Harley-Davidson Museum

Milwaukee, WI

10/19/2011

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Mechanical Option

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[TECHNICAL REPORT TWO]

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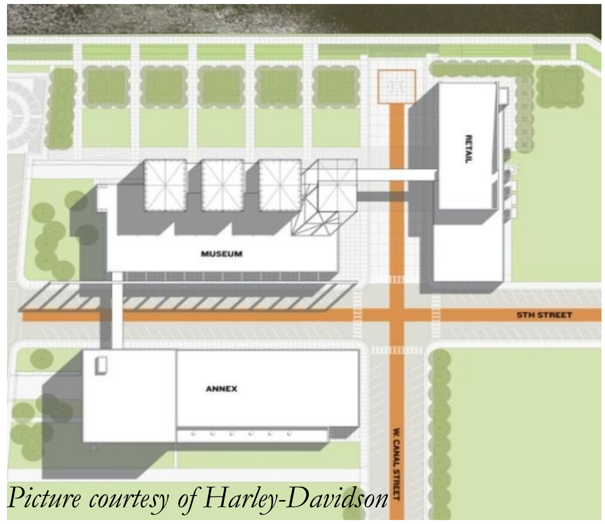
Executive Summary

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



Picture courtesy of Harley-Davidson

The purpose of this report is to evaluate 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. This information will be used to point out weaknesses in the building and areas for improvement, which will be studied further in later reports.

A comprehensive load and energy model was conducted 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 15,293,176 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 and will be a vital tool in analyzing new alternative designs in future investigations.

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.

Some energy efficiency features in the mechanical design include; operating pumps using variable speed drive controllers, multiple boilers operating at part load capacity, multiple chillers 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.

LOAD CALCULATION

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. TRACE weather inputs are shown in Appendix A. 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 Driftpoint	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 considerably lower than the standard. Table 2 compares the designed occupant density for the most common space in the building with the ASHRAE 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 report.

Table 2 – Most Common Occupant Density

Modeled Occupant Density		
	Sq Ft/person	
Space	Design	ASHRAE
Museums	19	25

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 4.

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 4 – 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

Table 5 – 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	-

Construction:

The Harley-Davidson Museum is designed with four major wall types and one roof type. Details of the construction types used in the TRACE model are in Appendix B and summarized in Table 5. Information used in the construction templates were taken from construction documents and specifications provided by the architects and engineers at HGA.

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 misc. 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, misc. 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.

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 6, was compared with the calculated load from TRACE.

Table 6 – 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 do to the uniqueness of exhibits and spaces compared to an ordinary museum. With this extra load on the space it would be expected that the refrigeration density would also be high, which it is. The TRACE calculations for refrigeration density and total tons also match the designed values and are illustrated in Table 7 for comparison. The modeled peak heating plant load also falls in a reasonable range to the designed MBh and is illustrated in Table 8.

Table 7 – 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 8 – 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 9. 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 10 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 9- 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 10- TRACE Systems

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

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

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

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

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

Energy Calculation and Operating Costs

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.

Energy Consumption:

Table 11 below is a breakdown of energy consumption calculated from the TRACE energy model. Figure 1 and 2 illustrates the data in Table 11 and shows that lighting is the major contributor to energy usage in the building. It is also noteworthy that primary heating uses 24% of the building's energy, but only 10% of total source energy and primary cooling uses 15% of the building's energy and 17% of total source energy. This is because most of the Primary heating uses onsite combustion as opposed to the primary cooling which uses electricity from WE Energies. Auxiliary energy which is fans and pumps, is the second leading contributor to energy consumption.

Table 11- Energy Consumption

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

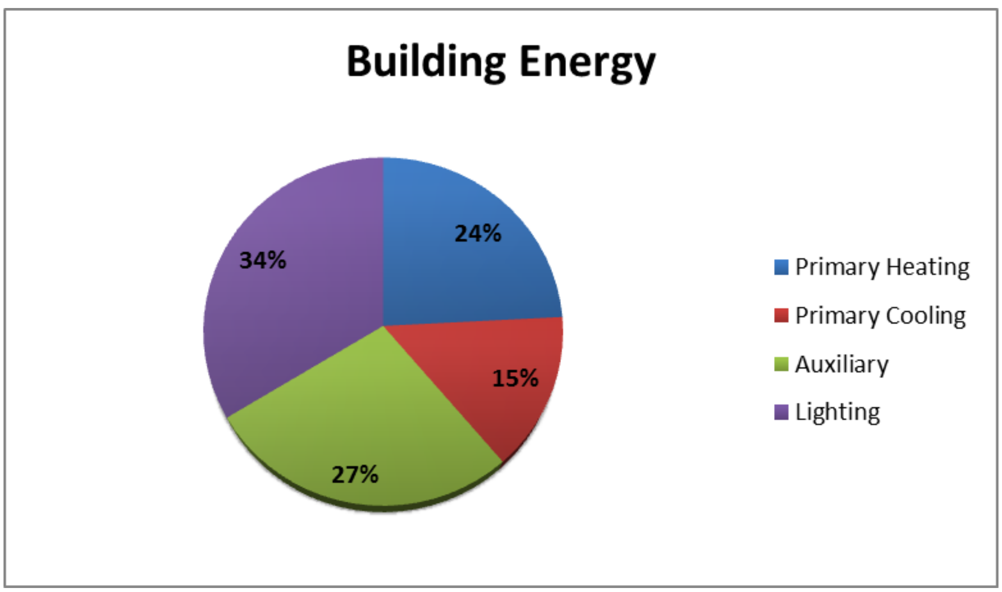


Figure 1 – Building Energy Breakdown

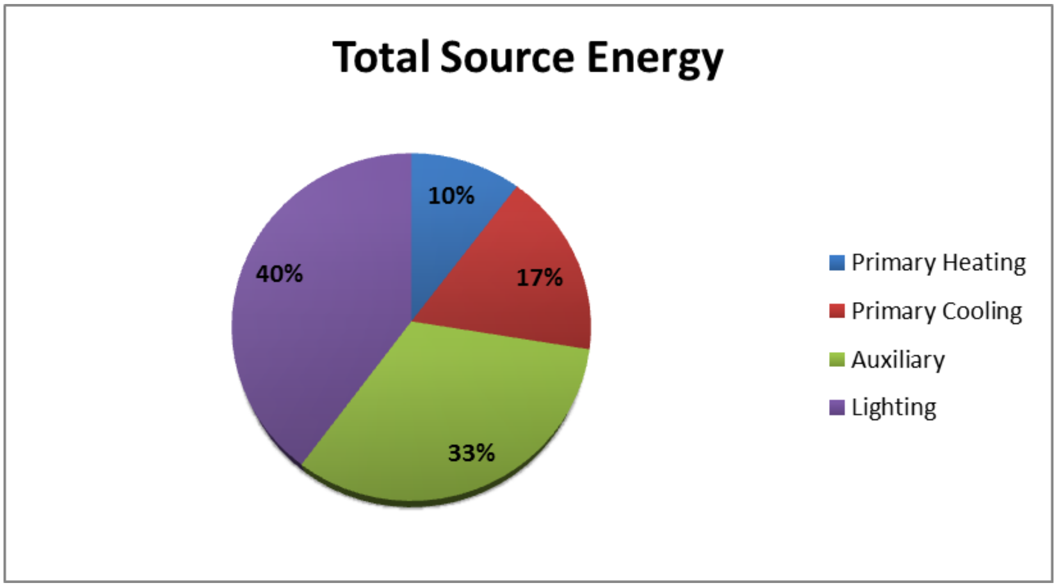


Figure 2 – Building Total Source Energy Breakdown

Figure 3 below illustrates the monthly cooling and heating profiles. From this graph, it is clear that heating dominates in the colder months and cooling dominates in the hot months just as one would expect. The load profile for heating and cooling is not flat, meaning that equipment will not be running near peak performance for the majority of the year.

