Harley-Davidson Museum

Milwaukee, WI.

Jonathan Rumbaugh, BAE/MAE

Mechanical Option

Advisor: Dr. William Bahnfleth

Project Sponsors

Harley-Davidson Motor Cycles

HGA.

Pentagram

b'ber

Presentation Outline

- Project Background
- Existing Conditions
- Thesis Goals
- Structural Breadth:
  - Thermal Bridging
- Mechanical Depth:
  - Air vs. Water
- Electrical Breadth
  - CHP Feasibility
- Conclusion

Project Sponsors

Project Background

- Project Background
  - Building Statistics
  - Location & Layout
- Existing Conditions
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- Structural Breadth
- Mechanical Depth
- Electrical Breadth
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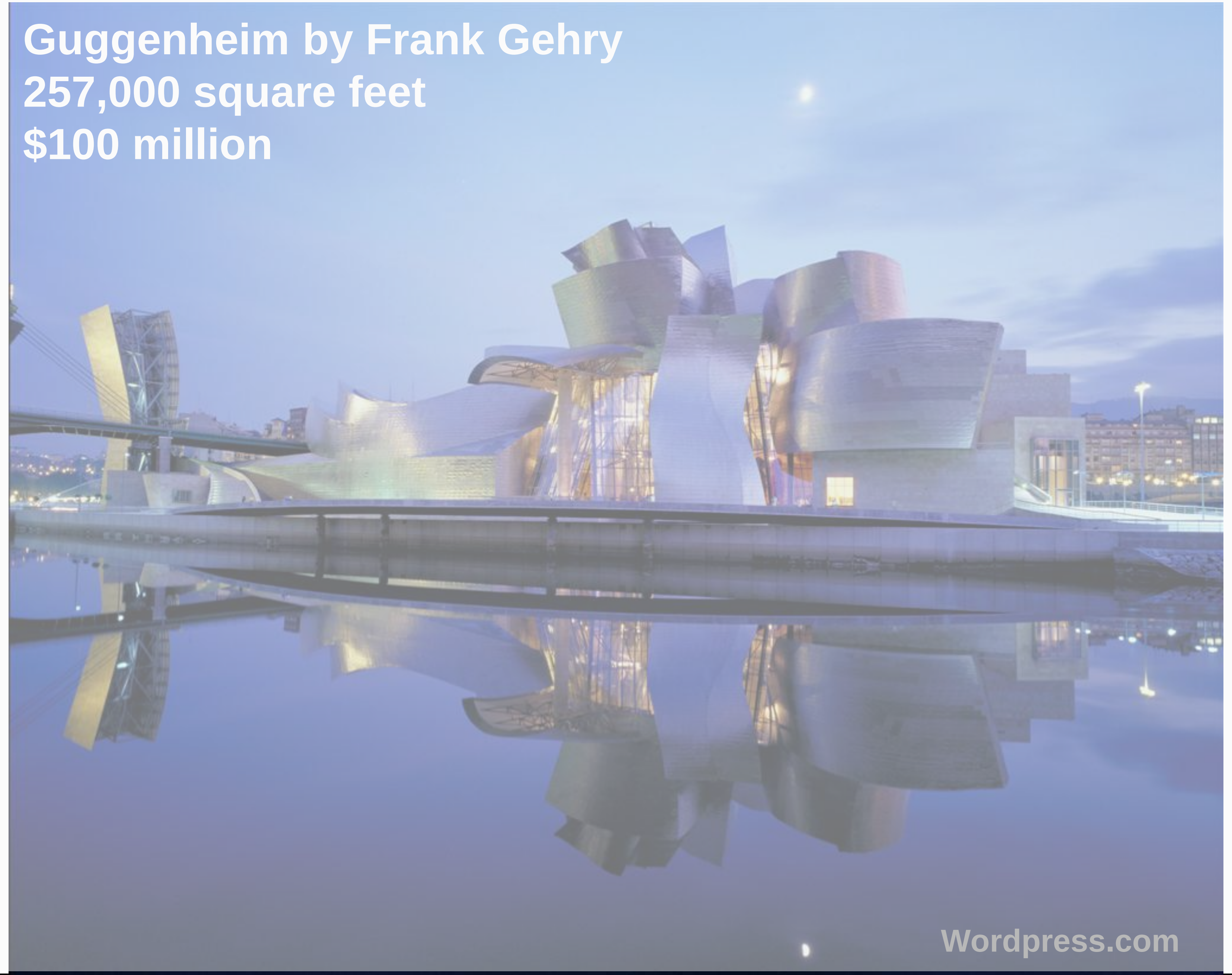
Building Statistics

- Size (Total Square Feet): 130,000
- Number Stories Above grade: 3
- Construction timeline : April 2005 – May 2008
- Overall Project Cost: $75 million



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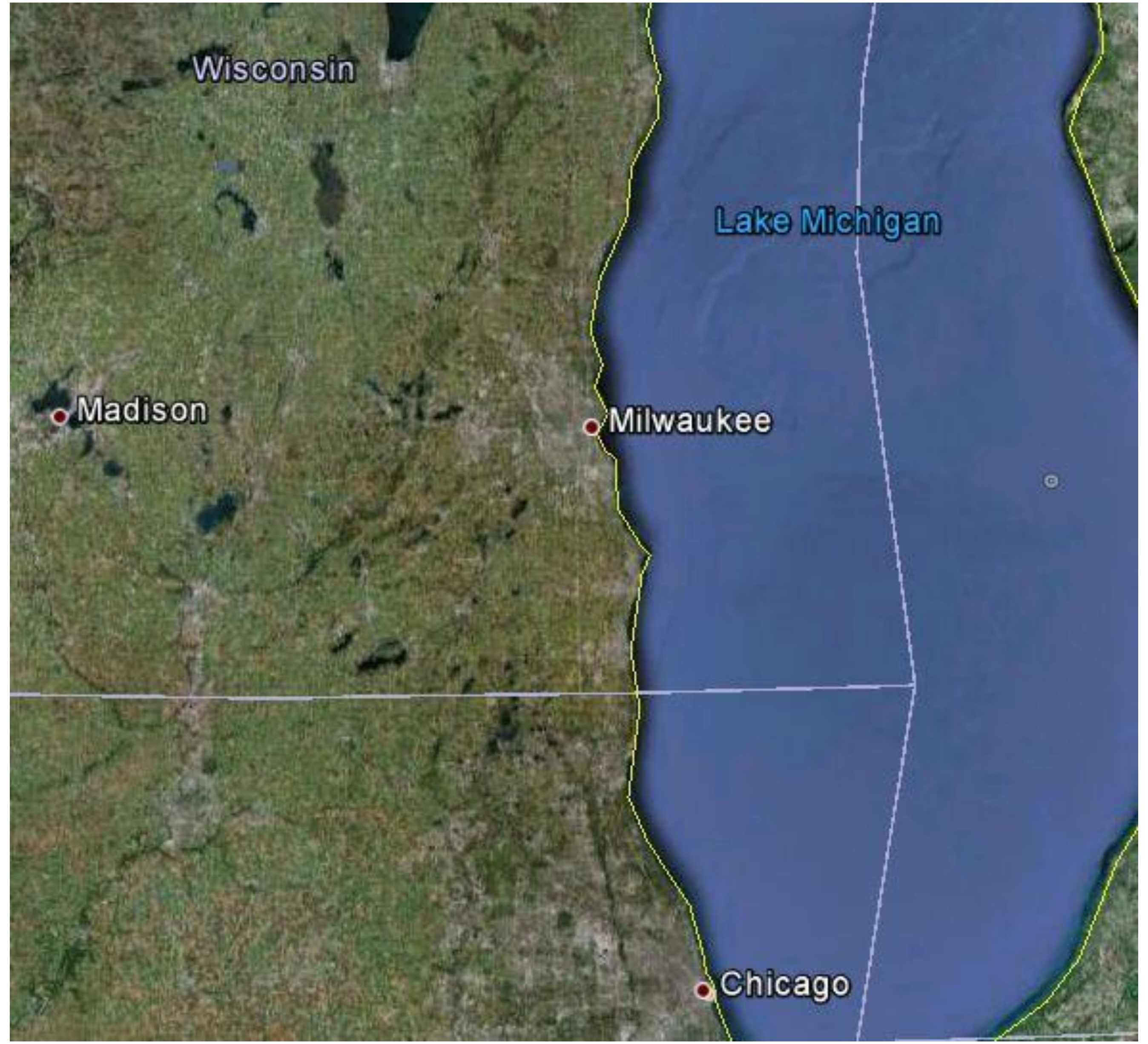

