because it had the greatest opportunity for thermal bridging and the most occupied zone in the building. Heat transfer through the beam was calculated conservatively and was studied for every hour of a year based on ASHRAE weather data. It was concluded that the existing design consumes 272,407 Watts annually. The alternative design consumes only 100 Watts annually, saving $1,217.00 every year. The saving determined in this study can be applied to many of the other zones in the facility. It can be approximated that if all zones were studied, the savings could be tenfold.

Once the thermal break was proven to be a solution to thermal bridging through the steel structure it was then analyzed structurally. It was concluded that the exterior steel structure was designed for only aesthetic reasons and is independent of the interior supporting structure. It was also concluded that the thermal break can support the loading needed. The structural analysis is summarized in Table 36.

Table 36 – Structural Summary

Member	Force	Allowable	Actual	OK?
Beam	Bending Moment	64.12 ft kips	18.5 ft kips	Yes
Beam	Shear	79.1 kips	3.7 kips	Yes
Girder	Bending Moment	3723 ft kips	686	Yes
Girder	Shear	886 kips	40.05 kips	Yes
Girder	Live Load Deflection	3.4”	2.75”	Yes
Girder	Total Deflection	6.85”	6.6”	Yes
Column	Load	355 kips	50	Yes
Thermal Break	**Shear**	**13,400 psi**	**2.24 psi**	**Yes**

5.4 Conclusion Closing

The proposed alternatives create a progressive design for the Harley-Davidson Museum, limiting energy consumption, emissions, and cost. This is accomplished by preventing thermal bridging through utilizing thermal breaks, increasing efficiency of chilled water production by utilizing local water from the adjacent river, and by becoming energy independent by means of generating electricity on site and utilizing wasted heat for thermal loads. Implementing these alternatives would result in a savings of over $160,000 annually and a CO_2 reduction of 65%; thus, saving the building owner money and reducing their carbon footprint.

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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

ASHRAE Standard 62.12007

Section 5: Systems & Equipment

Section 5.1 – Natural Ventilation

This section is not applicable; natural ventilation is not incorporated into the design of this building.

Section 5.2 – Ventilation Air Distribution

The Harley-Davidson Museum is able to meet the ventilation air distribution requirement. Mechanical ventilation systems have means of adjustment such that the minimum ventilation airflow specified in section 6 can be maintained under any load. Section 6 is discussed later in this report. Manual dampers are located to adjust supply and return airflow to each ventilation zone. Airflow rates are clearly labeled in the design documents for balancing.

Section 5.3 – Exhaust Duct Location

Rooftop electrical fans maintain a constant negative pressure throughout the exhaust duct to prevent exhaust air leaking into occupied spaces. All exhaust ducts are held at negative 2 inch wg. Generator exhaust is insulated and sealed in accordance with SMACNA Seal Class A.

Section 5.4 – Ventilation System Controls

AHU's supplying ventilation to zones have supply and return fans each having dedicated variable speed drives. The BAS has access to all VSD control points. The supply fan starts when indexed to occupied mode by the BAS. Flow measuring stations are used to monitor the outdoor air damper minimum position to maintain the programmed minimum outside air intake set point. VAV boxes have a minimum position that meets minimum ventilation requirements for each zone given in section 6 of standard 62.1. The Harley-Davidson Museum complies with section 5.4.

Section 5.5 – Airstream Surfaces

Products that come in contact with stainless steel have a leachable chloride content of less than 50 ppm when tested according to ASTM C 871. Flexible elastomeric duct liner is made of unicellular polyethylene thermal plastic complying with ASTM C 534. Specification state that all non-metal ductwork is listed and labeled as complying with UL 181. All other ductwork is G90 galvanized steel and falls under the general exception for sheet metal surfaces and metal fasteners.

Section 5.6 – Outdoor Air Intake

The ventilation system outdoor intakes are designed in accordance with table 5-1 from section 5.6 of ASHRA standard 62.1. All outdoor air intakes are located such that the shortest distance from intake to any specific potential outdoor contaminant source is equal or greater than the distances listed in table 38.

Table 37 – Air intake Minimum Separation Distance

TABLE 5-1 Air Intake Minimum Separation Distance

Object	Minimum Distance, ft (m)
Significantly contaminated exhaust (Note 1)	15 (5)
Noxious or dangerous exhaust (Notes 2 and 3)	30 (10)
Vents, chimneys, and flues from combustion appliances and equipment (Note 4)	15 (5)
Garage entry, automobile loading area, or drive-in queue (Note 5)	15 (5)
Truck loading area or dock, bus parking/idling area (Note 5)	25 (7.5)
Driveway, street, or parking place (Note 5)	5 (1.5)
Thoroughfare with high traffic volume	25 (7.5)
Roof, landscaped grade, or other surface directly below intake (Notes 6 and 7)	1 (0.30)
Garbage storage/pick-up area, dumpsters	15 (5)
Cooling tower intake or basin	15 (5)
Cooling tower exhaust	25 (7.5)

Note 1: Significantly contaminated exhaust is exhaust air with significant contaminant concentration, significant sensory-irritation intensity, or offensive odor.
Note 2: Laboratory fume hood exhaust air outlets shall be in compliance with NFPA 45-1991[3] and ANSI/AIHA Z9.5-1992.[4]
Note 3: Noxious or dangerous exhaust is exhaust air with highly objectionable fumes or gases and/or exhaust air with potentially dangerous particles, bioaerosols, or gases at concentrations high enough to be considered harmful. Information on separation criteria for industrial environments can be found in the ACGIH Industrial Ventilation Manual [5] and in the *ASHRAE Handbook—HVAC Applications*.[6]
Note 4: Shorter separation distances are permitted when determined in accordance with (a) Chapter 7 of ANSI Z223.1/NFPA 54-2002[7] for fuel gas burning appliances and equipment, (b) Chapter 6 of NFPA 31-2001[8] for oil burning appliances and equipment, or (c) Chapter 7 of NFPA 211-2003[9] for other combustion appliances and equipment.
Note 5: Distance measured to closest place that vehicle exhaust is likely to be located.
Note 6: No minimum separation distance applies to surfaces that are sloped more than 45 degrees from horizontal or that are less than 1 in. (3 cm) wide.
Note 7: Where snow accumulation is expected, distance listed shall be increased by the expected average snow depth.

Outdoor air intakes that are part of the mechanical ventilation system meet the rain entrainment requirements of section 5.6.2. Louvers restrict wind-drive rain penetration and enlarged O.A.I plenums reduce flow velocity and the chance of rain being brought into the building.

Section 5.7 – Local Capture of Contaminants

The discharge from non-combustion equipment that captures the contaminants generated by the equipment is ducted directly to the outdoors or the equipment is specifically designed for discharge indoors; therefore, the Harley-Davidson Museum meets this requirement.

Section 5.8 – Combustion Air

The emergency generator located in the Annex building of the Harley-Davidson Museum has adequate outside air regulated by a motorized damper to ensure a full combustion process. Its exhaust is directly vented out of the building through the roof.

