Harley-Davidson Museum

Milwaukee, WI

01/30/2012

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Mechanical Option

Advisor: Dr. William Bahnfleth

[THESIS PROPOSAL]

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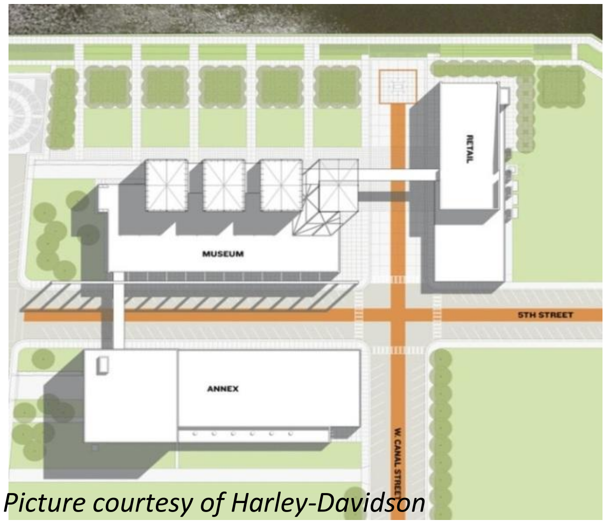
Executive Summary

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



Picture courtesy of Harley-Davidson

Figure 1 - Plan

This proposal outlines the topics, methods, and timeline that will be approached for the mechanical redesign and the electrical and structural breadth topics. The mechanical redesign proposal will replace the air-cooled chillers with a water-cooled system. An electric chiller and an absorption chiller will be investigated along with an investigation into water source river heat rejection. In addition to the redesign of the mechanical system two breadth studies will also be conducted. The first breadth will be an investigation on the implementation of on-site energy production through the use of fuel cells. The waste heat from the fuel cell will be reclaimed and used to power the absorption chiller. This investigation will include an economic analysis and particulate emission analysis. The second breadth will be an investigation of the 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 will examine the benefits of implementing thermal breaks in the structural system compared to the existing solution of using heat trace.

A schedule of the spring semester has been created to organize material and allocate design hours for the thesis project. In the research phase, information needed for design will be acquired from various sources including, but not limited to, ASHRAE publications, and online resources. Facilities that have been designed similar to the proposed redesign of the Harley-Davidson Museum will be studied in order to gain familiarity and knowledge of the areas of study. In the design phase, Trane Trace, a building energy modeling software will be used in conjunction with Microsoft Excel to calculate the necessary information needed to determine whether or not the redesign is feasible, practical and accurate.

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.

Mechanical 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 1500MBH 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, 75 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.

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, use of outdoor air for making chilled water during winter, operating air handling units using variable speed drive controllers, use of air flow measuring stations in outdoor air intake, and use of outdoor air for cooling during cooler days.

The facility's ventilation was not designed to comply with ASHRAE 62.1.2007 because of the high occupancy the Museum owner wanted the buildings to be designed for and the low frequency of when maximum occupancy would actually be seen, the engineers at HGA used ventilation rates to only meet the ventilation 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.

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 will be a vital tool in analyzing new alternative designs in future investigations.

The mechanical system only consumes 7% of the overall square footage of the building and is $54.75 per square foot which is a reasonable number for a building of its type. Proposed areas for improvement will focus on efficiency rather than reducing space or overall first cost; however, these components shall still be 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.

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 was 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.

Mechanical Proposed 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, reduce operating cost as much as necessary to have a satisfactory rate of return, and to achieve sufficient LEED credits to enable the facility to become LEED certified. The proposed redesign is to replace the existing air-cooled chillers with a water-cooled system. An electric chiller and an absorption chiller utilizing waste heat from onsite generation (discussed in electrical breadth) will be investigated along with an investigation of utilizing water from the adjacent Milwaukee river for heat rejection.

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 current method for heating is with four condensing boilers. The condensing boilers used in the facility are efficient and use natural gas as the primary fuel. An investigation will be conducted on the implementation of utilizing waste heat from onsite power production to heat the building. The efficiency of heat production through combined heat and power is not as efficient as a condensing boiler; however, if the power generation system is sized appropriately 100% of the thermal load can be treated with the byproduct of onsite power generation. Furthermore, onsite power can have a high capital cost; therefore, a life cycle cost analysis will be conducted.

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.