MECHANICAL DESIGN

- Project Background
- **Existing Conditions**
  - **Mechanical Design**
  - **Energy Model**
  - **Emissions**
  - **Comparison**
- Thesis Goals
- Structural Breadth
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- Two Roof Mounted 300 Ton Air-cooled Rotary Screw Chillers
- Four 2000 MBH Sealed Combustion Condensing Boilers
- Variable Primary Flow
- 11 Air Handling Units

ENERGY MODEL

- Project Background
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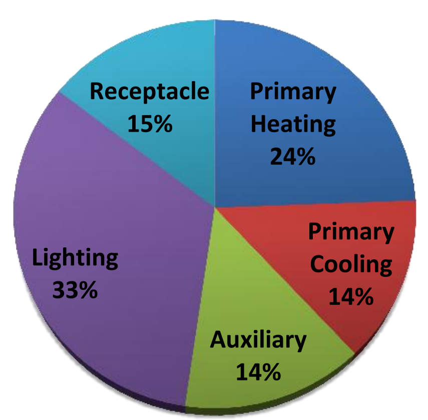
Peak Cooling Plant Loads		
Desgin	TRACE MODEL	Design to Model
ton	ton	%Δ
600	585.3	-2%

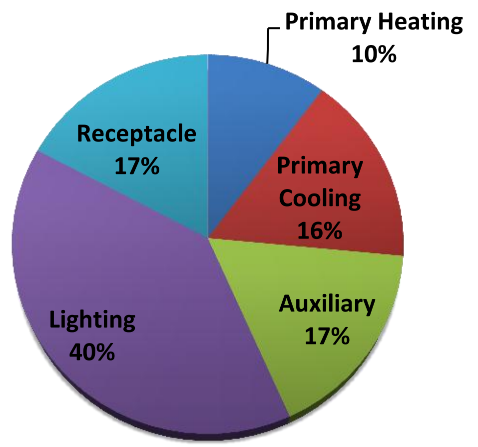
Peak Heating Plant Loads		
Desgin	TRACE MODEL	Design to Model
MBh	MBh	%Δ
8000	9073	13%

$0.10 / kWh Electricity
$0.80 / Therm Natural Gas

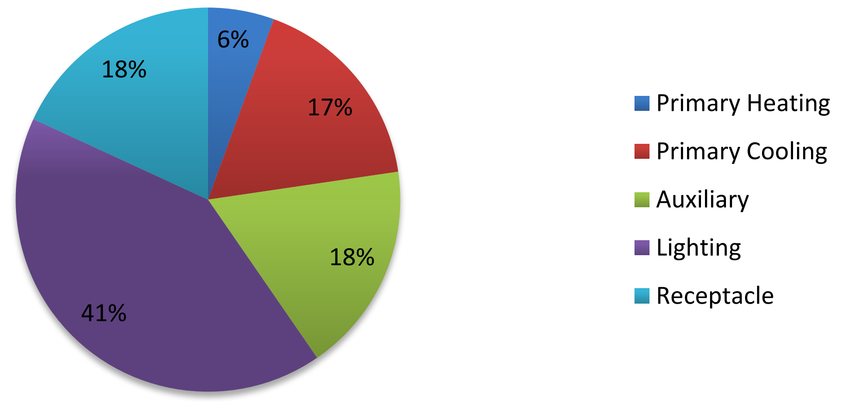
Total Building Energy [kBtu/yr]



Total Source Energy [kBtu/yr]



Annual Cost Breakdown



Cost Breakdown	
	Cost
Primary Heating	$ 20,252.00
Primary Cooling	$ 62,223.50
Auxiliary	$ 64,463.40
Lighting	$ 150,907.60
Receptacle	$ 65,906.60
Total	$ 363,753.10