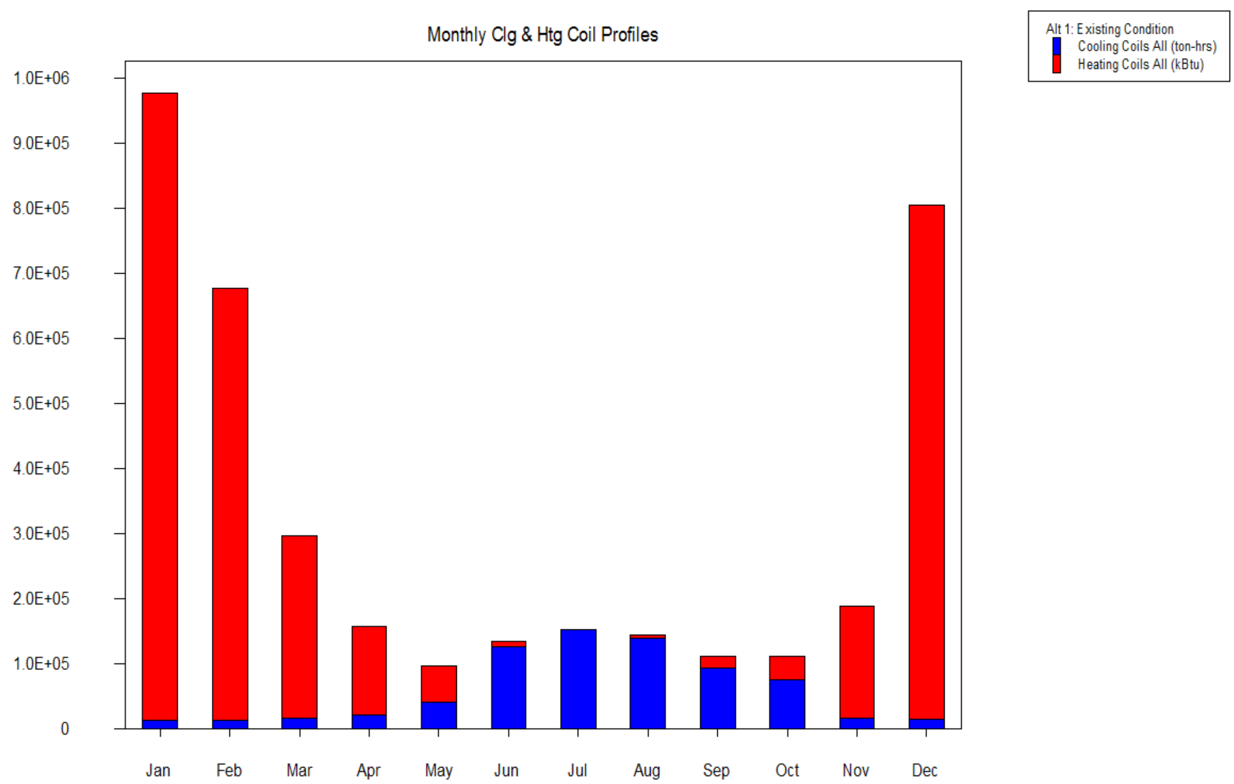


Figure 3 – Monthly Coil Profiles

Figure 4 below illustrates the breakdown of HVAC energy consumed in the building. In this graph it is shown that most of the energy consumed by the HVAC equipment is in the coldest months of the year.

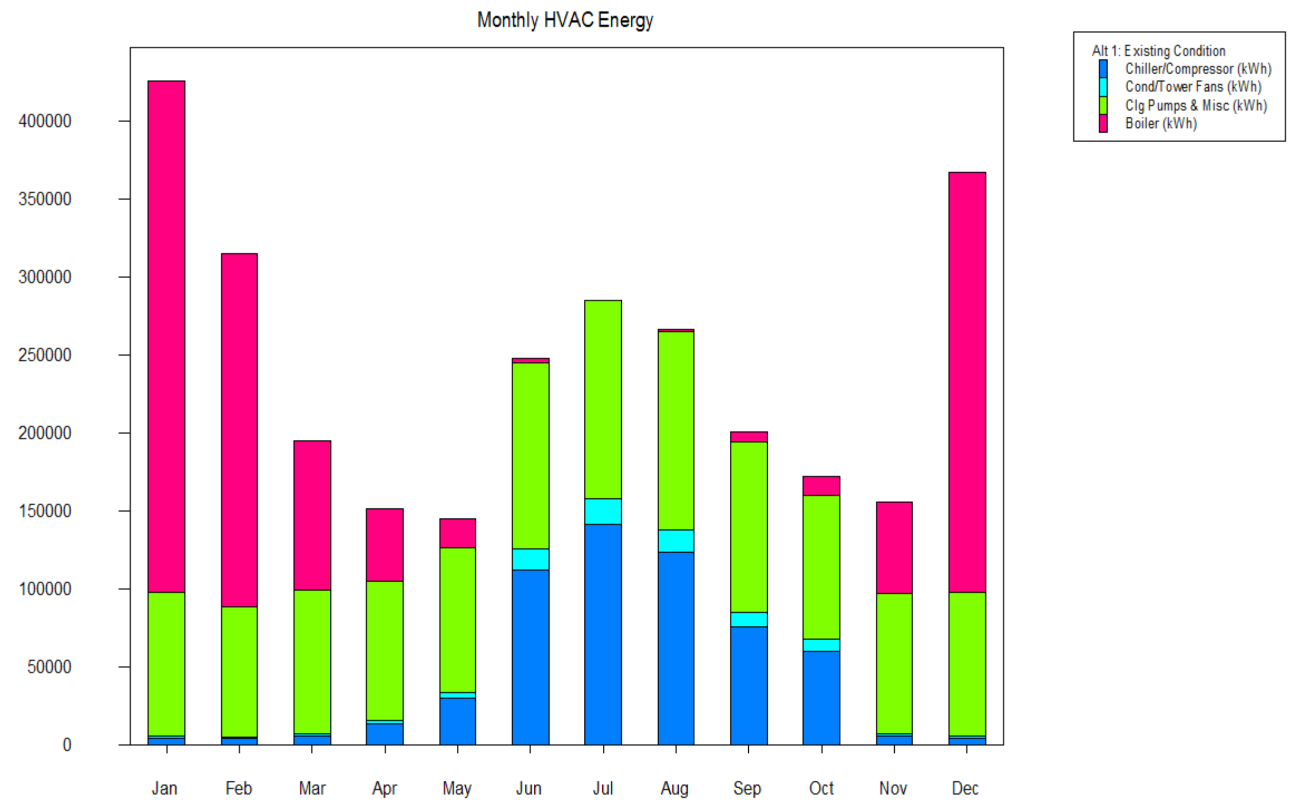


Figure 4- Monthly HVAC Energy Breakdown

Energy Comparison:

Figure 5 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 6 shows the actual monthly electricity used with actual temperatures for each month. Figure 7 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.