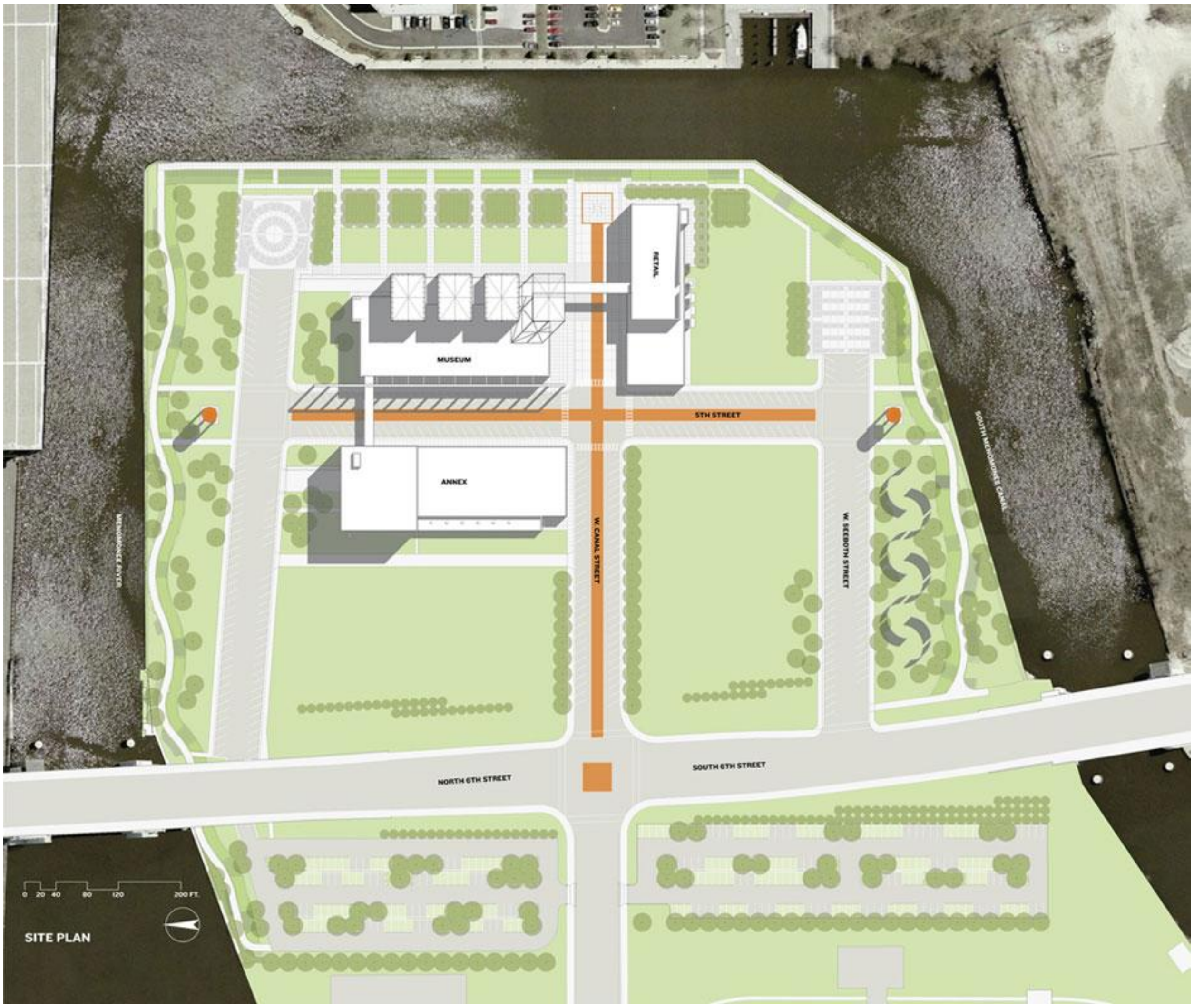


Figure 2 – Site

Figure 3 – View from river

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. Generating power on-site, rather than centrally, eliminates the cost, complexity, interdependencies, and inefficiencies associated with transmission and distribution, and shifts control to the consumer.