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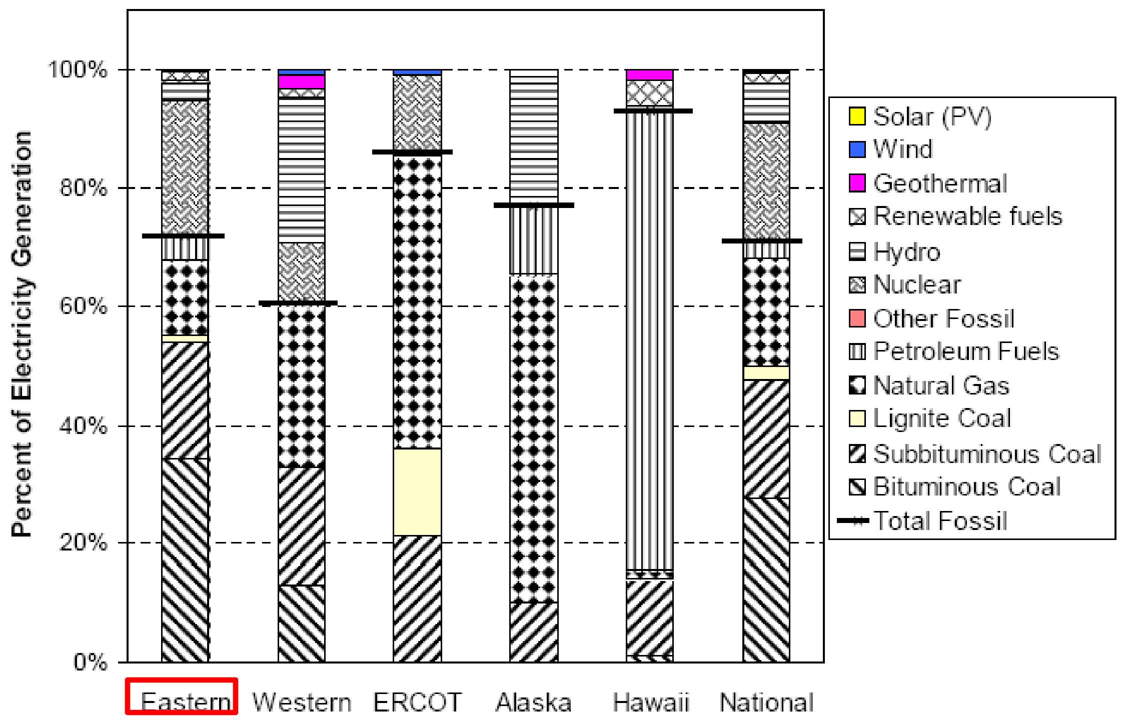
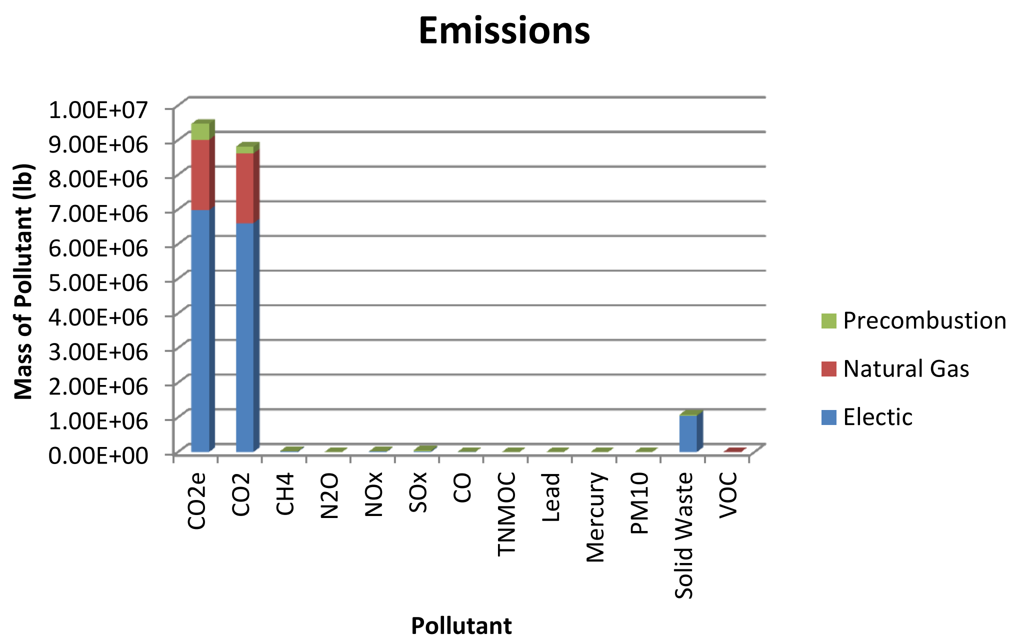
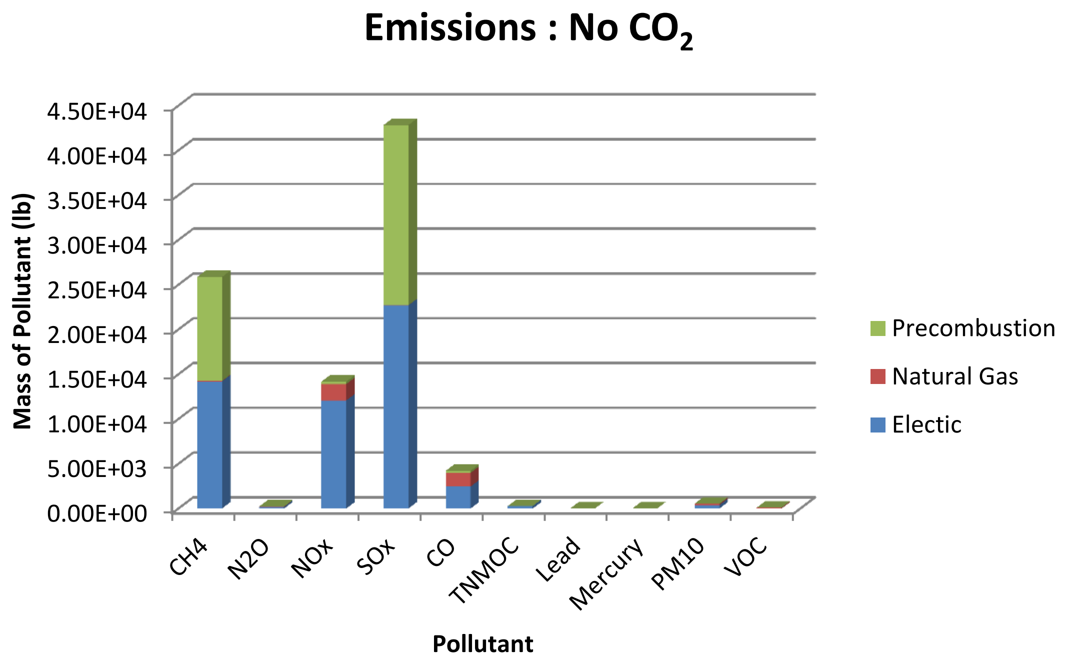
EMISSIONS





Calculations use factors from the Regional Grid emissions Factors 2007. table B-10