Section 5.9 – Particulate Matter Removal

The filters used have a minimum efficiency that meets ASHRAE standard 52.2-1999. Every AHU uses a 30% pleated pre filter followed by a 95% cartridge filter. See Air Filter Schedule for filter details in Table 39. These filters reduce the rate of accumulation of particulate matter and reduce the level or airborne particles that may be harmful to humans, such as microorganisms and respirable particles to a level that complies with this section.

Table 38 – Air Filter Schedule

AIR FILTER SCHEDULE (AF)

TAG	LOCATION	TOTAL CFM	FILTER TYPE	EFF (%)	FILTER DATA DEPTH (IN)	AREA (SQ FT)	APD (IN WG)	SERVICE ACCESS	MANUFACTURER	MODEL	NOTES
AF-A1A	AHU-A1	9,500	PLEATED	30	2	18.9	0.75	SIDE	PURAFIL		1,2
AF-A1B	AHU-A1	9,500	CARTRIGE	95	12	18.9	1.5	SIDE	PURAFIL		1,2
AF-A2A	AHU-A2	25,200	PLEATED	30	2	54.3	0.75	SIDE	PURAFIL		1,2
AF-A2B	AHU-A2	25,200	CARTRIGE	95	12	54.3	1.5	SIDE	PURAFIL		1,2
AF-A3A	AHU-A3	16,500	PLEATED	30	2	34.1	0.75	SIDE	PURAFIL		1,2
AF-A3B	AHU-A3	16,500	CARTRIGE	95	12	34.1	1.5	SIDE	PURAFIL		1,2
AF-A4A	AHU-A4	3,000	PLEATED	30	2	5.6	0.75	SIDE	PURAFIL		1,2
AF-A4B	AHU-A4	3,000	CARTRIGE	95	12	5.6	1.5	SIDE	PURAFIL		1,2
AF-A4C	AHU-A4	3,000	GAS PHASE	-	12	12	0.5	SIDE	PURAFIL		2,3,4
AF-AG1	GEN. RM.	16,500	PLEATED	30	2	34.1	0.75	BOTTOM	PURAFIL		2,5
AF-M1A	AHU-M1	45,000	PLEATED	30	2	104	0.75	FRONT	PURAFIL		1,2
AF-M1B	AHU-M1	45,000	CARTRIGE	95	12	104	1.5	FRONT	PURAFIL		1,2
AF-M2A	AHU-M2	45,000	PLEATED	30	2	104	0.75	FRONT	PURAFIL		1,2
AF-M2B	AHU-M2	45,000	CARTRIGE	95	12	104	1.5	FRONT	PURAFIL		1,2
AF-R1A	AHU-R1	10,400	PLEATED	30	2	21.5	0.8	SIDE	PURAFIL		1,2
AF-R1B	AHU-R1	10,400	CARTRIGE	95	12	21.5	1.5	SIDE	PURAFIL		1,2
AF-R2A	AHU-R2	3,200	PLEATED	30	2	6.9	0.75	SIDE	PURAFIL		1,2
AF-R2B	AHU-R2	3,200	CARTRIGE	95	12	6.9	1.5	SIDE	PURAFIL		1,2
AF-R3A	AHU-R3	15,000	PLEATED	30	2	30.3	0.75	SIDE	PURAFIL		1,2
AF-R3B	AHU-R3	15,000	CARTRIGE	95	12	30.3	1.5	SIDE	PURAFIL		1,2
AF-R4A	AHU-R4	11,000	PLEATED	30	2	21.9	0.75	SIDE	PURAFIL		1,2
AF-R4B	AHU-R4	11,000	CARTRIGE	95	12	21.9	1.5	SIDE	PURAFIL		1,2
AF-R5A	AHU-R5	14,200	PLEATED	30	2	28.3	0.75	SIDE	PURAFIL		1,2
AF-R5B	AHU-R5	14,200	CARTRIGE	95	12	28.3	1.5	SIDE	PURAFIL		1,2

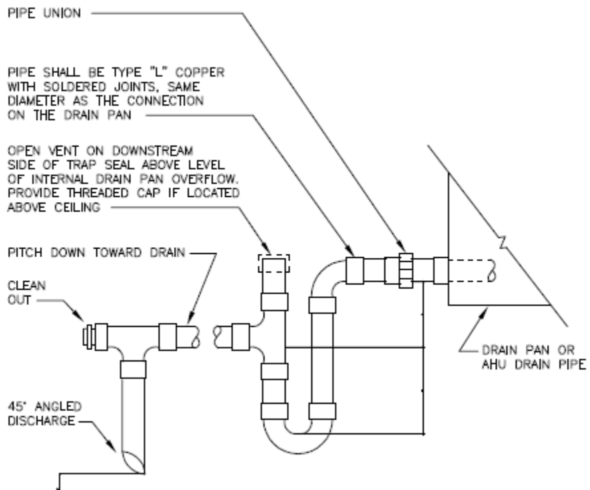
NOTES:
1. FILTER PART OF RESPECTIVE AIR HANDLING UNIT SCHEDULED IN AIR HANDLING UNIT SCHEDULE.
2. APD BASED ON DIRTY FILTER.
3. GAS PHASE WITH ACTIVATED CARBON FILTER MEDIA.
4. PROVIDE DEDICATED SIDE ACCESS FILTER HOUSING OUTSIDE AHU.
5. FILTER BANK TO CONSIST OF NINE (9) 24 x 24 FILTERS IN A 18ft. X 2ft. BANK.

Section 5.10 – Dehumidification Systems

The maximum relative humidity in the Harley-Davidson Museum is 50%. This complies with the limited 65% set by ASHRAE. Because of the exhibits sensitivity to humidity, the museum is held at a constant 50% RH by a tight control system. Recent tests have shown that the annex building is not able to maintain a maximum of 50% RH. This is due to an over estimate in occupancy and a reduced amount of chilled/dehumidified air to the space. There is no reheat, so there is no option to over cool to dehumidify.

Section 5.11 – Drain Pans

All drain pans are designed to prevent standing water and limit water droplet carryover. Drain configurations that result in negative static pressure at the drain pan relative to the drain outlet includes a trap, shown in Figure 71, to maintain a seal against the entry of ambient air while allowing complete drainage of the drain pan under any normally expected operating conditions. Specifications state - "Install drain traps for each condensate drain pan for cooling coils in air handling units and fan-coil units. Provide vented water seal and terminate with a turned-down elbow at a clear water waste hub drain." Drain pans extend downstream from the leaving face or edge to a distance that complies with section 5.11.4 and can be seen in figure 72.