This electrical breadth will study the valued alternative of on-site generation; particularly a solid oxide fuel cell (SOFC) developed by Bloom Energy. Bloom claims that the efficiency built into their fuel cell systems allows a typical customer to achieve a 3-5 year financial payback making it an easy and economically sound choice. Customers can also cut their CO_2 emissions by 40%-100% compared to the U.S. grid (depending on their fuel choice) and virtually eliminate all SOx, NOx, and other harmful smog forming particulate emissions. Installing Bloom Energy Servers allows you to dramatically reduce your carbon footprint, but not at the cost of your bottom line.

Other fuel cell technologies like proton exchange membranes, phosphoric acid fuel cells, and molten carbonate fuel cells, all required expensive precious metals, corrosive acids, or hard to contain molten materials. Bloom has developed a solid oxide fuel cell that uses low cost ceramic materials, increasing its benefits over legacy fuel cells, but until recently there were significant technical challenges inhibiting the commercialization of this technology. SOFCs have high electrical efficiencies because they operate at extremely high temperature (typically above 800°C). Running at high temperatures creates engineering challenges that Bloom has solved with breakthroughs in material science. Other on-site power production methods will also be considered.

Bloom Energy's SOFC has already been successfully utilized by companies such as: Walmart, The Coca-Cola Company, Google, Ebay, and FedEx. This breadth study will investigate if the Harley-Davidson Motor Company could potentially add its name to this list.

In this study electrical calculation will be conducted to properly size the fuel cell. Wire size and conduit selection will also be conducted on areas related directly to the fuel cell. An inverter will also need to be investigated to transform the DC power to AC.