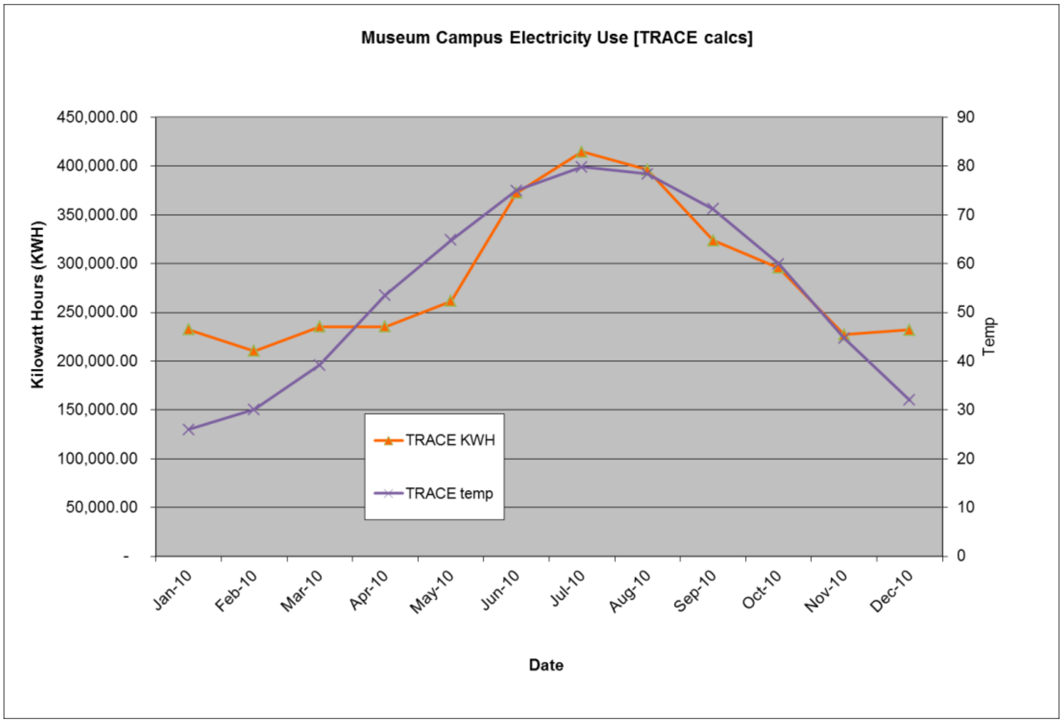


Figure 5 – Modeled Museum Electricity Usage

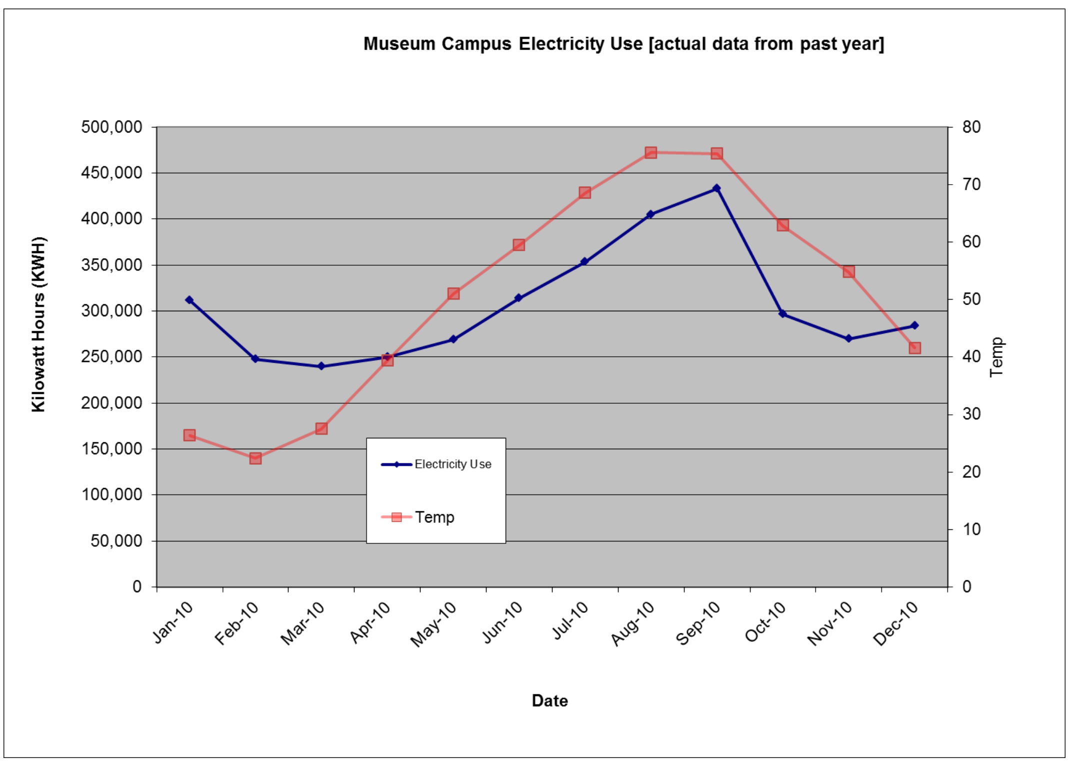


Figure 6 – Actual Museum Electricity Usage

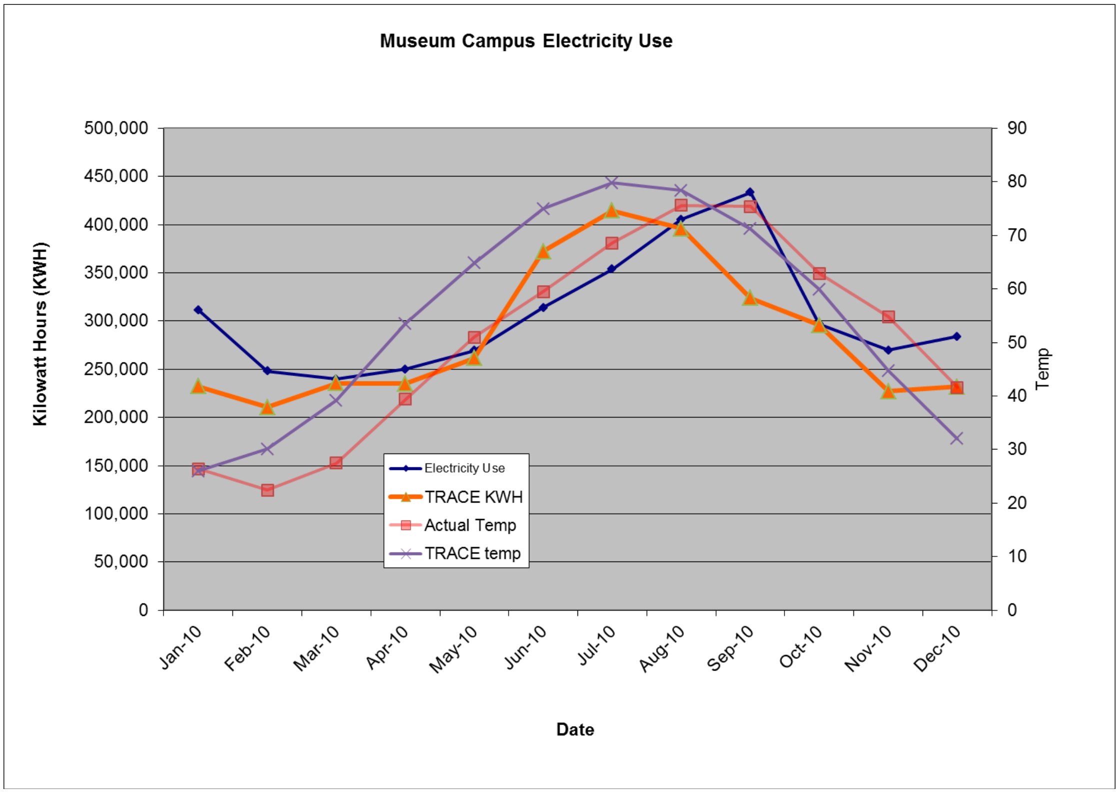


Figure 7 – Comparison of Model to Actual Energy Usage

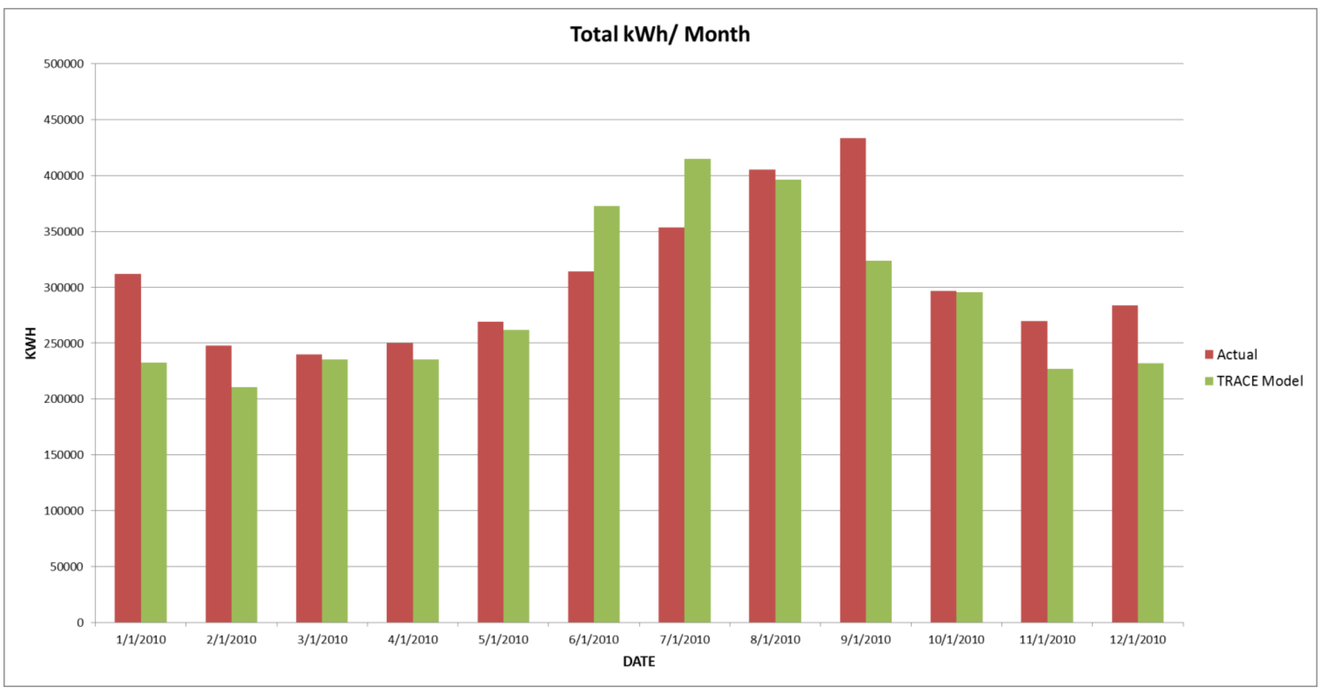


Figure 8 – Summary of Total kWh/ Month for Actual Data vs. Modeled Data

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

Table 12 – 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 9 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.

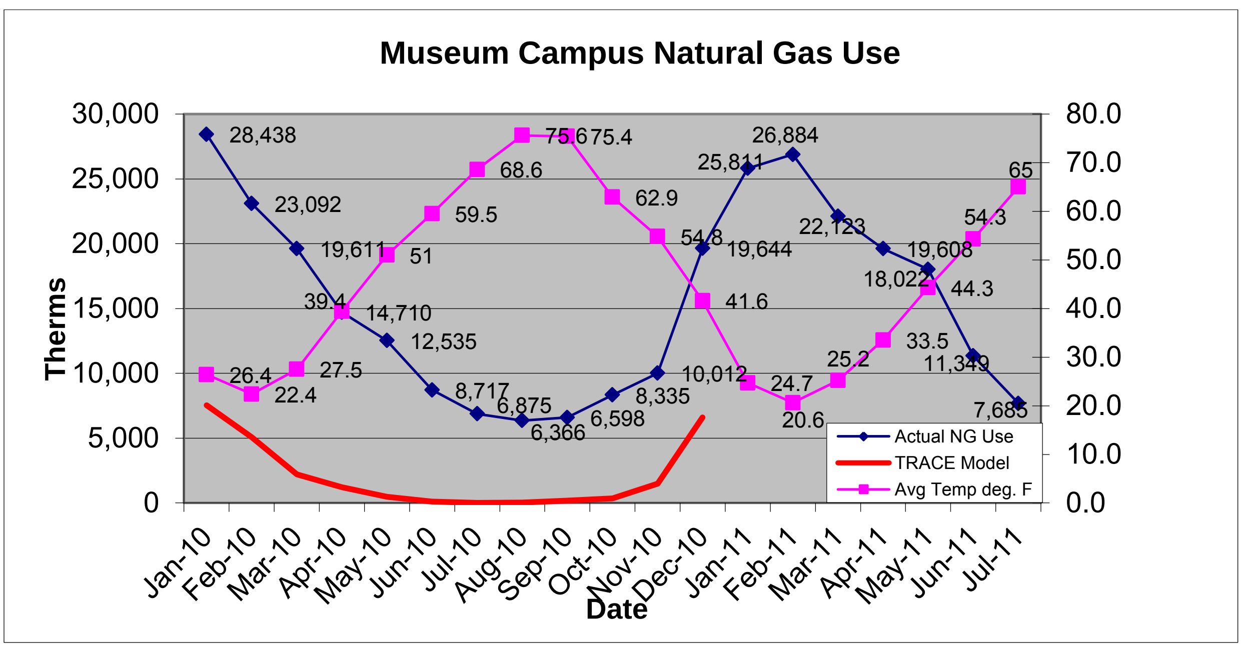


Figure 9 – Natural Gas Monthly Profile: Actual vs. Model

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 10 and 11. An electric demand of $10.00/kW was used in the Model. This rate structure seamed high and in Table 13 and Figure 12 it is clear that the rates were relatively high and is not the correct rate structure used by Harley-Davidson. After further investigation of the information provided by Harley-Davidson it was concluded that the rate structure was simply $0.09/kW. This more closely matched the actual cost and is shown in Figure 12. Another analysis was conducted using a standard built in rate structure from TRACE and was concluded to be similar to the $0.09/kW rate structure.