	A DIM.	B DIM.
DRAW THRU	1" + X	.5" * X
BLOW THRU	.5" * X	1" + X

Figure 71- detail of the cooling coil drain piping and trap

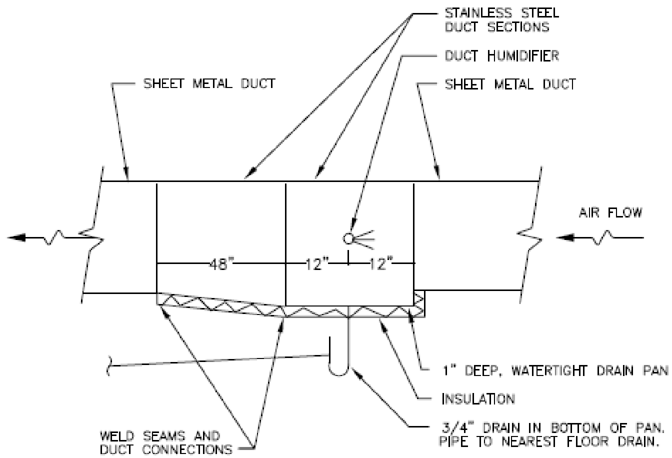


Figure 72- detail of the duct humidifier and drain

Section 5.12 – Finned-tube Coils and Heat Exchangers

All drain pans are in accordance with section 5.11; therefore, they comply with section 5.12. Finned-tube coils have adequate access space for cleaning. All fin tubes used are 1 row and 40 fins per foot, having a lower pressure drop then maximum 0.75 in. specified in this section; therefore, it complies.

Section 5.13 – Humidifiers and Water-Spray Systems

Water used for humidification originates directly from a potable source. There are no obstructions downstream of the humidifier in a short enough distance that would cause condensation or collection of water; therefore, the design complies with this section. Drip pans are located under the humidifier and comply with this section and section 5.11.

Section 5.14 – Access for Inspection, Cleaning, and Maintenance

Air handling units M1 and M2 are tightly placed in individual mechanical rooms. Entry doors to these two mechanical rooms are placed strategically to allow access and removal of filters for maintenance. All other mechanical rooms have adequate space for routine maintenance specified by the National Electric Code. All ventilation systems have access doors for unobstructed access for inspection, maintenance, and calibration of ventilation system components. Mechanical chases have access panels that coordinate with architectural access.

Section 5.15 – Building Envelope

Appropriate weather barriers are provided to prevent water penetration into the envelope. An exterior vapor retarder is provided to limit water vapor diffusion to prevent condensation on cold surfaces within the envelope. Water is able to drain behind brick. All interior surfaces that may be colder than the dew point temperature of the surrounding air are insulated and comply with this section.

Section 5.16 – Buildings With Attached Parking Garages

The Harley-Davidson Museum does not have a parking garage; therefore, this section does not apply.

Section 5.17 – Air Classification Recirculation

Commercial kitchen hoods classified as air class 4 and 3 in table 5-2 from ASHRAE are 100% exhausted to the outside. All restrooms are also exhausted 100% to the outside. The retail, restaurant, kitchen, special events, museum, and offices each have separate air circulation with no cross contamination.

Table 39 - Airstreams

TABLE 5-2 Airstreams

Description	Air Class
Diazo printing equipment discharge	4
Commercial kitchen grease hoods	4
Commercial kitchen hoods other than grease	3
Laboratory hoods	4
Residential kitchen vented hoods	3

Section 5.18 – Requirements for Buildings Containing ETS Areas and ETS-Free Areas

The Harley-Davidson Museum is a smoke free facility; therefore this section does not apply.

Section 6: Ventilation Rate Procedure Analysis

ASHRAE Standard 62.1, 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. This study is a comparison of calculated minimum ventilation to the designed ventilation of the Harley-Davidson Museum.

In this study of the mechanical ventilation of the Harley-Davidson Museum, 9 of 10 air handling units were analyzed. AHU-4A serves the paper archives in the Annex Building and was not included in the study because of its limited need for ventilation and controlling requirement for humidity and temperature control.

The following calculations were used in the study and come from ASHRAE Standard 62.1.6

- The ventilation rate required to control both people related sources (V_p) and building related sources (Va) is the sum of ventilation required to control each of them alone at the breathing zone (Vbz).
  - Vbz = Vp+ Va
  - Vbz = Rp · Pz + Ra · Az (Equation: 6-1)
    - Az = zone floor area (ft^2)
    - Pz = zone population: largest number of people expected to occupy the zone during typical usage. When Pz could not be predicted default occupant density listed in Table 6-1 ASHRAE 62.1 were used.
    - Rp = outdoor airflow rate per person (CFM/person) (Values from Table 6-1)
    - Ra = outdoor airflow rate per unit area (CFM/ft^2) (Values from Table 6-1)
- The outdoor airflow that must be provided to the zone by the supply air distribution is determined by equation 6-2
  - Voz = Vbz/Ez (Equation: 6-2)
    - Ez = zone air distribution effectiveness. In this study Ez was assumed to be 1.
  - When one air handler supplies a mixture of outdoor air and recirculating air to only one zone the outdoor air intake flow (Vot) = Voz (Equation: 6-3)
- For multiple-zone recirculating systems (Vot) is determined by the following equations:
  - Vot = Vou / Ev (Equation: 6-8)
  - Ev is found in ASHRAE Table 6-3 based on maximum Zp value or in ASHRAE appendix A.
  - Zp = Voz/Vpz (Equation: 6-5)
    - Zp = zone primary outdoor air fraction
    - Vpz = minimum expected primary airflow for design purposes
  - Vou = D · (Vbz) (Equation: 6-6)
    - D = diversity factor (assumed to be 100% in this study)

Results:

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

Figure 73 – Ventilation Results

ASHRAE Standard 62.1 Summary

The Harley-Davidson Museum is 100% compliance with Section 5 of ASHRAE Standard 62.1.The Harley-Davidson Museum was not designed to comply with ASHRAE section 6 because of the high people count the Museum 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. 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.

ASHRAE Standard 90.12007

Section 5: building Envelope

Section 5.1.4 - Climate

The Harley-Davidson Museum is classified as nonresidential conditioned space located in Milwaukee WI, corresponding to the cold-humid 6a climate zone determined by Figure 74 taken from ASHRAE 90.1.