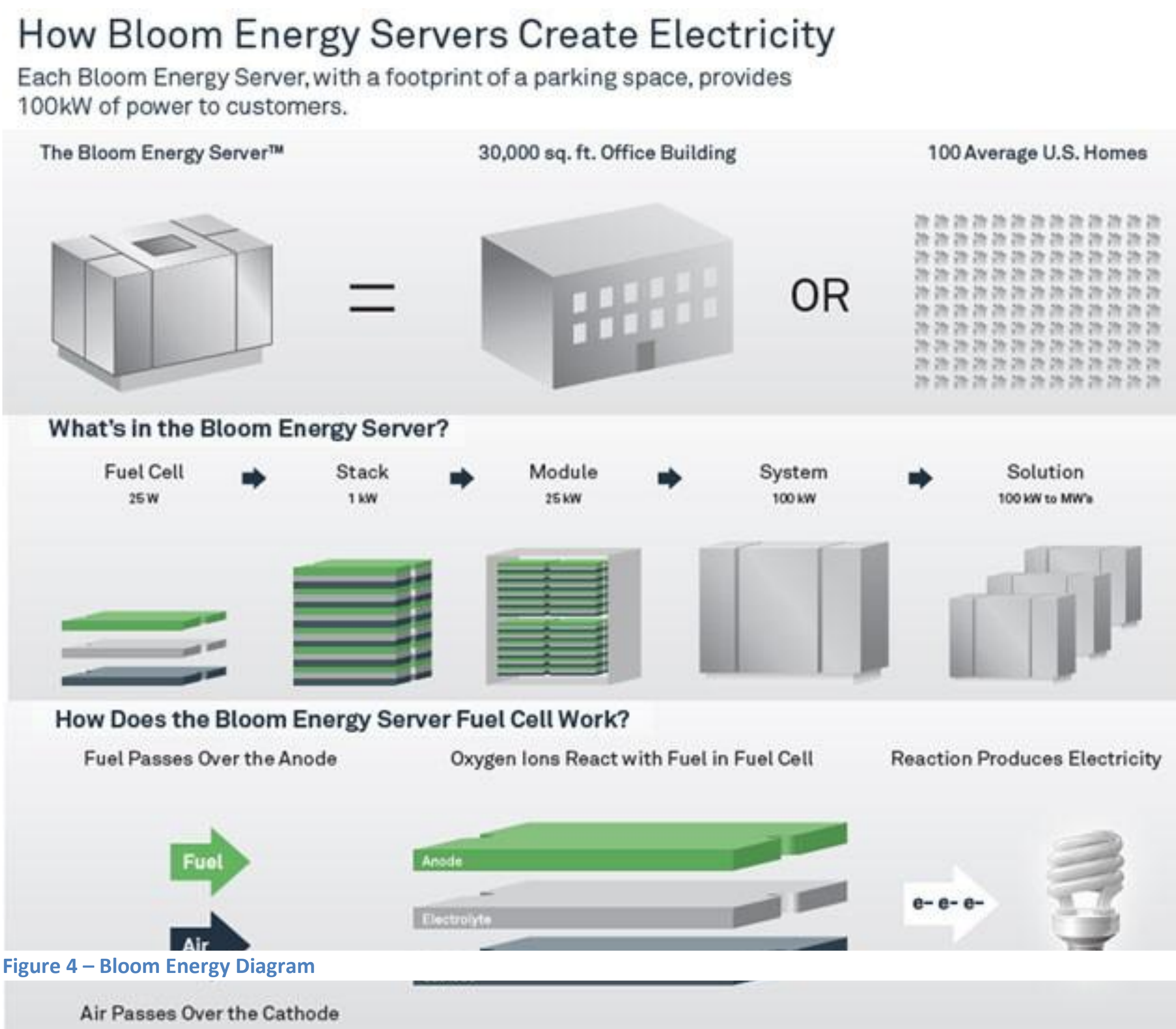


Figure 4 – Bloom Energy Diagram

Structural Breadth

The structural system of the Harley-Davidson Museum presents many areas of thermal bridging through the exterior façade; shown is Figures 5 and 6. Thermal bridging occurs when there is a conductive path between two separate zones at different temperatures. In the Harley-Davidson Museum there are many areas where thermal bridging is present. Many of the steel beams and several columns penetrate the exterior façade of the facility. The figures in Appendix A illustrate two common penetration details. 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. 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.

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 A and shown in Figure 5. An investigation of the structural properties of the break and the existing structural system loads will be investigates in this breadth study and a determination will be made as to if the structural breaks will support the structural loads and prevent thermal bridging.

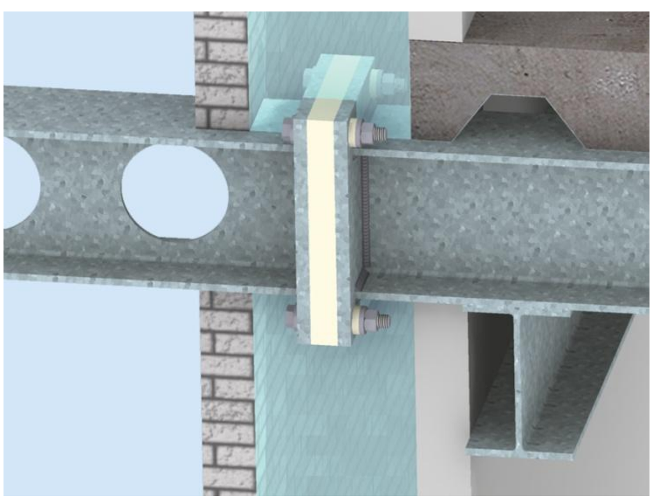


Figure 5 – Thermal Break

Figure 6 – Beams where thermal bridging is established

Figure 7 – Columns where thermal bridging is established

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 will be carefully examined first by researching product designs, publications and published research. After the research phase, a thorough analysis water-cooled system alternatives will be pursued by hand calculations and the aid of Trane Trace, an energy modeling software. Once the mechanical redesign has been developed and written, a careful study of the breadth topics will be reviewed. Using the same approach as with the mechanical redesign, the breadth topics will first involve researching product designs, publications, and published research related to the topics. The energy model used for the mechanical redesign will also be utilized in the electrical breadth to determine the size of the fuel cell. The economic analysis will examine the simple payback and the rate of return of the fuel cell system and will be equated to the existing purchased energy economics. Emissions from the on-site energy production will also be equated to emissions from the off-site power plant. Most of the emission calculations will be done by hand and with the aid of Microsoft Excel. For the structural breadth, most of the thermal bridging calculations will be done by hand for later comparisons. The structural design software, RAM, will be used to calculate the loading and forces within the structural system to determine if the thermal breaks are will support the loading while preventing thermal bridging.

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

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 may be used in the investigation of fuel cells. AE 559, Computational Fluid Dynamics may be used to analyze the effects of thermal bridging.