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 10 – WE Energy Level 3 Rates

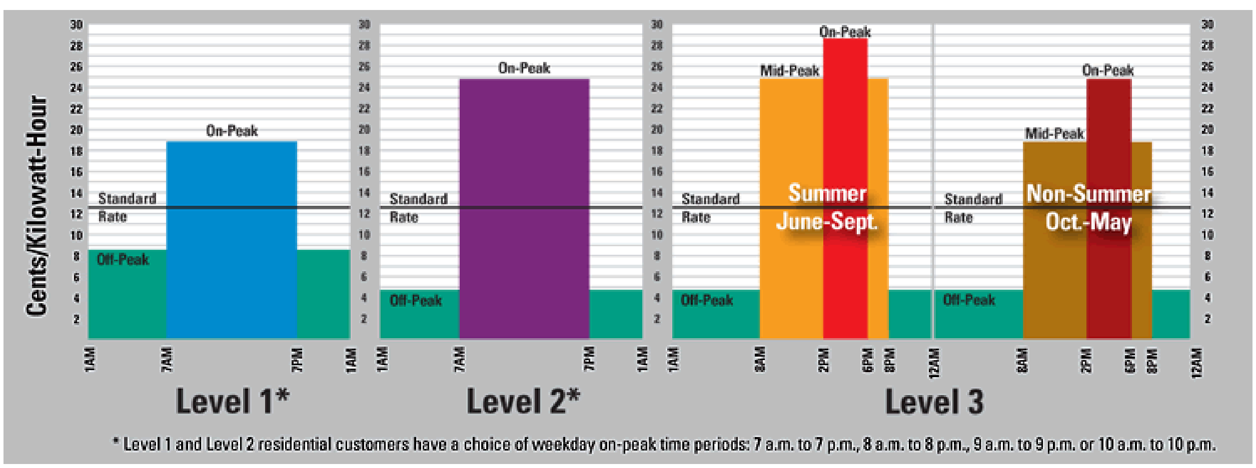


Figure 11 – WE Energy Rate Structures

Table 13 – Electricity Cost Comparison

Monthly Utility Cost Comparison								
	Museum	Annex	Retail	Total	TRACE Model: WE Energy	TRACE kwh	.09/kwh	Standard TRACE built in Rates
January	$10,471.91	$8,814.67	$6,472.96	$25,759.54	$72,078.00	232,418.00	$ 20,917.62	-
February	$9,139.90	$7,631.74	$5,369.61	$22,141.25	$65,763.00	210,507.00	$ 18,945.63	-
March	$10,135.52	$6,851.84	$5,502.33	$22,489.69	$73,075.00	235,313.00	$ 21,178.17	-
April	$13,077.00	$5,894.36	$5,747.06	$24,718.42	$74,113.00	235,240.00	$ 21,171.60	-
May	$14,538.80	$5,684.21	$5,842.70	$26,065.71	$84,401.00	261,619.00	$ 23,545.71	-
June	$18,488.35	$5,429.63	$6,077.33	$29,995.31	$119,612.00	372,389.00	$ 33,515.01	-
July	$24,193.01	$4,756.08	$5,839.81	$34,788.90	$132,494.00	414,710.00	$ 37,323.90	-
August	$26,438.25	$4,586.95	$6,238.63	$37,263.83	$126,447.00	395,992.00	$ 35,639.28	-
September	$28,070.69	$5,133.51	$6,668.10	$39,872.30	$104,643.00	323,880.00	$ 29,149.20	-
October	$18,543.28	$4,773.60	$5,994.65	$29,311.53	$84,199.00	295,749.00	$ 26,617.41	-
November	$15,504.32	$4,900.71	$5,823.11	$26,228.14	$61,927.00	226,994.00	$ 20,429.46	-
December	$13,594.81	$6,769.54	$6,626.98	$26,991.33	$62,696.00	231,986.00	$ 20,878.74	-
			Total:	$345,625.95	$1,061,448.00		$309,311.73	$ 242,463.00

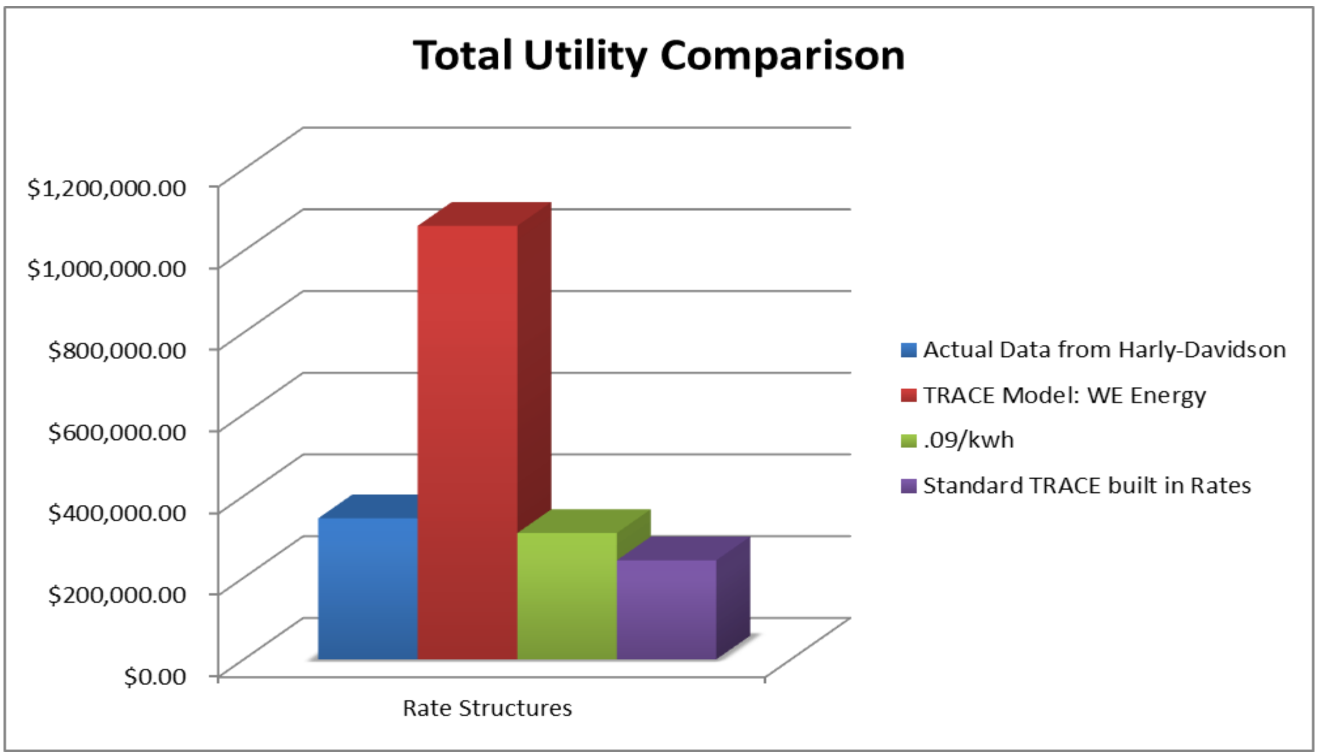


Figure 12 – Electricity Utility Rate Comparison

Table 14 – 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 15 and Figure 13. It is interesting to see how primary heating cost is only 6% of the total, but consumes 24% of the total energy, shown in Figure 1. This is largely due to the fact that primary heating is only 10% when converted to source energy.

Table 15 – Cost Breakdown

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

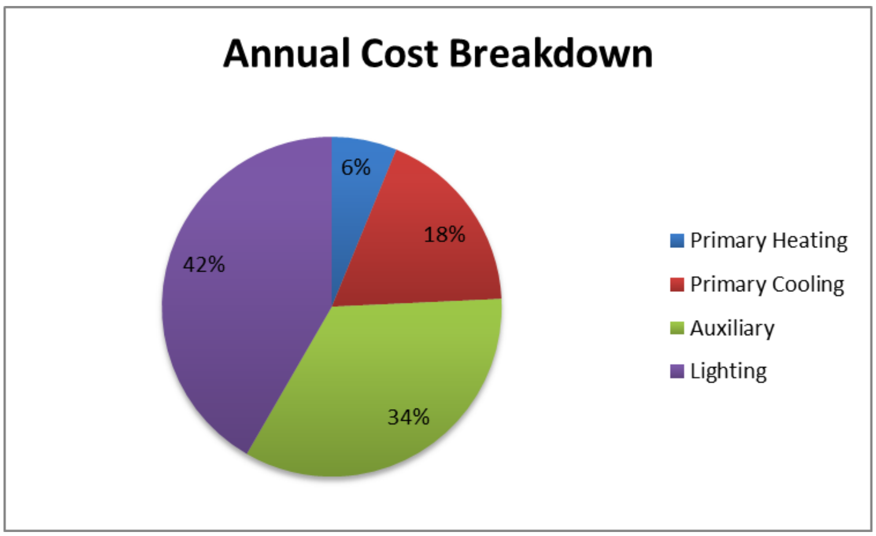


Figure 13 – Percentage Cost Breakdown

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 Tables 16 and 17. 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 illustrate 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 14.