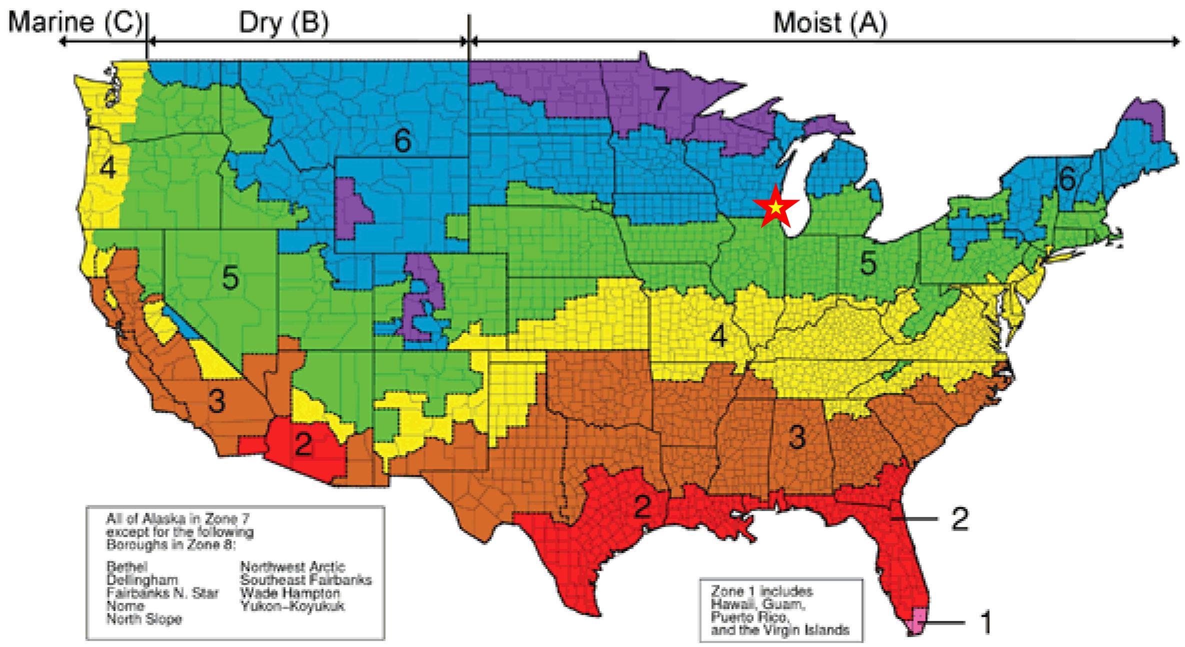


Figure 74 - Climate zones for the United States (ASHRAE)

Section 5.4 – Mandatory Provisions

The building envelope of the Harley-Davidson Museum is sealed, caulked, gasketed, or weather-stripped to minimize air leakage in all areas complying with ASHRAE 5.4.3.1. Building entrances that separate conditioned space from the exterior are protected with an enclosed vestibule equipped with self-closing doors separated no less than 7 feet.

Section 5.5 – Prescriptive Building Envelope

A building envelope comparison was conducted to examine if the design of the Harley-Davidson Museum complies with section 5.5 of ASHRAE 90.1. Worst case design values were compared to values specified in ASHRAE table 5.5-6. This study concluded that the walls of the Harley-Davidson Museum are not designed to comply with ASHRAE and allow more heat transfer then generally desired. Table-2 illustrates the results of this study.

A second comparison was conducted to examine the vertical fenestration area of the Harley-Davidson Museum to the standard set forth by ASHRAE. The study concludes that the Harley-Davidson Museum has a total vertical fenestration area of 33.5% and complies with the maximum of 40% set forth by ASHRAE. The low percent of vertical fenestration is due to the sensitivity of light in many of the gallery zones. The main gallery zone has automatic louvers that close with increase amount of sunlight. It is reported that the museum leaves the louvers closed at all times of the day, however in this study worse case scenarios were assumed and the louvers were not analyzed in this section. Table 41 illustrates the results of this study.

Table 40 - Building Envelope

Building Envelope Requirements For Climate Zone 6a							
Table 5.5-6 ASHRAE		Nonresidential ASHRAE		Nonresidential Design		ASHRAE Compliant	
		Assembly Maximum	Insulation Min. R-Value	Assembly Maximu	Insulation Min. R-Value		
Opaque Elements	Construction	U-value C-value F-value	R-Value	U-value C-value F-value	R-Value	U-value C-value F-value	R-Value
Roof	Metal Building	0.065	19	0.0446	22.42152466	Yes	Yes
Walls, Above-Grade	Steel Fram	0.064	13	0.096	10.41666667	No	No
Walls, Below-Grade	Below-Grade	0.119	7.5	NA	NA	NA	NA
Floors	Mass	0.064	12.5	NA	NA	NA	NA
Slab-On-Grade Floor	Unheated	0.54	10	0.49	10.2	Yes	Yes
Opaque Doors	Swinging	0.7					
Fenestration		U-Value	SHGC	U-Value	SHGC	U-value	SHGC
Verticle Glazing	Metal Framing	0.45	0.3915	0.29	0.2697	Yes	Yes

Table 41 - Vertical Fenestration

Vertical Fenestration Area				
Total Building Window Area (sf)	Total Building Wall Area (sf)	Building Total Window %	ASHRAE Standard	ASHRAE Compliant
30602	91234	33.50%	40%	Yes

Section 6: Heating, Ventilating, and Air Conditioning

Section 6.2 – Compliance Path(s)

ASHRAE 90.1 Section 6.2 defines two methods to evaluate the efficiency of the overall building mechanical system. The Simplified Approach method cannot be used for the Harley-Davidson Museum Building because it does not comply with section 6.3. The Mandatory Provision method is described in section 6.4

Section 6.4 – Mandatory Provisions

The Harley-Davidson Museum meets all minimum equipment efficiencies set forth in ASHRAE tables 6.8.1A through 6.8.1G. Condensing boilers and air cooled chiller compliances are illustrated in Table 43.

Table 42- Compliance with Section 6.4.1.1

Compliance with Section 6.4.1.1 - ASHRAE Table 6.8.1						
Condensing Boilers						
Tag	Equipment type	Subcategory	Size Category (Btu/h)	Minimum Efficiency	Design Efficiency	ASHRAE Compliant
B-M1	Hot water	Gas-Fired	>300,000	75%	86%	Yes
B-M2	Hot water	Gas-Fired	>300,000	75%	86%	Yes
B-M3	Hot water	Gas-Fired	>300,000	75%	86%	Yes
B-M4	Hot water	Gas-Fired	>300,000	75%	86%	Yes
Air Cooled Chiller						
CH-M1	Condeser, electrically operated	All Capacities		2.80 COP	2.80 COP	Yes
CH-M2	Condeser, electrically operated	All Capacities		2.80 COP	2.80 COP	Yes

The Control system consists of sensors, indicators, actuators, interface equipment, accessories, and software connected to controllers operating on a network and programmed to control mechanical systems. An operator workstation permits interface with the network via dynamic color graphics with each mechanical system, building floor plan, and control device depicted by point-and-click graphics. The operator workstation serves the following functions: Real-time graphical viewing and control of environment, scheduling and override of building operations, collection and analysis of historical data, alarm reporting, routing, messaging, and acknowledgment, and program editing. The BAS provides a calendar type format for simplification of time-of-day scheduling and overrides of building operations. Schedules reside in operator's PC workstation, DDC Controller, and HVAC Mechanical Equipment Controller to ensure time equipment scheduling when PC is off-line; PC is not required to execute time scheduling, complying with section 6.4.3.3.1 of ASHRAE 90.1.

Zones are individually controlled by thermostatic controls responding to temperature within the zone. Thermostatic controls have a dead band of 5 degrees complying with section 6.4.3.1.2. A DDC controller and room temperature sensor modulates vav box dampers and hot water reheat coil control valves in sequence to provide heating and cooling to satisfy space temperature set points.

All supply and return ducts and plenums installed as part of the HVAC air distribution system are stated in the specs to have duct liner of sufficient thickness to comply with energy code and ASHRAE/IESNA 90.1.

Section 6.5 – Prescriptive Path

All air handling units have an occupied mode and a non-occupied mode. The two air handling units serving the gallery spaces in the museum have an additional chilled water system economizer mode meeting the requirements set forth in sections 6.5.1.1 through 6.5.1.4.