Schedule

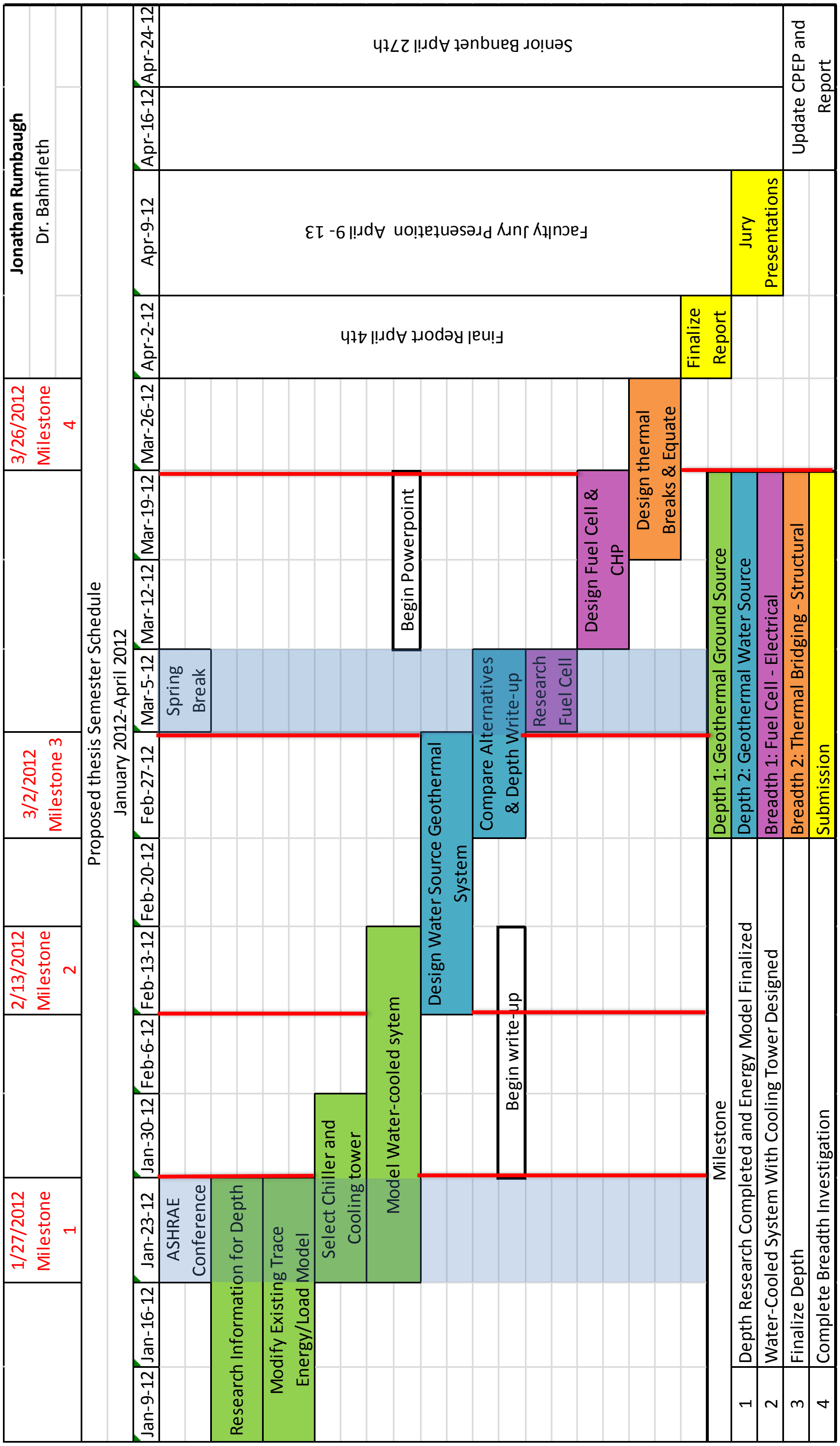


Figure 8 - Timeline

Preliminary Research

- Swisher, Joel N. *Multiple Benefits of Distributed Fuel Cell Generation in Commercial Buildings*. Tech. Rocky Mountain Institute
    - This paper explains the economic benefits of fuel cell distributed generation and discusses technologies that reduce electricity generation and distribution costs, while improving reliability of service.
- *Bloom Energy | Be The Solution*. Web. 08 Dec. 2011. <http://www.bloomenergy.com/>.
    - This website will be used to get all specification needed for the SOFC design.
- "BuildingGreen.com LIVE: Structural Thermal Breaks for Steel Framing by Brent Ehrlich on 06/30/2011." *Home - BuildingGreen.com*. Web. 08 Dec. 2011. <http://www.buildinggreen.com/live/index.cfm/2011/6/30/Structural-Thermal-Breaks-for-Steel-Framing>.
    - BuildingGreen.com is website that discusses structural thermal breaks for steel framing and will be used for the structural breadth study.
- Hackel, Scott. *Ten Year Update: Emissions and Economic Analysis of Geothermal Heat Pumps in Wisconsin*. Rep. no. 249-1. Wisconsin: Energy Center. online. <http://www.ecw.org/ecwresults/249-1.pdf>.
    - This is a report of a study that was conducted on geothermal systems in Wisconsin. The report applied economic and emissions frameworks along with calculations to determine the current cost-effectiveness and environmental impact of geothermal heat pump systems.
- Sackrison, Chris. *Why Water Source Heat Pump Systems Are So Efficient*. Rep. no. 13. McQuay, 2002. online.< http://www.mcquay.com/mcquaybiz/literature/lit_systems/EngNews/1002.pdf>
    - This is a report that reviews why water source heat pumps are efficient. It will be used to investigate potential advantages of water source heat pump systems.

~ More research will be conducted before proceeding with design as noted in the schedule.