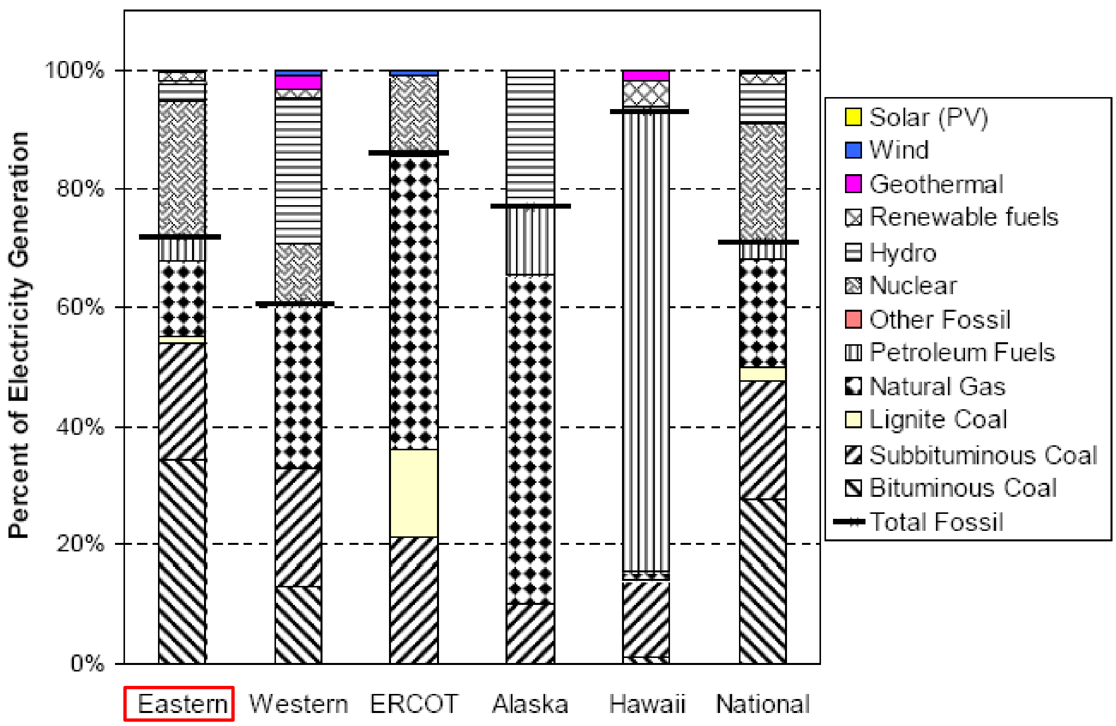


Figure 14 – Electricity generation fuel mix for the continental United States from the Regional Grid Emission Factors 2007 database.

Table 16 - 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
CO2e	2.03E+00	3413592	6.93E+06	123	25315	2531.5	311374.5	164933	16493.3	2028675.90	7.24E+06	8.96E+06
CO2	1.92E+00	3413592	6.55E+06	122	25315	2531.5	308843	164933	16493.3	2012182.60	6.86E+06	8.57E+06
CH4	4.13E-03	3413592	1.41E+04	0.0025	25315	2531.5	6.32875	164933	16493.3	41.23	1.41E+04	1.41E+04
N2O	5.32E-05	3413592	1.82E+02	0.0025	25315	2531.5	6.32875	164933	16493.3	41.23	1.88E+02	2.23E+02
NOx	3.51E-03	3413592	1.20E+04	0.111	25315	2531.5	280.9965	164933	16493.3	1830.76	1.23E+04	1.38E+04
SOx	6.60E-03	3413592	2.25E+04	0.000632	25315	2531.5	1.599908	164933	16493.3	10.42	2.25E+04	2.25E+04
CO	7.13E-04	3413592	2.43E+03	0.0933	25315	2531.5	236.18895	164933	16493.3	1538.82	2.67E+03	3.97E+03
TNMOC	8.26E-05	3413592	2.82E+02	-	25315	2531.5	-	164933	16493.3	-	2.82E+02	2.82E+02
Lead	1.97E-07	3413592	6.72E-01	0.0000005	25315	2531.5	0.00126575	164933	16493.3	0.01	6.74E-01	6.81E-01
Mercury	4.01E-08	3413592	1.37E-01	2.60E-07	25315	2531.5	0.00065819	164933	16493.3	0.00	1.38E-01	1.41E-01
PM10	1.11E-04	3413592	3.79E+02	8.40E-03	25315	2531.5	21.2646	164933	16493.3	138.54	4.00E+02	5.17E+02
Solid Waste	3.03E-01	3413592	1.03E+06	-	25315	2531.5	-	164933	16493.3	-	1.03E+06	1.03E+06
VOC	-	-	-	6.13E-03	25315	2531.5	15.518095	164933	16493.3	101.10	1.55E+01	1.01E+02
		Model	**w/ Actual Gas Usage									
	*Total CO2e (lb):	7.24E+06	8.96E+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 17 - Precombustion

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
CO2e	2.78E+01	2.53E+03	7.04E+04	1.65E+04	4.59E+05	7.00E+06	7.39E+06
CO2	1.16E+01	2.53E+03	2.94E+04	1.65E+04	1.91E+05	6.58E+06	6.75E+06
CH4	7.04E-01	2.53E+03	1.78E+03	1.65E+04	1.16E+04	1.59E+04	2.57E+04
N2O	2.35E-04	2.53E+03	5.95E-01	1.65E+04	3.88E+00	1.82E+02	1.85E+02
NOx	1.64E-02	2.53E+03	4.15E+01	1.65E+04	2.70E+02	1.20E+04	1.23E+04
SOx	1.22E+00	2.53E+03	3.09E+03	1.65E+04	2.01E+04	2.56E+04	4.27E+04
CO	1.36E-02	2.53E+03	3.44E+01	1.65E+04	2.24E+02	2.47E+03	2.66E+03
TNMOC	4.56E-05	2.53E+03	1.15E-01	1.65E+04	7.52E-01	2.82E+02	2.83E+02
Lead	2.41E-07	2.53E+03	6.10E-04	1.65E+04	3.97E-03	6.73E-01	6.76E-01
Mercury	5.51E-08	2.53E+03	1.39E-04	1.65E+04	9.09E-04	1.37E-01	1.38E-01
PM10	8.17E-04	2.53E+03	2.07E+00	1.65E+04	1.35E+01	3.81E+02	3.92E+02
Solid Waste	1.60E+00	2.53E+03	4.05E+03	1.65E+04	2.64E+04	1.04E+06	1.06E+06
VOC	-	-	-	-	-	-	-
	Factors taken from the regional Grid Emission factors 2007, Table 6						