EXISTING CONDITIONS

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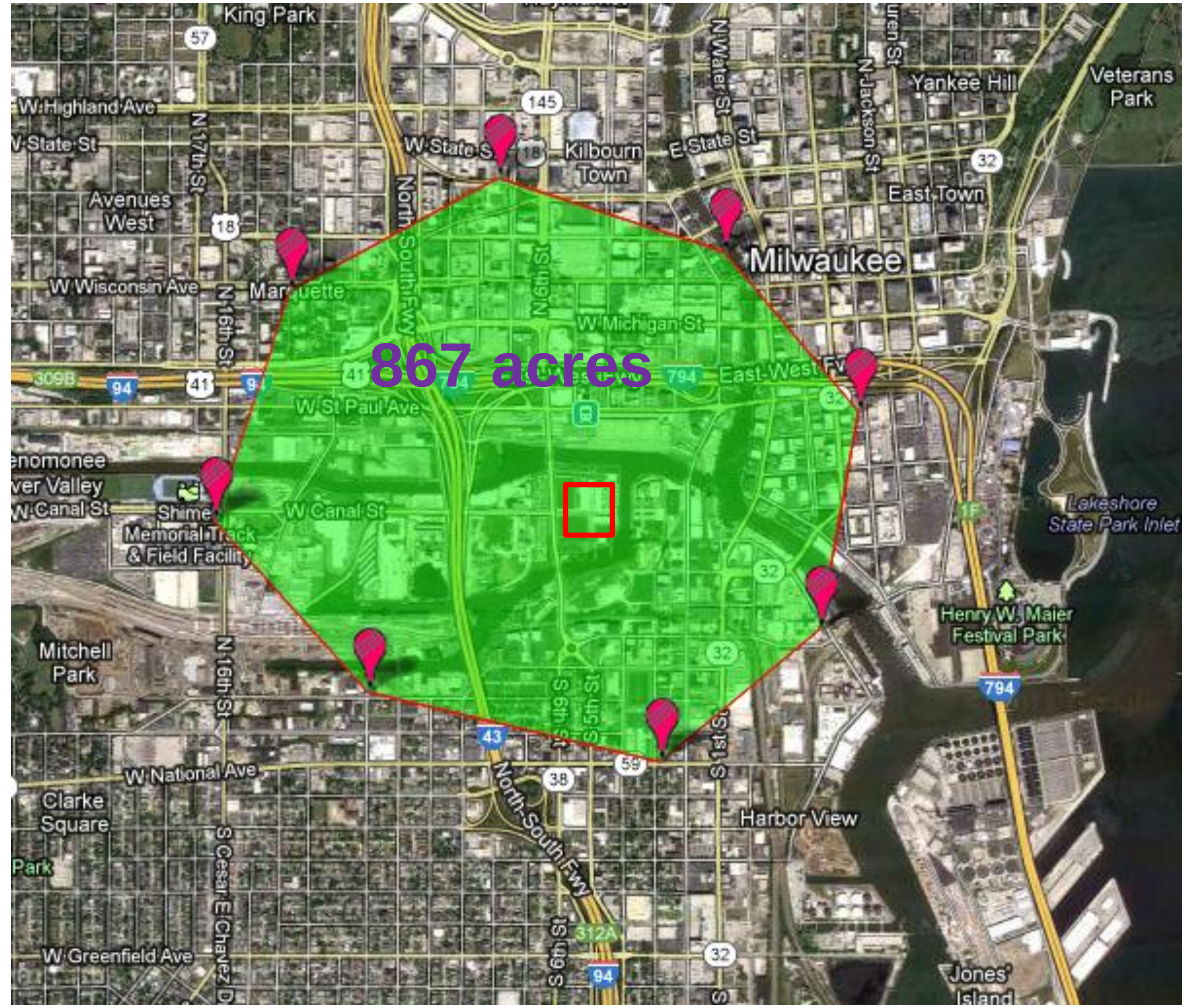
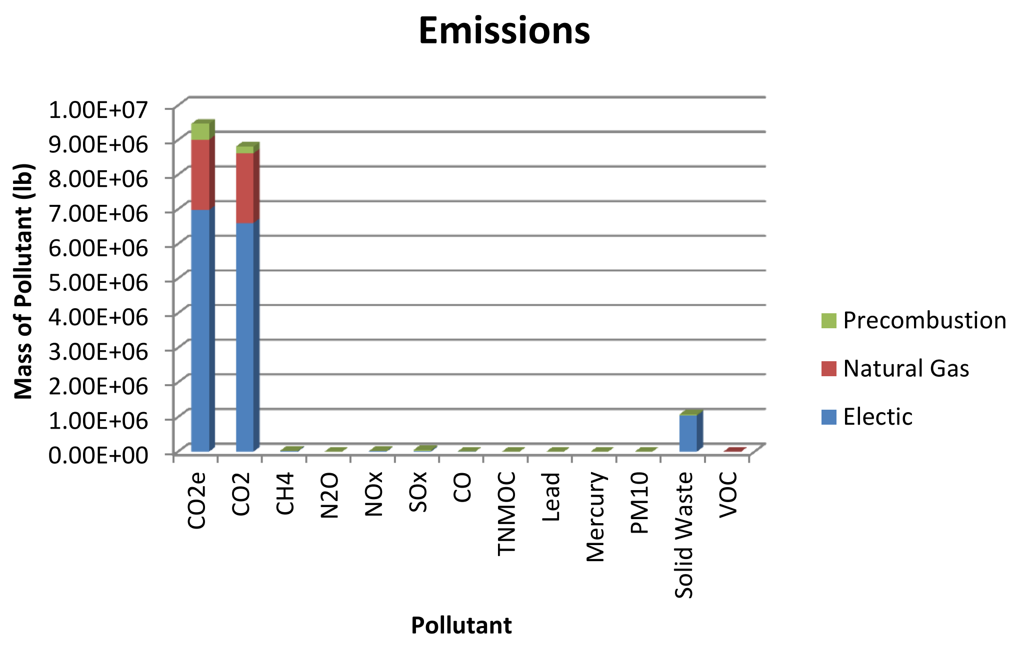
9 Million lbs. of CO_{2e} / year

EMISSIONS





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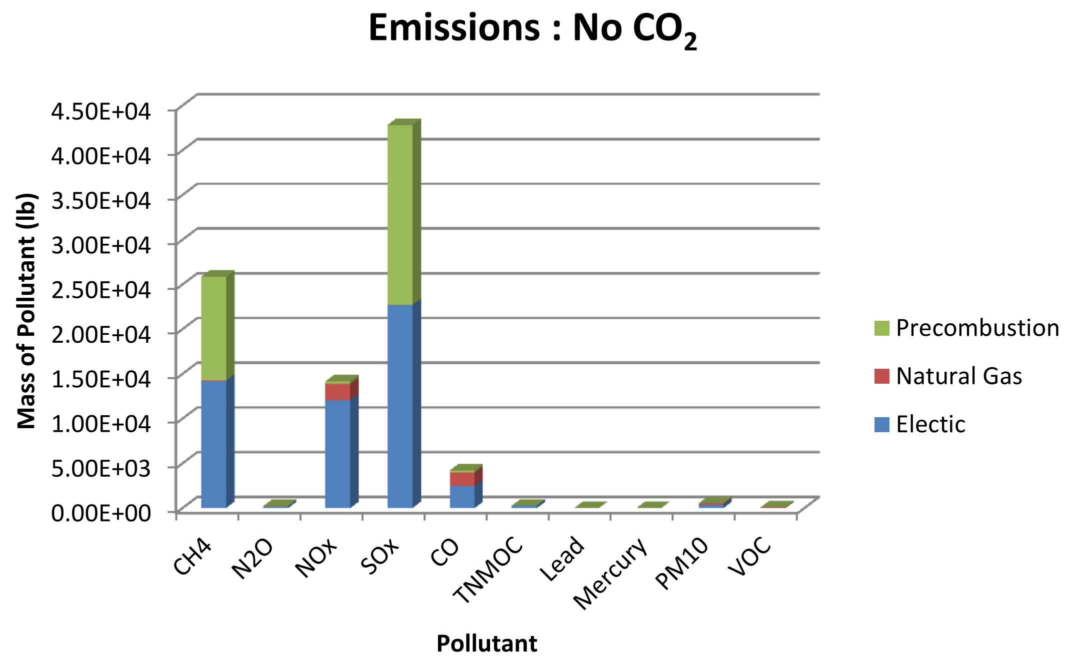