Sub-References

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

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

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

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

Pocket Guide. Atlanta: ASHRAE, 2005

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

Project Team

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

APPENDIX A

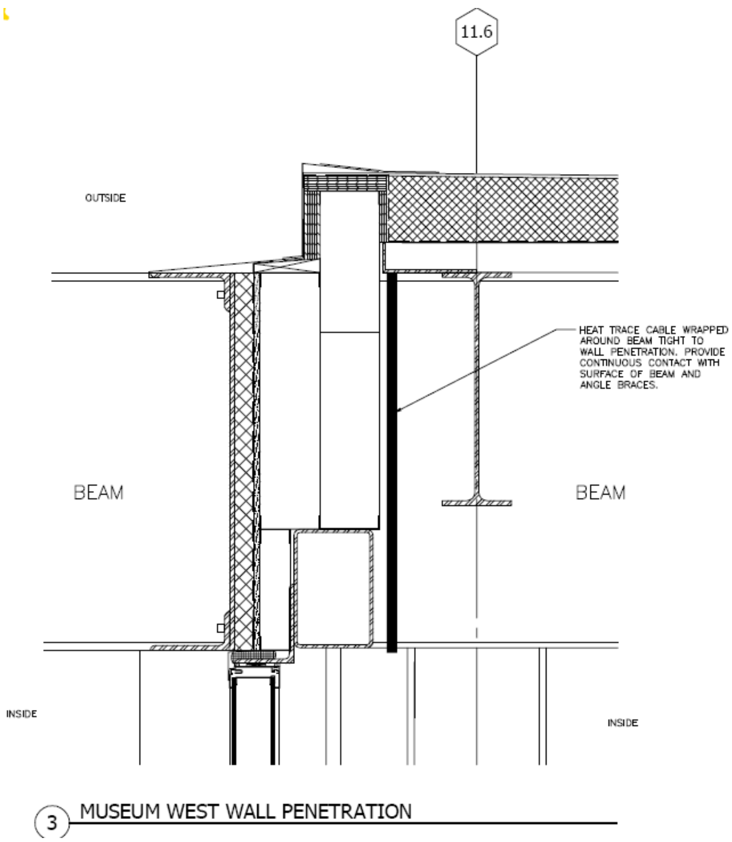


Figure 10 – Beam Penetration

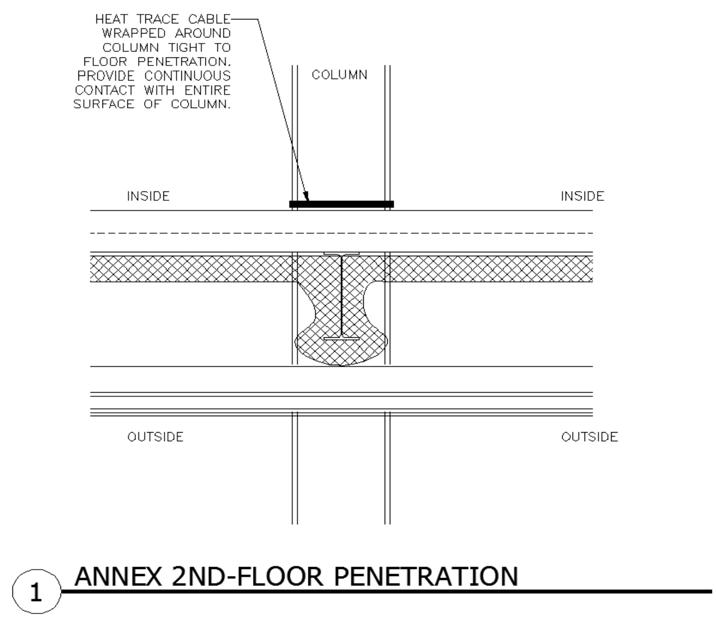
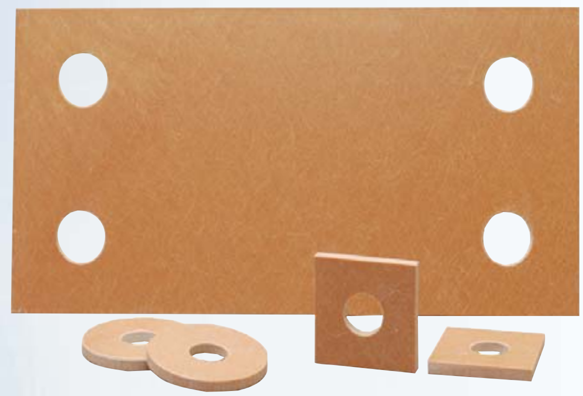


Figure 21 – Column Penetration

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.



*Color may vary.

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"