Based on the Motor Nameplate Horsepower method of calculating fan system power limitations there are 5 fan systems that exceed the allowable fan system motor nameplate hp set forth in Table 6.5.3.1.1A and illustrated in Table 44. Many of the fan powers are significantly lower than the established limit; therefore, the fans that exceed the limit by a minimal fraction will not put a noteworthy burden on the energy load of the building.

Table 43 - Fan Power

Fan Power Limitations - ASHRAE Table 6.5.3.1.1A				
Fan Tag	hp	CFM	Limit	ASHRAE Compliant
RF-A#	10.00	13860	20.79	Yes
RF-M1	20.00	36700	55.05	Yes
RF-M2	20.00	36700	55.05	Yes
SF-A1	15.00	9500	14.25	No
SF-A2	30.00	25200	37.8	yes
SF-A3	30.00	16500	24.75	No
SF-A7	7.50	3000	4.5	No
SF-M1	60.00	45000	67.5	Yes
SF-M2	60.00	45000	67.5	Yes
SF-R1	15.00	10400	15.6	Yes
SF-R2	7.50	3200	4.8	No
SF-R3	25.00	15000	22.5	No
SF-R4	15.00	11000	16.5	Yes
SF-R6	20.00	14200	21.3	Yes
RF-A1	7.50	34000	37.4	Yes
RF-R1	1.50	10400	11.44	Yes
RF-R2	2.00	14200	15.62	Yes
RF-R5	2.00	14200	15.62	Yes
EF-A1	1.00	1200	1.32	yes
EF-A2	0.17	300	0.33	Yes
EF-A3	0.75	5000	5.5	Yes
EF-M1	0.20	300	0.33	Yes
EF-M2	0.25	1700	1.87	Yes
EF-M3	1.50	7000	7.7	Yes
EF-R1	0.33	2200	2.42	Yes
EF-R2	0.75	1350	1.485	Yes
EF-R3	3.00	4800	5.28	Yes
EF-R4	3.00	5400	5.94	Yes
EF-R5	3.00	5400	5.94	Yes
EF-R6	1.50	3500	3.85	Yes

The Limit for Constant Volume Fans is CFM x 0.0011 and Variable Volume fans is CFM x 0.0015

Section 6.7 – Submittals

The Harley-Davidson Museum operation personnel received full construction documents and ample training for start-up, testing, and operating the control systems and equipment. Operator instructions were provided with training and included the overall operational program, equipment functions, commands, system generation, advisories, and maintenance. Construction documents and manuals provide the building owner the location and performance data on each piece of equipment, general configurations of duct, and pipe distribution system.

Section 7: Service Water Heating

Section 7.4 – Mandatory Provisions

All water heating equipment, hot-water supply boiler used solely for heating potable water, and hot-water storage tanks meet the criteria listed in ASHRAE Table 7.8 and are illustrated in Table 45. The Museum Building and the Annex Building each have dedicated domestic hot water systems. Each system consists of one high efficiency sealed combustion condensing natural gas fired domestic water heater with integral 50 gal. storage tanks. Hot water is maintained at 115 °F and is recirculated. The retail building has a dedicated domestic hot water system consisting of two high efficiency sealed combustion condensing natural gas fired domestic water heated with integral 75 gal. storage tanks. Hot water is maintained at 140 °F and is blended with cold water to provide 115 °F. 180 °F hot water for kitchen use is generated locally near the point of use.

Table 44 – ASHRAE TABLE 7.8 Compliance

Compliance with Section 7 - ASHRAE Table 7.8					
Gas Water Heater					
Tag	Equipment Type	Subcategory	Performance Required	Design Performance	ASHRAE Compliant
GWH-A1	Gas Storage	>75,000 BTU/h	80%	94%	Yes
GWH-M1	Gas Storage	>75,000 BTU/h	80%	94%	Yes
GWH-R1	Gas Storage	>75,000 BTU/h	80%	94%	Yes
GWH-R2	Gas Storage	>75,000 BTU/h	80%	94%	Yes

Section 7.5 – Prescriptive Path

Service heating systems are exclusively used for potable water and are not used for additional functions such as space heating; therefore, this section does not apply.

Section 8: Power

The Harley-Davidson Museum wiring specification states - A voltage drop of 6% or higher is not acceptable. This does not comply with the maximum voltage drop of 2% for feeders and 3% for branch circuits set forth in ASHRAE standard 8.4.1.

Section 9: Lighting

Section 9.4 – Mandatory Provisions

Lighting in the Harley-Davidson Museum is controlled with automatic controlling devices to shut off building lighting in every space. Lights are on an “eight day” program – uniquely programed for each weekday and for holidays. Outdoor lights are connected to outdoor photoelectric switches with a monitoring range of 1.5 – 10 foot-candles. A direction lens is in in front of the photocell to prevent fixed light sources from causing turn off and a time delay of 15 seconds is used to prevent false operation. Indoor spaces are equipped with occupancy sensors which unless otherwise indicated turn lights on when its covered area is occupied and off when unoccupied. There is a time delay for turning lights off with adjusted range of 1 – 30 minutes. This design complies with ASHRAE 90.1 Section 9.4.1.1.

Section 9.5 – Building Area Method Compliance Path.

ASHRAE Table 9.5.1 specifies that museums should have a maximum of 1.1 LPD (W/ft^2). A study was completed and the results concluded that the Harley-Davidson Museum has a LPD of 1.06 complying with the ASHRAE Standard.

Section 10: Other Equipment

Section 10.4 – Mandatory Provisions

Minimum efficiencies for motors are defined by ASHRAE based on rated horsepower and motor speed. The specifications for the Harley-Davidson Museum state that all motor efficiency's comply with NEMA MG1, thus the motors also comply with ASHRAE Table 10.8 since the values used in ASHRAE are in accordance with NEMA Standard MG1.

ASHRAE Standard 90.1 Summary

Standard 90.1 provides minimum requirements for the energy-efficient design of building and building system. The Standard specifies sensible design practices and technologies that minimize energy consumption without forgoing either the comfort or productivity of the occupants. By conducting a comprehensive comparison of the Harley-Davidson Museum to ASHRAE Standard 90.1 a detailed profile of energy efficiency can be examined.

The prescriptive performance evaluation method was used to determine compliance of ASHRAE Standard 90.1. As a whole, the Harley-Davidson Museum did not comply with the standard 100%, but significantly exceeded the standard in some areas. There were several areas in the design that could lead to poor overall comfort for occupants, and excess usage of energy. The Harley-Davidson Museum was designed with great weight on the overall architectural aesthetic. Sacrifices in the HVAC system and building envelope were made in order to provide the building owner with an overall exceptional and attractive building.

The building envelope has a smaller R-value then desired by ASHRAE. A slight increase in wall thickness would allow for more insulation that could easily meet the ASRHAE Standard, although the significantly lower percent in fenestration area may compensate for the loss in R-value.

All of the equipment in the Harley-Davidson Museum is compliant with ASHRAE except for 5 fans that exceed the limit by a small fraction. This could be due the architectural limitations on ductwork size in some locations in the building. A small adjustment in duct size could decrease pressure loss to a level that complies with ASHRAE.