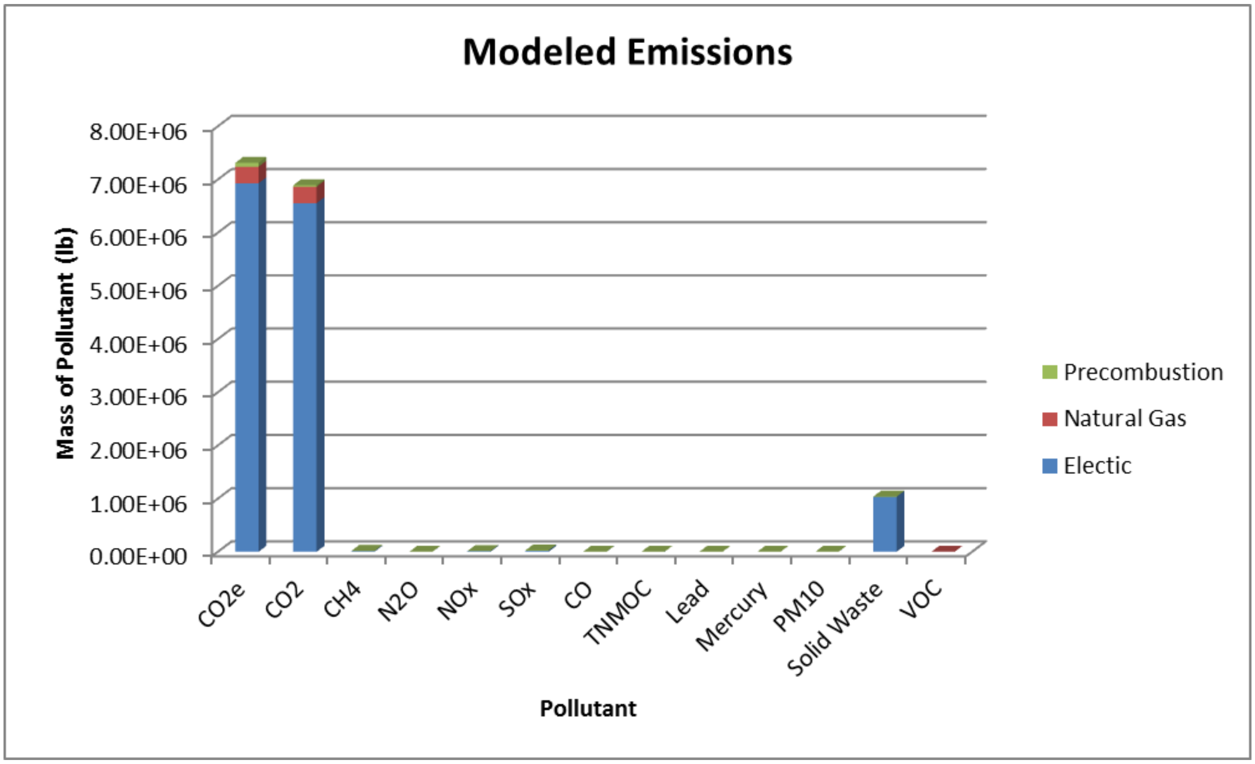


Figure 15- Modeled Emissions

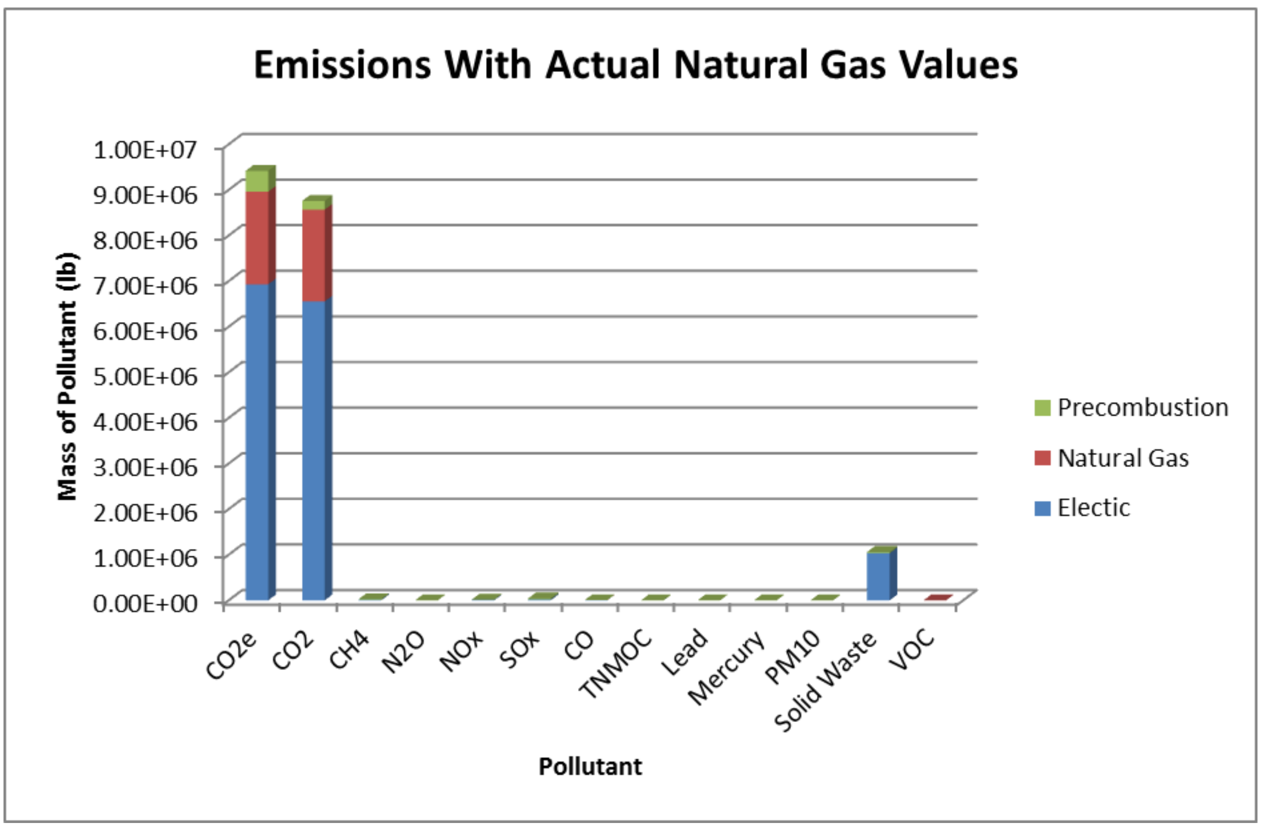


Figure 16 – Modeled Emissions with Actual Natural Gas Values

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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.

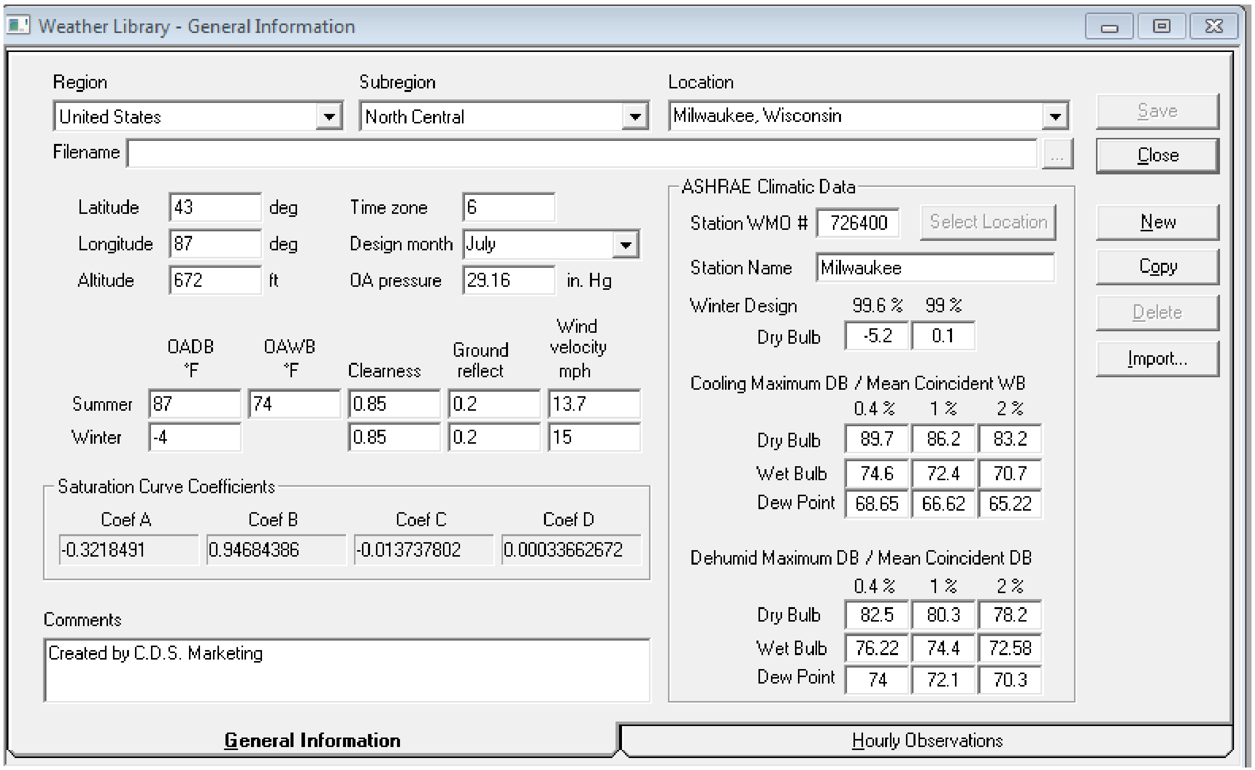
Pocket Guide. Atlanta: ASHRAE, 2005

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
- Environmental Services: The Sigma Group
- Landscape Architect: Oslund And Associates
- Civil Engineer: Graef Anhalt

APPENDIX A

Milwaukee, WI – Weather Design Conditions



APPENDIX B

Construction templates used in TACE.