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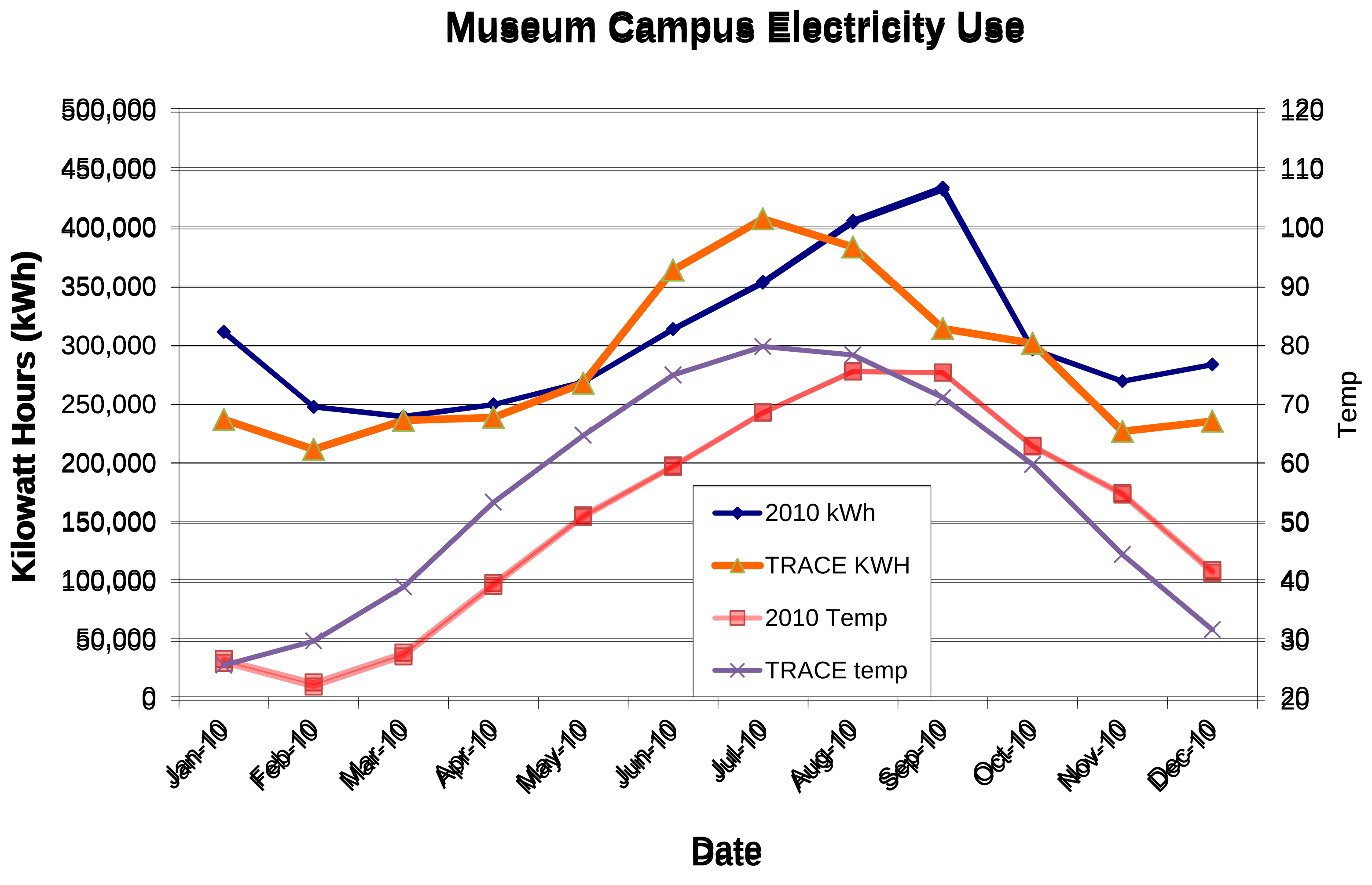
Comparison



Conclusion

Energy Model is an accurate representation of the energy consumption of the facility

Thesis Goals

- Project Background
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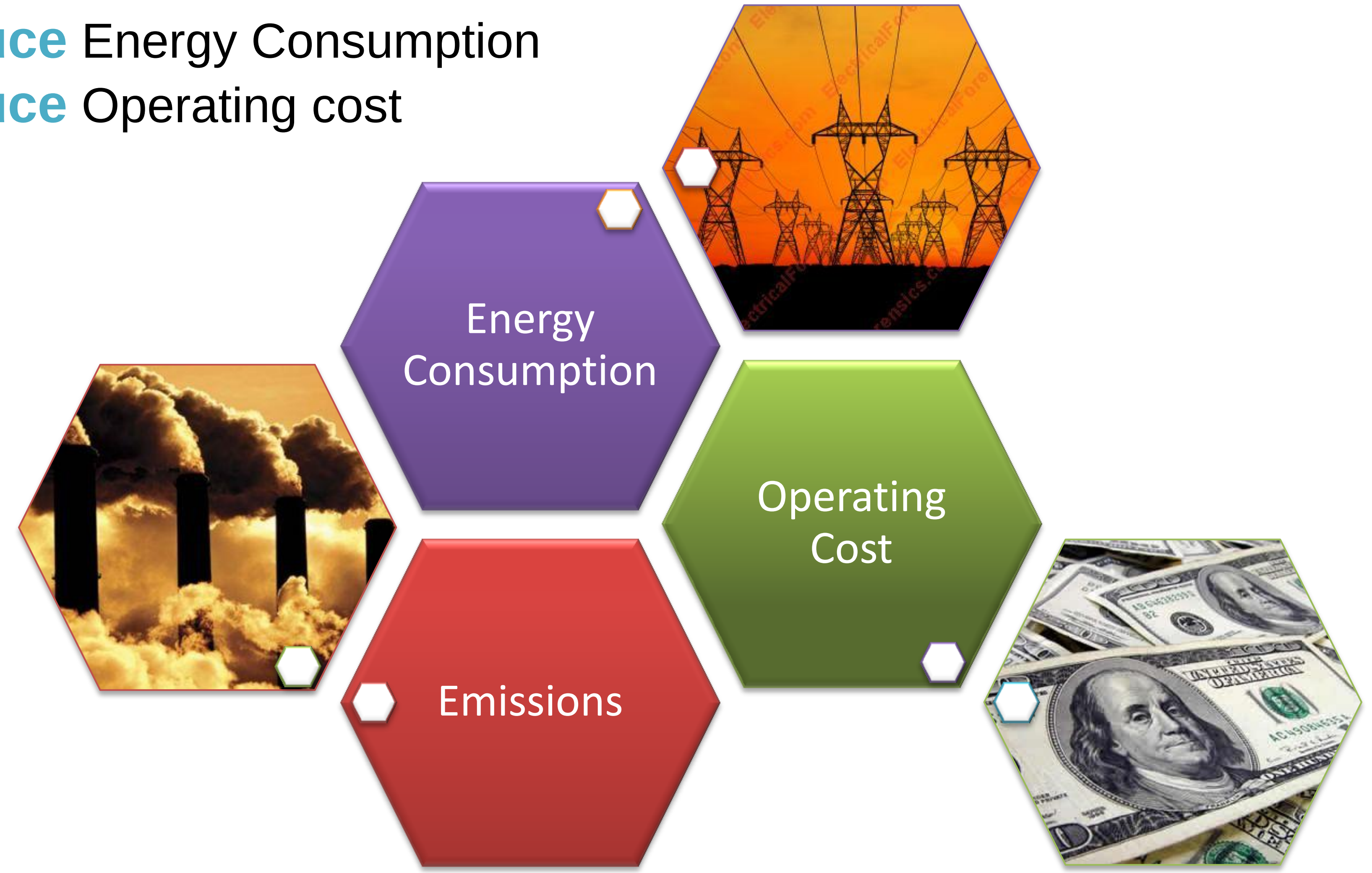
Goals

- **Reduce** Emissions
- **Reduce** Energy Consumption
- **Reduce** Operating cost