Although the Museum has a copious amount of luminaires the LPD is below the limit set forth by ASHRAE. The lower LPD reflects the use of high efficiency advanced lighting such as LEDs and T5HO linear fluorescents.

Appendix B

LEED Analysis

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 are 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.

Table 45- Worst Case Refrigerant case

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

Table 46 - Most Optimistic 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

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 to 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 are 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 space.

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:

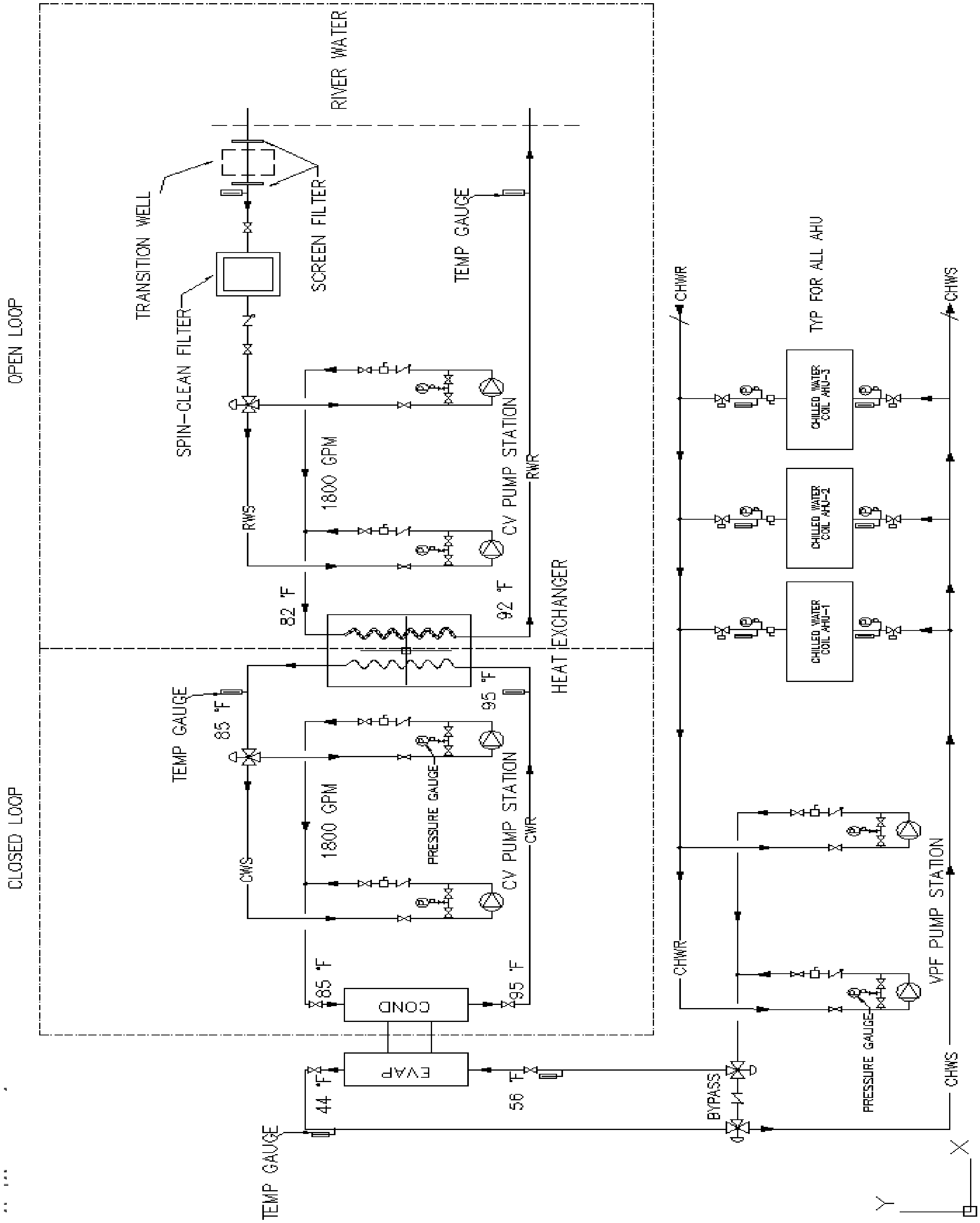
RP Credit 1.1-4: Regional Priority

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

Appendix C

CHILLED WATER FLOW DIAGRAM: RIVER WATER SYSTEM



Appendix D

CHP Cogeneration Technical Data & Spec Sheets

2G CENERGY®
Advanced Clean Energy Technologies

2G 380 NG – 380ekW Natural Gas
CHP Cogeneration Module
Lean Combustion Technology

Reliable, rugged and highly durable factory-designed, production line assembled, professionally packaged, and post-production tested **2G® Natural Gas Cogeneration Module**, supplied in an "all-in-one" package that is "connection-ready". Manufactured at 2G® ISO compliant production facilities in Germany, especially made for the U.S. cogeneration market.

This CHP (Combined Heat & Power) cogeneration equipment is a fully integrated power generation system, with state-of-the-art technology that results in optimum performance and efficiency. The 2G® CHP module integrates all cogeneration components into one unique package that converts energy more efficiently than conventional CHP systems.

The robust design utilizes full authority electronic engine management, incl. CHP performance monitoring that provides prolonged life, low maintenance, and high efficiency. Items such as, engine & system controls, synchronizing and paralleling switchgear, heat recovery (both for engine jacket water and exhaust), the entire thermal heat technology system, pumps, piping, plumbing, etc., are all included "within the module" dramatically reducing the risk of cost overruns and performance issues associated with conventional "site built" systems.

The 2G® CHP module allows for optimized efficiency by maximizing heat recovery and applying a more efficient combustion technology, leading to a higher electrical output.

Open Inside Installation

Optional Sound Attenuation

Compact & Small Foot-Print

Easy Service Access

Natural Gas

Prime Mover	MAN®
Core Engine Type	E2842 LE322
Configuration	2G® Natural Gas Optimized
Arrangement / Cylinders	V 12
Displacement / BHP	21.9 L / 534 BHP
Compression Ratio	12:1
Speed	1800 RPM
Frequency / Phase	60 Hz / 3-Phase
Voltage*	480 V
Electrical Output	380 ekW continuous
Thermal Output	538 kW continuous
Combined Output	918 kW continuous
Thermal Heat BTU	1,835,732 (usable)
Ø Water Flow HT	14,252 gph / 53,949 L/h
Hot Water Flow LT	7,027 gph / 26,600 L/h
Water Temperature	90°C / 194°F
Electrical Efficiency	37.20 %
Thermal Efficiency	52.60 %
Total Efficiency	89.80 %
Consumption m³/h	102.3 m³/h
Consumption cf/h	3,612 ft³/h
Consumption cf/m	60.20 ft³/m
Cons. BTU / ekW	9,030
Exhaust Gas Mass (Wet)	2,120 kg / 4,673 lbs
Exhaust Gas Volume	1,728 m³/h / 61,024 ft³/h

(*Other Voltages are available).