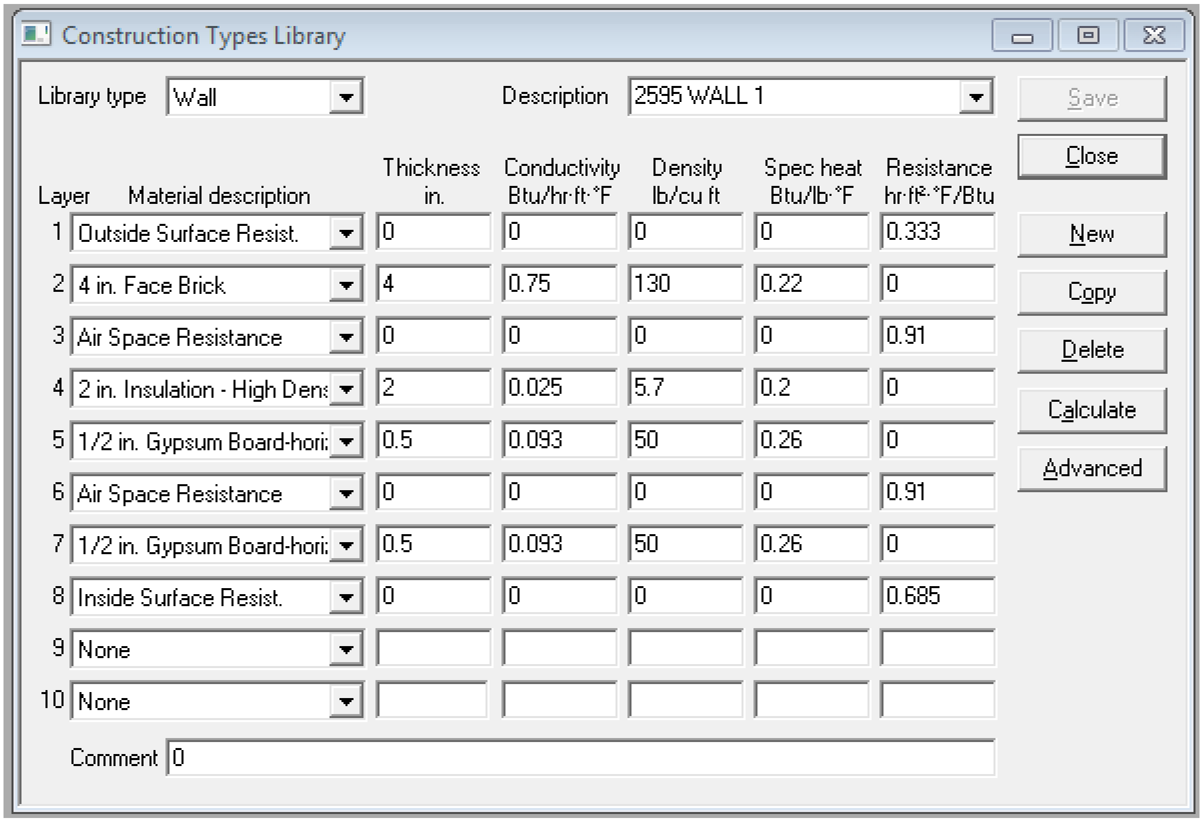
Construction Types Library

Library type: Roof   Description: HDM White Roof

Save | Close | New | Copy | Delete | Calculate | Advanced

Layer	Material description	Thickness in.	Conductivity Btu/hr·ft·°F	Density lb/cu ft	Spec heat Btu/lb·°F	Resistance hr·ft²·°F/Btu
1	Outside Surface Resist.	0	0	0	0	0.333
2	6 in. Insulation - High Dens	6	0.025	5.7	0.2	0
3	3/4 in. Plywood Sheathing	0.75	0.0675	34	0.29	0
4	3/8 in. Felt & Membrane	0.375	0.111	70	0.4	0
5	2 in. HW Concrete	2	1	140	0.2	0
6	Steel Siding	0.06	26	480	0.1	0
7	Inside Surface Resist.	0	0	0	0	0.685
8	None					
9	None					
10	None					

Comment: Steel sheet, 4" insulation



Construction Types Library

Library type: Wall   Description: 2595 WALL 1

Layer	Material description	Thickness in.	Conductivity Btu/hr·ft·°F	Density lb/cu ft	Spec heat Btu/lb·°F	Resistance hr·ft²·°F/Btu
1	Outside Surface Resist.	0	0	0	0	0.333
2	4 in. Face Brick	4	0.75	130	0.22	0
3	Air Space Resistance	0	0	0	0	0.91
4	2 in. Insulation - High Dens	2	0.025	5.7	0.2	0
5	1/2 in. Gypsum Board-hori:	0.5	0.093	50	0.26	0
6	Air Space Resistance	0	0	0	0	0.91
7	1/2 in. Gypsum Board-hori:	0.5	0.093	50	0.26	0
8	Inside Surface Resist.	0	0	0	0	0.685
9	None					
10	None					

Comment: 0

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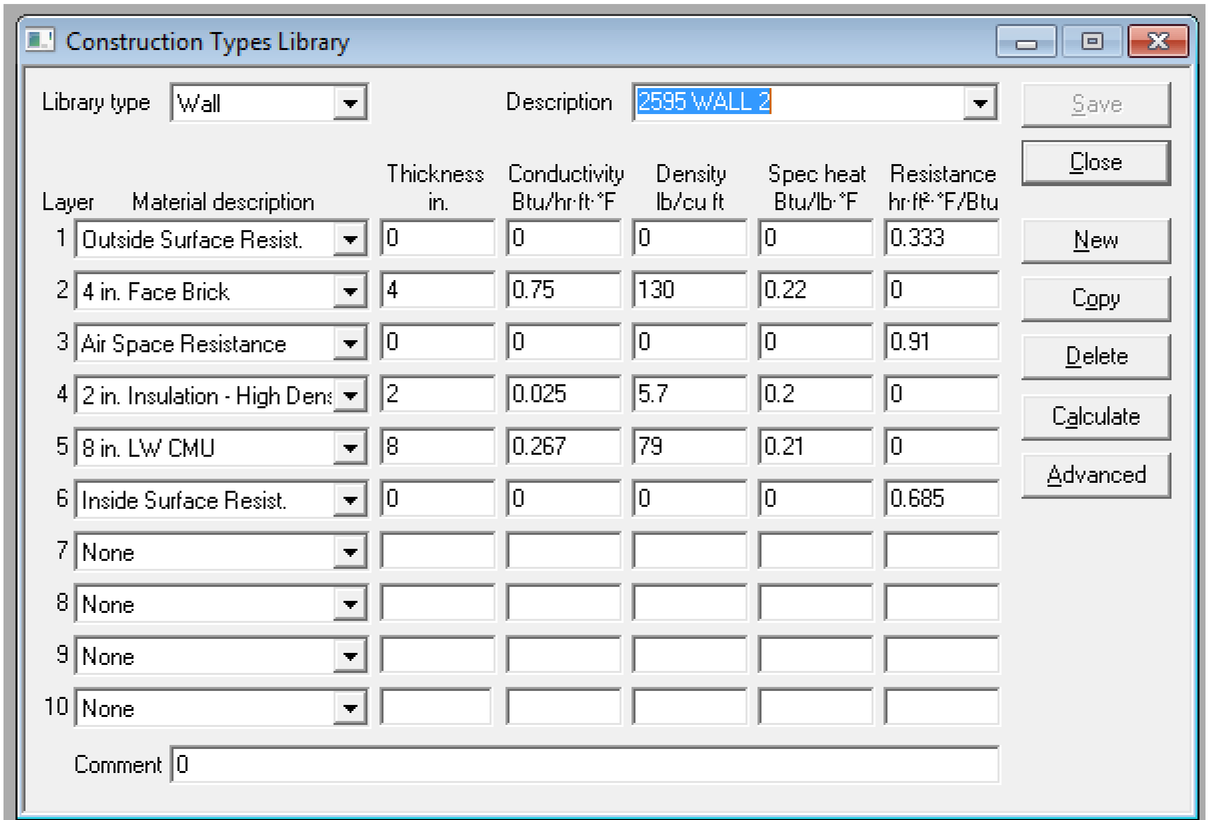

Construction Types Library

Library type: Wall Description: 2595 WALL 2

Layer	Material description	Thickness in.	Conductivity Btu/hr·ft·°F	Density lb/cu ft	Spec heat Btu/lb·°F	Resistance hr·ft²·°F/Btu
1	Outside Surface Resist.	0	0	0	0	0.333
2	4 in. Face Brick	4	0.75	130	0.22	0
3	Air Space Resistance	0	0	0	0	0.91
4	2 in. Insulation - High Dens	2	0.025	5.7	0.2	0
5	8 in. LW CMU	8	0.267	79	0.21	0
6	Inside Surface Resist.	0	0	0	0	0.685
7	None					
8	None					
9	None					
10	None					

Comment: 0

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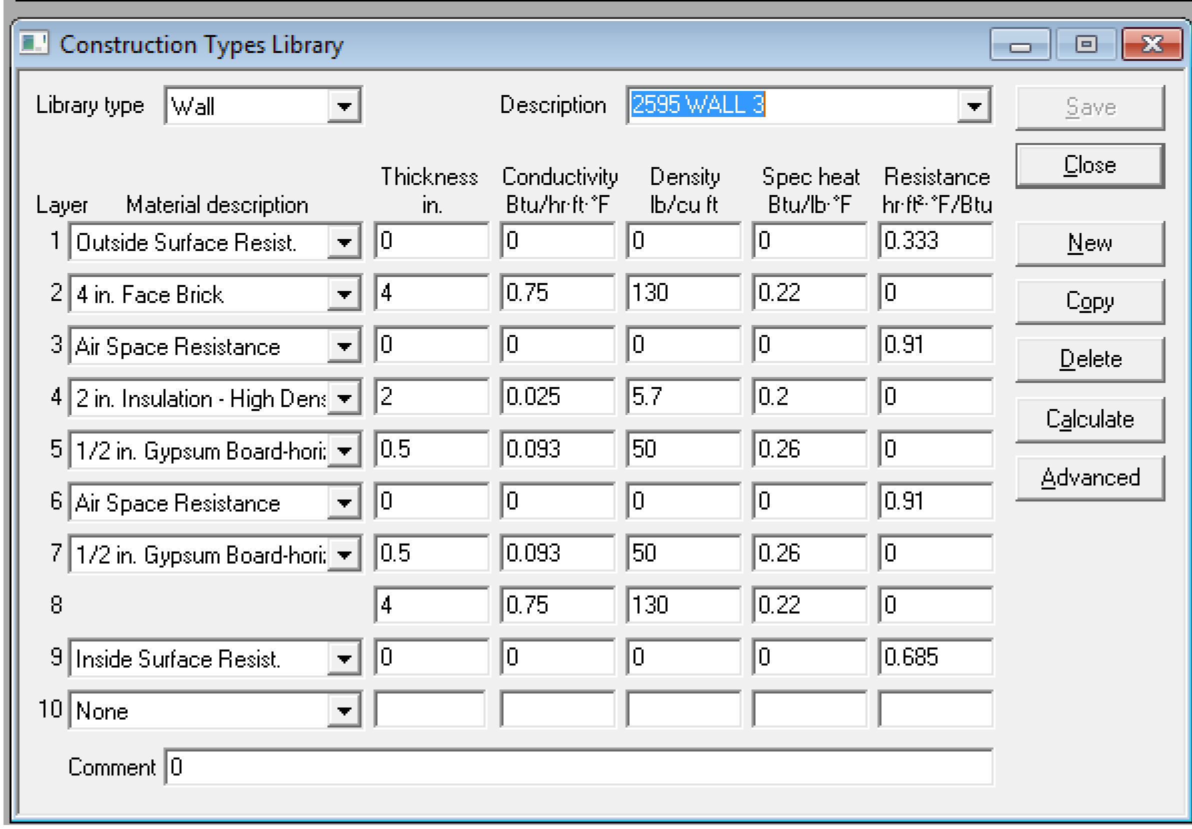