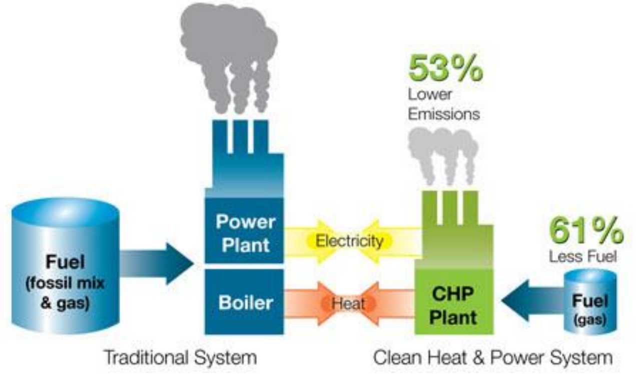


Proposal

- Decrease Thermal Loads Through Envelope

- Increase Efficiency of Chilled Water Production

- Become Energy Independent From Grid



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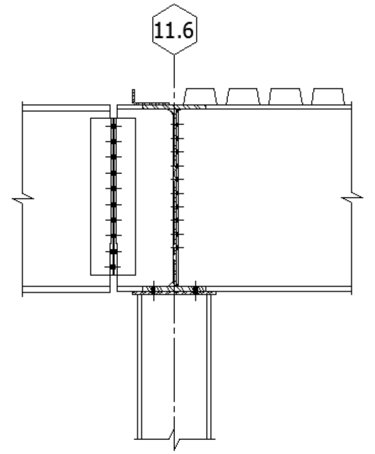
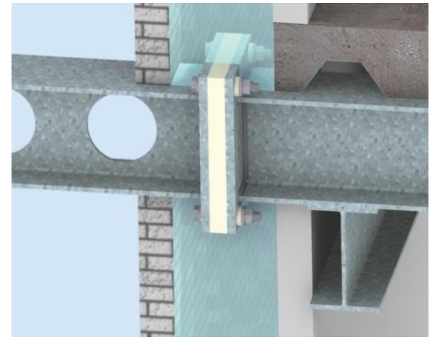
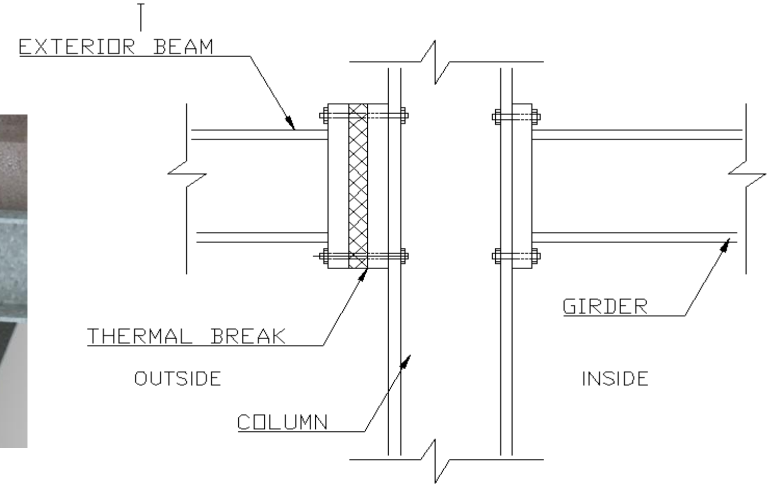
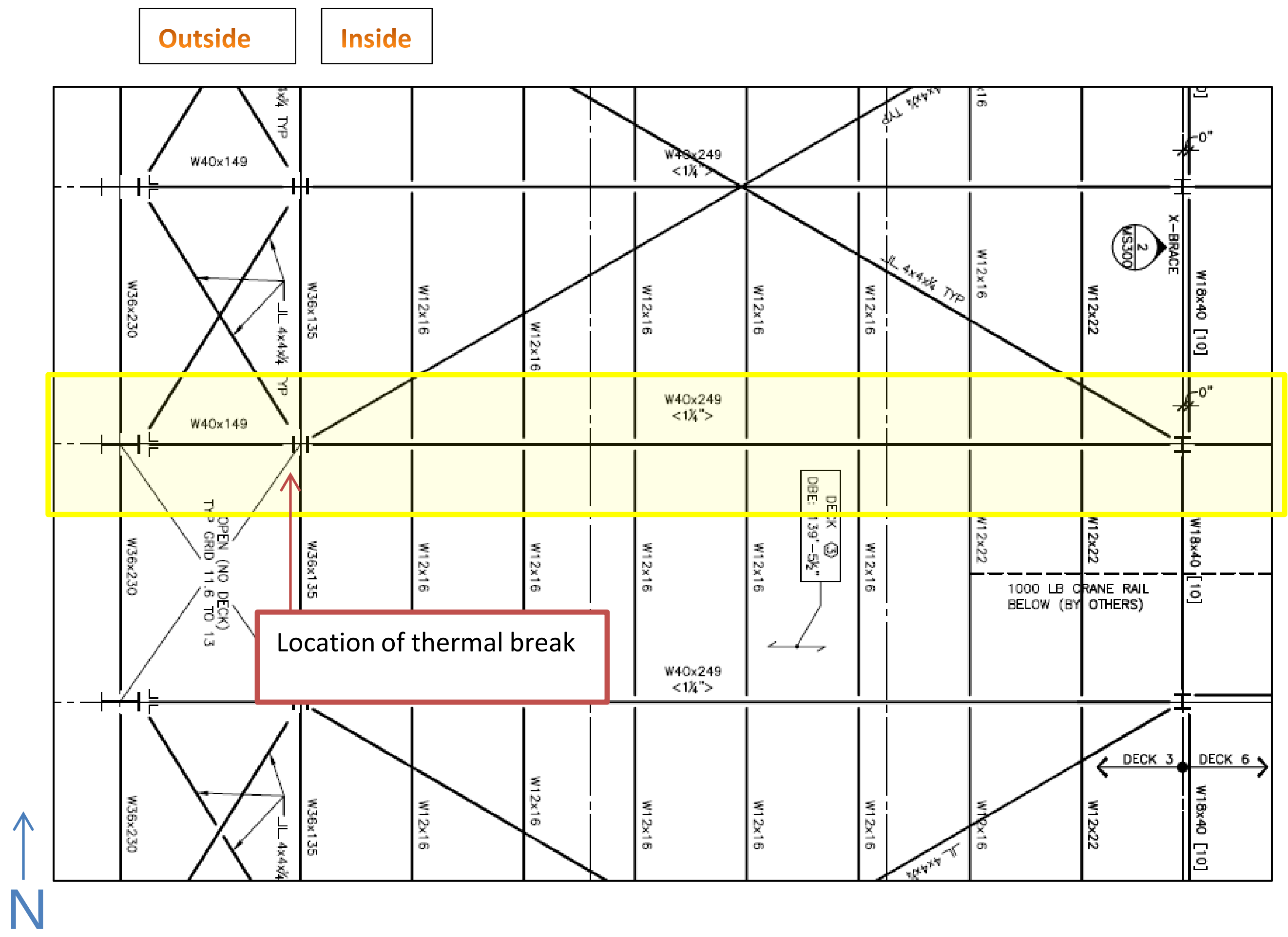
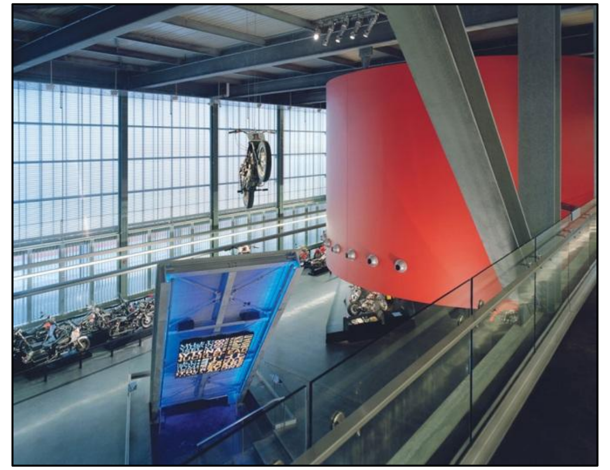






Thermal Bridging





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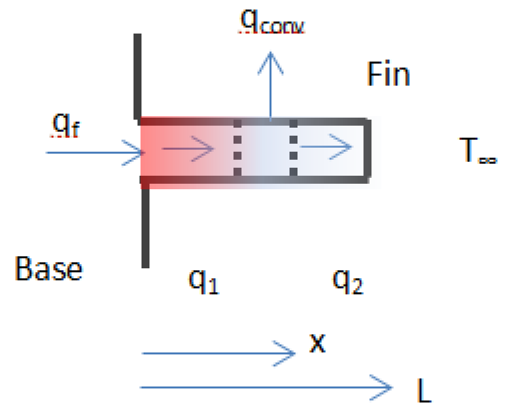