2G CENERGY®
Advanced Clean Energy Technologies

2G 380 NG – 380ekW Natural Gas CHP Cogeneration Module Lean Combustion Technology

1. Gas Inlet to the Gas Train
2. Lower Deck Compartment , Exhaust Heat Recovery Section, (incl. Exhaust Heat Exchanger, Gas Train Components)
3. Exhaust Exit (from Exhaust Gas Heat Exchanger)
4. JW Heat Exchanger & Expansion Vessel Section
5. Thermal Heat Management & Distribution and Pump Section
6. Water Circulation Connections (In and Out) pre-flanged
7. Closed Side Panels all around (can be removed easily)
8. Battery Compartment / Battery Box
9. Advanced High Efficiency Synchronous Generator
10. Generator Terminal Box

Optional the CHP Cogeneration Package is available as "All-In-One" and "Connection-Ready" <u>Sound Attenuated Container Module</u>.

Specially designed 2G® Sound Attenuated, weatherproof walk-in Power Module with Air Intake, Discharge Outlets, and Connection Fittings for Air Flow Funnels, Louvers, Exhaust Stack, Radiator Cooling System, lockable Access & Service Doors, Stainless Steel Hardware and Hinges, Sound-reducing Encapsulation, and extra large Floor Space for easy Service & Maintenance Access.

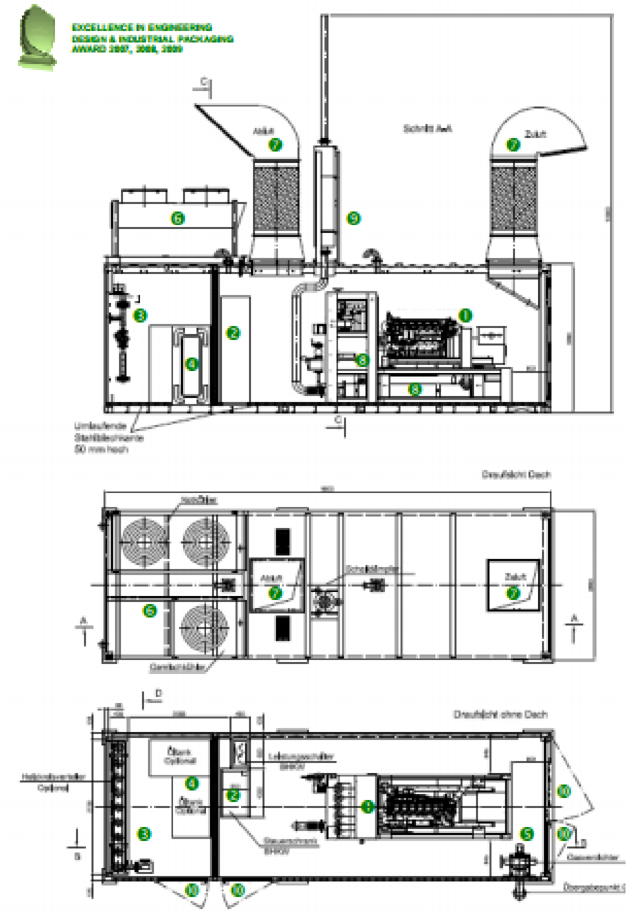
STANDARD EQUIPMENT INCLUDED:

- High Efficiency NG Engine (Lean Burn Technology)
- Advanced and Optimized Exhaust Gas Turbocharger
- Electrical Jacket Water Heater System
- Extra Large Oil Capacity Sump with Oil Refill Automatic
- Pressure Lubrication System with Gear Pump
- Advanced CHP Type Air Cleaner System
- Gas Train & NG Fuel System compliant with NFPA 37, tested and approved to UL, CSA, EU, and DIN Standards
- Low Fuel Pressure System 0.5 – 3.0 psi (34 – 207 mB)
- Advanced High Efficiency Two-Stage Fuel Mixer
- Proprietary Air/Fuel Ratio Controller
- Digital Microprocessor Controlled Electronic Ignition
- Vibration Detection & Detonation Protection
- Complete Heat Recovery System , Factory installed
- Self-Cleaning Jacket Water Plate Heat Exchanger
- High Efficiency Stainless Steel Exhaust Heat Exchanger
- Exhaust System incl. Silencer and Exhaust Stack
- Thermal Heat Distribution System fully integrated
- Advanced Cooling System, Mixture Inter-Cooler & Dry Radiator / Re-Circulation Cooling System (beltless)
- General Digital Control System with Protection Devices
- Heat Value Fluctuation Detection Technology
- Utility Grade Switchgear , CSA, UL, NEMA, IEEE Standards
- Grid Interconnection Relays per CSA/UL & IEEE 1547
- Electronically operated Circuit Breaker
- Optimized High Efficiency Synchronous Generator
- Electrical Load Share Governor System
- 24V Electrical Starter, Battery Rack & Cables
- Integrated High Performance Battery Charger
- Central Wiring Harness incl. Sensors
- Torsion-resistant Design with Solid Frame Structure
- Heavy Duty Oscillation Decoupling Devices
- Multiple Deck Design with integrated Spill Tray
- Natural Gas Micro Filtration System
- Fluidistor Gas Flowmeter & Gas Vacuum Sensor
- Gas Pressure, Gas Temperature, and Ambient Air Temperature Sensors
- Double Magnet Valve & Zero Pressure Regulator
- By-Directional Deflagration Flame Arrestor, ATEX Cert.
- Set of Pressurization & Expansion Vessels & Valves
- Three Way Valve & Electrothermic Actuator
- Set of GRUNDFOS VersaFlo® self-lubricated Main Hot Water Circulation Pumps and Sensors
- Thermal Distribution Assembly (up to 4 Circuits)
- Water Circulation Dirt Collection Unit
- Remote Monitoring & Control
- OXI-Cat Emission Reduction System

MADE FOR THE USA

2G CENERGY® Advanced Clean Energy Technologies

2G 380 NG – 380ekW Natural Gas CHP Cogeneration Module Lean Combustion Technology



❶ Natural Gas CHP Package
❷ CHP Control & Switchgear
❸ Thermal Distribution Assembly
❹ Fresh & Used Oil Tanks
❺ Gas Blower / Compr. (optional)
❻ Cooling System
❼ Air In-and Out Ventilation
❽ Heat Exchanger
❾ Oxi-Cat & Exhaust System
❿ Multiple Access Doors

2G® Container Modules are especially developed and designed. We don't utilize Standard Shipping Containers, or modify existing ISO Transport Containers. For many Reasons those ordinary Shipping Containers have shown NOT TO BE SUITABLE for CHP Cogeneration Plants. All 2G® containerized Packages are specifically developed, designed, and professionally manufactured for the Purpose of CHP Cogeneration. The extended Width and Height of 118" has proven to be an ideal Size for easy Inside Movement, and comfortable Service & Maintenance Access. This leads automatically to reduced Maintenance Cost, because any Type of Work can be performed much faster.

EMISSIONS & STANDARDS:

CO	< 2.5 g/BHP-h*	
NOx	< 0.99 g/BHP-h*	
HCHO	< 0.06 g/BHP-h*	
NMHC	< 0.19 g/BHP-h*	

In Compliance with the EPA United States Environmental Protection Agency

(< less than / with Oxi-Cat, Pre SCR After Treatment. For CARB and South California AQMD Emissions can be drastically reduced with 2G®'s SCR).*

2G® Engines & CHP Systems comply with EPA Rules & Regulations and are carrying the Manufacturers EPA Emissions Certificate.