Construction Types Library

Library type: Wall Description: 2595 WALL 3

Layer	Material description	Thickness in.	Conductivity Btu/hr·ft·°F	Density lb/cu ft	Spec heat Btu/lb·°F	Resistance hr·ft²·°F/Btu
1	Outside Surface Resist.	0	0	0	0	0.333
2	4 in. Face Brick	4	0.75	130	0.22	0
3	Air Space Resistance	0	0	0	0	0.91
4	2 in. Insulation - High Dens	2	0.025	5.7	0.2	0
5	1/2 in. Gypsum Board-hori:	0.5	0.093	50	0.26	0
6	Air Space Resistance	0	0	0	0	0.91
7	1/2 in. Gypsum Board-hori:	0.5	0.093	50	0.26	0
8		4	0.75	130	0.22	0
9	Inside Surface Resist.	0	0	0	0	0.685
10	None					

Comment: 0

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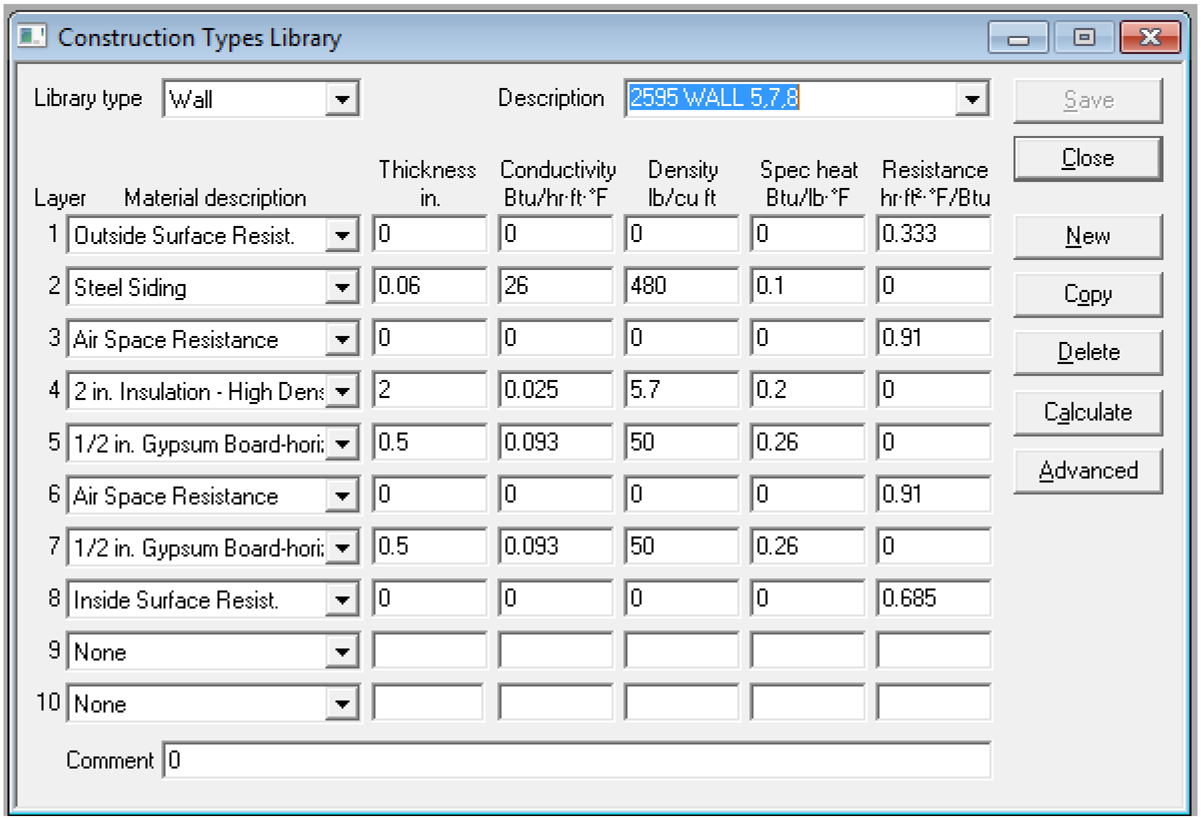

Construction Types Library

Library type: Wall — Description: 2595 WALL 5,7,8

Layer	Material description	Thickness in.	Conductivity Btu/hr·ft·°F	Density lb/cu ft	Spec heat Btu/lb·°F	Resistance hr·ft²·°F/Btu
1	Outside Surface Resist.	0	0	0	0	0.333
2	Steel Siding	0.06	26	480	0.1	0
3	Air Space Resistance	0	0	0	0	0.91
4	2 in. Insulation - High Dens	2	0.025	5.7	0.2	0
5	1/2 in. Gypsum Board-hori:	0.5	0.093	50	0.26	0
6	Air Space Resistance	0	0	0	0	0.91
7	1/2 in. Gypsum Board-hori:	0.5	0.093	50	0.26	0
8	Inside Surface Resist.	0	0	0	0	0.685
9	None					
10	None					

Comment: 0

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APPENDIX C

Schedules used in TRACE model.

Scheduless of Utilization

Schedule	Space		Percentage		
Light Schedule	Annex Building		Midnight -7:00 AM	7:00 AM - 7:00 PM	7:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	100	10
		Weekend	10	50	10
	Museum building		Midnight -7:00 AM	7:00 AM - 7:00 PM	7:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	100	10
		Weekend	10	100	10
	Restaurant		Midnight -9:00 AM	9:00 AM - 7:00 PM	7:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	100	100
		Weekend	10	100	100
	Retail		Midnight -7:00 AM	7:00 AM - 9:00 PM	9:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	100	10
		Weekend	10	100	10
	Shop		Midnight -7:00 AM	7:00 AM - 7:00 PM	7:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	100	10
		Weekend	0	25	0
	Sp Event		Midnight -7:00 AM	7:00 AM - 9:00 PM	9:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	100	10
		Weekend	10	100	10
	Temp Exhibit		Midnight -7:00 AM	7:00 AM - 7:00 PM	7:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	100	10
		Weekend	10	100	100
Misc Schedule	Annex Building		Midnight -7:00 AM	7:00 AM - 7:00 PM	7:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	0	100	0
		Weekend	0	50	0
	Museum building		Midnight -7:00 AM	7:00 AM - 7:00 PM	7:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	100	10
		Weekend	0	0	0
	Restaurant		Midnight -9:00 AM	9:00 AM - 7:00 PM	7:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	100	100
		Weekend	10	100	100
	Retail		Midnight -7:00 AM	7:00 AM - 9:00 PM	9:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	100	10
		Weekend	10	100	10
	Shop		Midnight -7:00 AM	7:00 AM - 7:00 PM	7:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	100	10
		Weekend	0	20	0
	Sp Event		Midnight -7:00 AM	7:00 AM - 9:00 PM	9:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	100	10
		Weekend	10	100	10
	Temp Exhibit		Midnight -7:00 AM	7:00 AM - 7:00 PM	7:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	100	10
		Weekend	10	100	10
	Process		Midnight -7:00 AM	7:00 AM - 7:00 PM	7:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	100	100	100
		Weekend	100	100	100

Scheduless of Utilization

Schedule	Space		Percentage		
People Schedule	Annex Building		Midnight -7:00 AM	7:00 AM - 7:00 PM	7:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	0	100	0
		Weekend	0	50	0
	Museum building		Midnight -7:00 AM	7:00 AM - 7:00 PM	7:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	0	60	10
		Weekend	0	100	0
	Restaurant		Midnight -8:00 AM	8:00 AM - 11:00 AM	11:00 AM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	60	90
		Weekend	10	60	90
	Retail		Midnight -7:00 AM	7:00 AM - 9:00 PM	9:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	0	100	0
		Weekend	0	100	0
	Shop		Midnight -7:00 AM	7:00 AM - 7:00 PM	7:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	100	10
		Weekend	0	25	0
	Sp Event		Midnight -7:00 AM	7:00 AM - 9:00 PM	9:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	100	10
		Weekend	10	100	10
	Temp Exhibit		Midnight -7:00 AM	7:00 AM - 7:00 PM	7:00 PM - Midnight
		Cooling	100	100	100
		Heating	0	0	0
		Weekday	10	60	10
		Weekend	10	100	10