Thermal Analysis

Starting with the conservation of energy equation

$q_2 = q_1 + dq$ (From Conservation of Energy)

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

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

$dq_{conv} = h\, dA_s (T - T_\infty)$

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

$$\frac{d^2T}{dx^2} - \frac{hP}{kA_c}(T - T_\infty) = 0$$

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

$m^2 \equiv \left(\frac{hP}{kA_c}\right)$, $\theta = T - T_\infty$

$\frac{d^2\theta}{dx^2} - m^2\theta = 0 \rightarrow \theta(x) = C_1 e^{mx} + C_2 e^{-mx}$ (General Solution)

Boundary Conditions:

1. Adiabatic Tip: $\left.\frac{dT}{dx}\right|_{x=L} = 0$
2. One Direction Heat Transfer: Δ T(base) = $T(base) - T_\infty$

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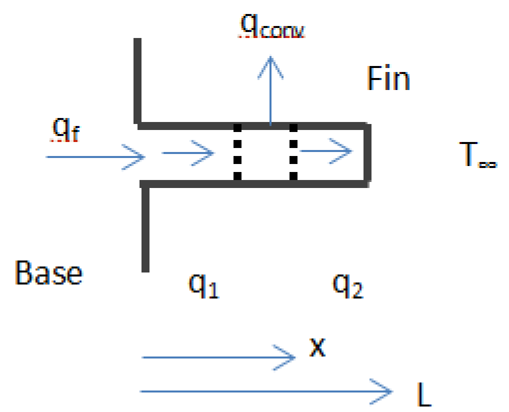

Thermal Analysis

$$C_1 = \frac{\theta_b e^{-mL}}{e^{mL}+e^{-mL}} \qquad C_2 = \theta_b - C_1$$

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

$$q_f = -kA_c \left.\frac{d\theta}{dx}\right|_{x=0} = \int_{A_F} h\theta(x)dA_s \Big\} \; q_{cond} \text{ at base of fin}$$

$$\boldsymbol{q_f = -kA_c \left.\frac{dT}{dx}\right|_{x=0} = Mtanh(mL)}$$

$m = \sqrt{\frac{hP}{kA_c}}$, $\quad M = \sqrt{hPkA_c}\,(T_b - T_\infty)$, L = length of fin

$$\frac{d^2T}{dx^2} - \frac{hP}{kA_c}(T - T_\infty) = 0$$

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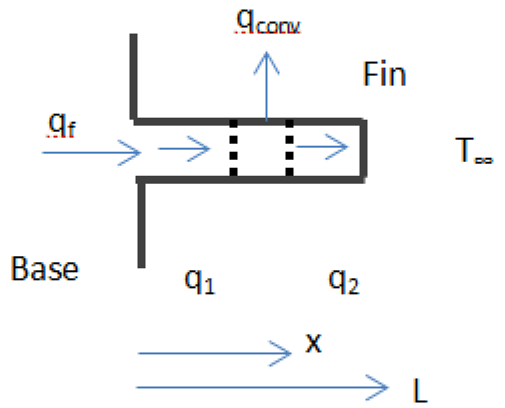

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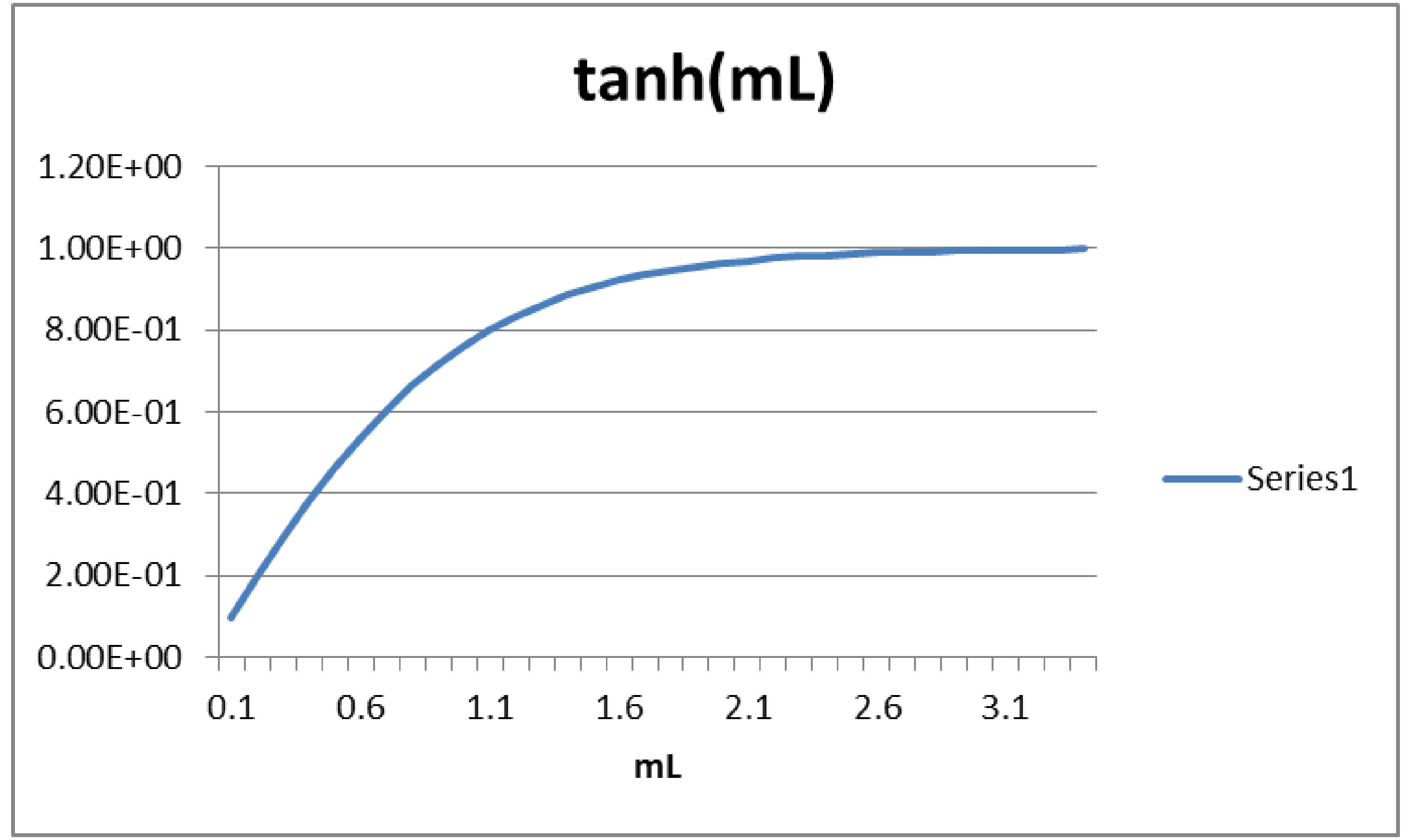