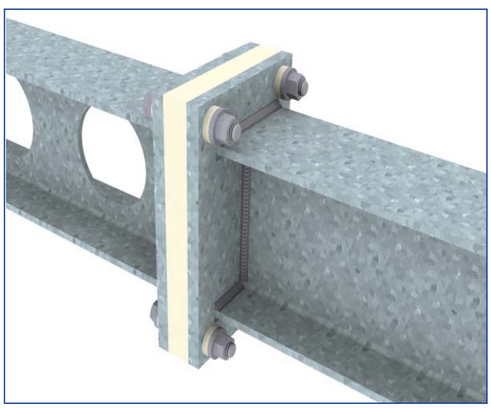
Flame Resistance

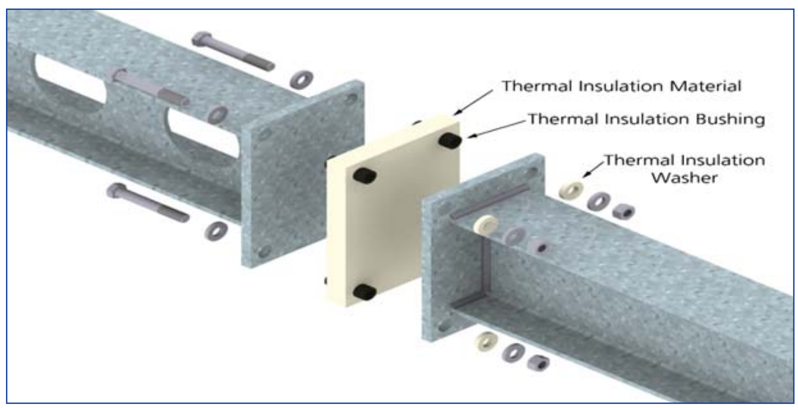
Oxygen Index	$\%O_2$	ASTM D2863	21.8

Thermal Properties

Coefficient of Thermal Expansion	in/in/°Cx10^{-5}	ASTM D696	2.2
Thermal Conductivity	BTU/Hr/ft²/in/°F	ASTM C177	1.8**
	W/m*K		0.259

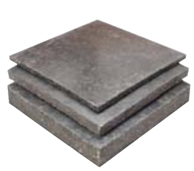
***Reference:* Thermal Conductivity of Steel	BTU/Hr/ft²/in/°F	374.5
	W/m*K	54.0

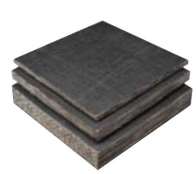




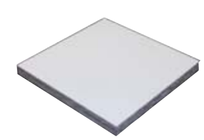
Additional Products for Building & Construction


Expansion Bearings


SA-47 Bearing Pads


Fabreeka Bearing Pads


Isolation Washers & Bushings


PTFE Bearing Pads

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