2G® is compliant to the applicable Federal Code:
EPA – Subpart JJJJ of Part 60 (Natural Gas, Digester Gas, Biogas, LFG) rich burn & lean burn Gas Engine (IC Internal Combustion) - 73 FR 3591, Jan. 18, 2008.

All Data according to full Load and Subject to Technical Development, Modification and Change. Exhaust Gas Emissions correspond to Dry Exhaust Gas with 15% residual Oxygen O_2. Lean Burn Technology provides Exhaust Emissions well below EPA Federal Guidelines & Regulations. Additional Emissions Treatment and Reduction Technologies (SCR, De-NOx, etc.) are available as an Option if required.

Electrical Output based on ISO Standard and Conditions according to ISO 3046/1-1995 and to VDE 0530 with respective Tolerance. Technical Data is based on a Gas Quality "Methane # 80" Natural Pipeline Gas, and a Heat Value of >10 kWh/Nm³. For Conditions or Fuels other than Standard, consult 2G-CENERGY.

Continuous Output available without varying Load for an unlimited Time, and 10% Overload, in Accordance with ISO8528, ISO3046/1, AS2789, DIN6271, and BS5514. All Ratings are based on SAE J1349 Standard Conditions.

Tolerances: Electrical Output ISO 3046/1, Fuel Consumption +/- 5%, Thermal Output +/- 8%. Typical Heat Data is shown, however no Guarantee is expressed or implied. Data will vary due to Variations in Site and Ambient Conditions.

All electrical Systems comply with DIN, VDE, CE, and CSA Certifications, and NEMA / UL compliant Designs / Configurations. The Generator is compliant with International Standards & Regulations IEC 60034, NEMA MG 1.22, ISO 8528/3, CSA, UL 1446, UL 1004B, DIN 6280-3, VDE 0530, ÖVE-M 10, ISO 8528-3, BS 5000, IEC 34, designed and manufactured in an ISO 9001 and ISO 14001 Environment.

For all other Gas Types: Weak Gases, e.g. Biogas, Landfill Gas, Sewage Gas, Coal Mine Gas, and other Special Gases (Wood Gas, Syngas, Coke Gas, Pyrolysis Gas) see Biogas Spec Sheets and consult 2G-CENERGY.

The Manufacturer reserves the Right to change or modify technical Details without prior Notice.

2G CENERGY® Advanced Clean Energy Technologies

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Date: 12/2010

Appendix E

Fabreeka Thermal Break

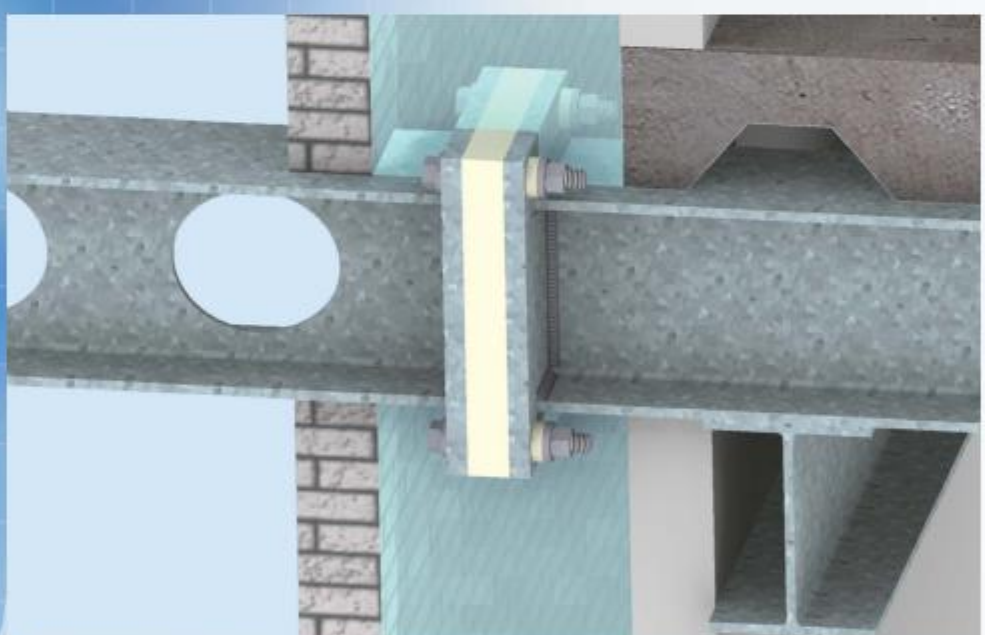
Thermal Insulation Material

Thermal insulation material (TIM) is manufactured from a fiberglass-reinforced laminate composite. The properties of this material provide a thermally efficient, energy-saving product that prevents thermal bridging in structural connections. TIM is a load bearing "thermal break" used between flanged steel connections. The primary benefit is that it maintains structural integrity while reducing heat loss.

TIM material is supplied in sheets or cut to size per customer drawings/specifications and is available in thicknesses of 1/4", 1/2" and 1". It is also supplied as thermal break washers for the bolted connections between external and internal steelwork.

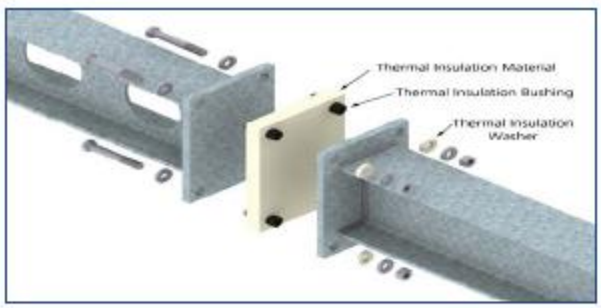
Features and Attributes

- Thermally efficient, energy-saving construction
- Eliminates potential condensation and mold
- High load capacity maintains structural integrity
- Low thermal conductivity reduces heat loss



Properties of Fabreeka's Thermal Insulation Material

Mechanical Properties			
Tensile Strength	PSI	ASTM D638	9,400
Flexural Strength	PSI	ASTM D790	22,300
Compressive Strength	PSI	ASTM D695	38,900
Compressive Modulus	PSI	ASTM D695	1,450,377
Shear Strength	PSI	ASTM D732	13,400
Thickness	in	-	1/4", 1/2", 1"
Flame Resistance			
Oxygen Index	$\%O_2$	ASTM D2863	21.8
Thermal Properties			
Coefficient of Thermal Expansion	in/in/°Cx10^{-5}	ASTM D696	2.2
Thermal Conductivity	BTU/Hr/ft²/in/°F W/m*K	ASTM C177	1.8** 0.259
***Reference:* Thermal Conductivity of Steel	BTU/Hr/ft²/in/°F W/m*K		374.5 54.0



Additional Products for Building & Construction

Expansion Bearings | SA-47 Bearing Pads | Fabreeka Bearing Pads | Isolation Washers & Bushings | PTFE Bearing Pads

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