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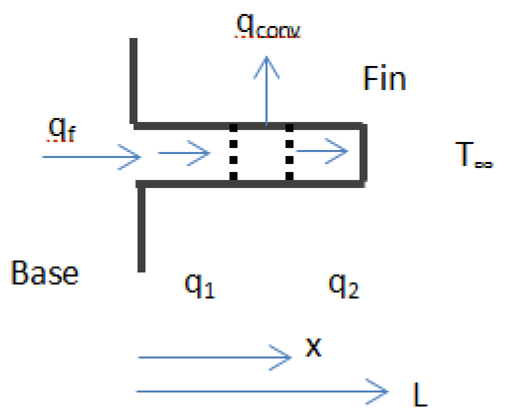

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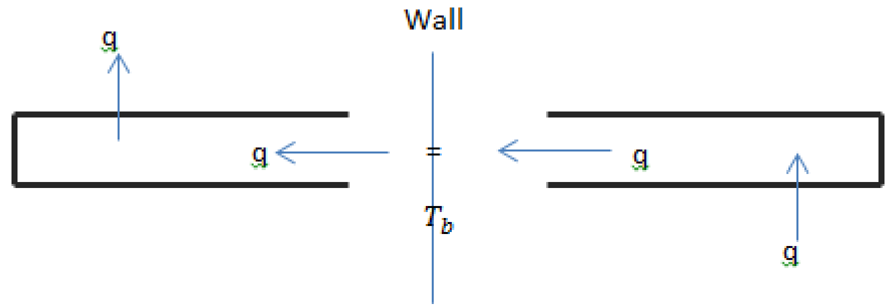

$$q_{outside} = -q_{inside} \rightarrow M_{outside} = M_{inside}$$

$$\sqrt{h_o P k A_c}\,(T_b - T_{\infty_o}) = -\sqrt{h_i P k A_c}\,(T_b - T_{\infty_i})$$

$$T_b = \frac{\sqrt{h_i}\,T_{\infty_i} + \sqrt{h_o}\,T_{\infty_o}}{\sqrt{h_o} + \sqrt{h_i}} = \mathbf{29.8\,^0F}$$

$$q = M = \sqrt{hPkA_c}\,(T_b - T_\infty) = \mathbf{422\ Watts}$$

Constants:

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

A_c = Cross section area of a W40x149 = 0.047 m^2

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

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

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

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

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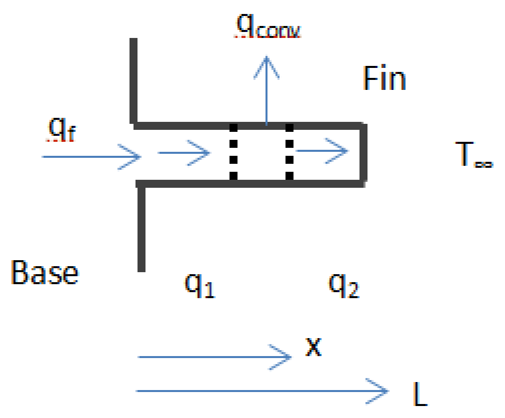

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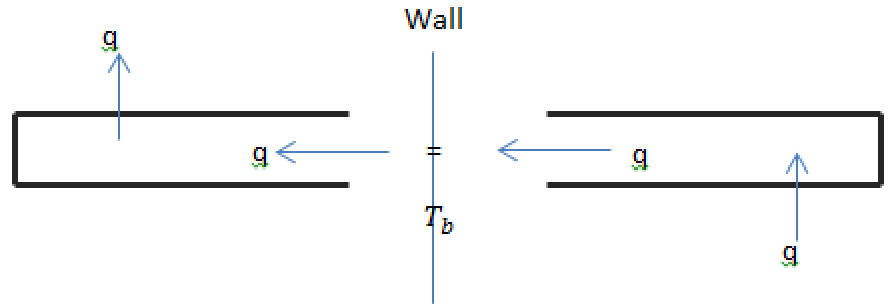

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$$\sqrt{h_o PkA_c}\,(T_b - T_{\infty_o}) = -\sqrt{h_i PkA_c}\,(T_b - T_{\infty_i})$$

$$T_b = \frac{\sqrt{h_i}\,T_{\infty_i} + \sqrt{h_o}\,T_{\infty_o}}{\sqrt{h_o} + \sqrt{h_i}} = \mathbf{29.8\,^oF < 53\,^oF} \text{ dp}$$

$$q = M = \sqrt{hPkA_c}\,(T_b - T_\infty) = \mathbf{422\ Watts}$$

8760 hr. study

Total: 272,407.12 Watts per year

THERMAL ANALYSIS

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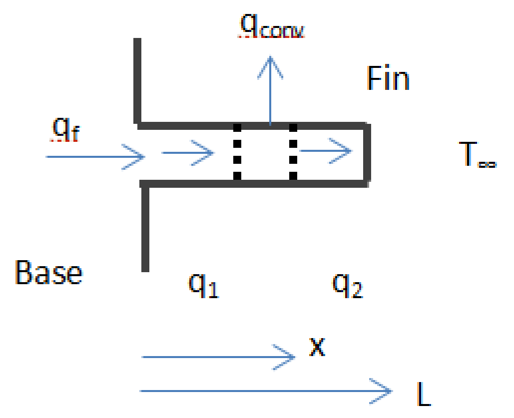

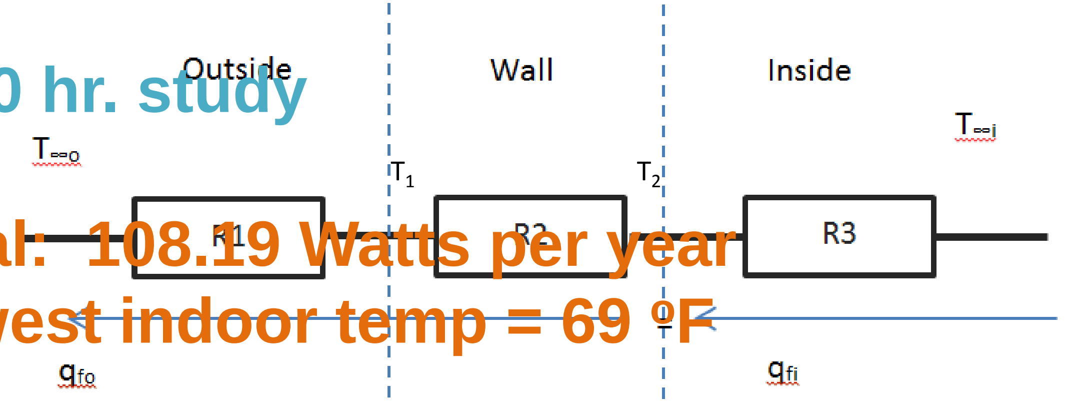

8760 hr. study

Total: 108.19 Watts per year

Lowest indoor temp = 69 ºF

Savings: $1,271.19 / year [Main gallery]

For a simple payback of 5 years

Each Thermal Break = $653

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

$$R_2 = \frac{L_r}{k_r A_c}$$

Thermal Break

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

$$T_2 = \frac{\sqrt{h_i P K A_c}\left(\frac{1}{\sqrt{h_o P k A_c}} + \frac{L_r}{k_r A_c}\right) T_{\infty o} + T_{\infty i}}{1 + \sqrt{h_i P k A_c}\left(\frac{1}{\sqrt{h_o P k A_c}} + \frac{L_r}{k_r A_c}\right)}$$

$$q = -\sqrt{h_i P k A_c}\,(T_2 - T_{\infty i})$$

Structural Breadth

Thermal Analysis

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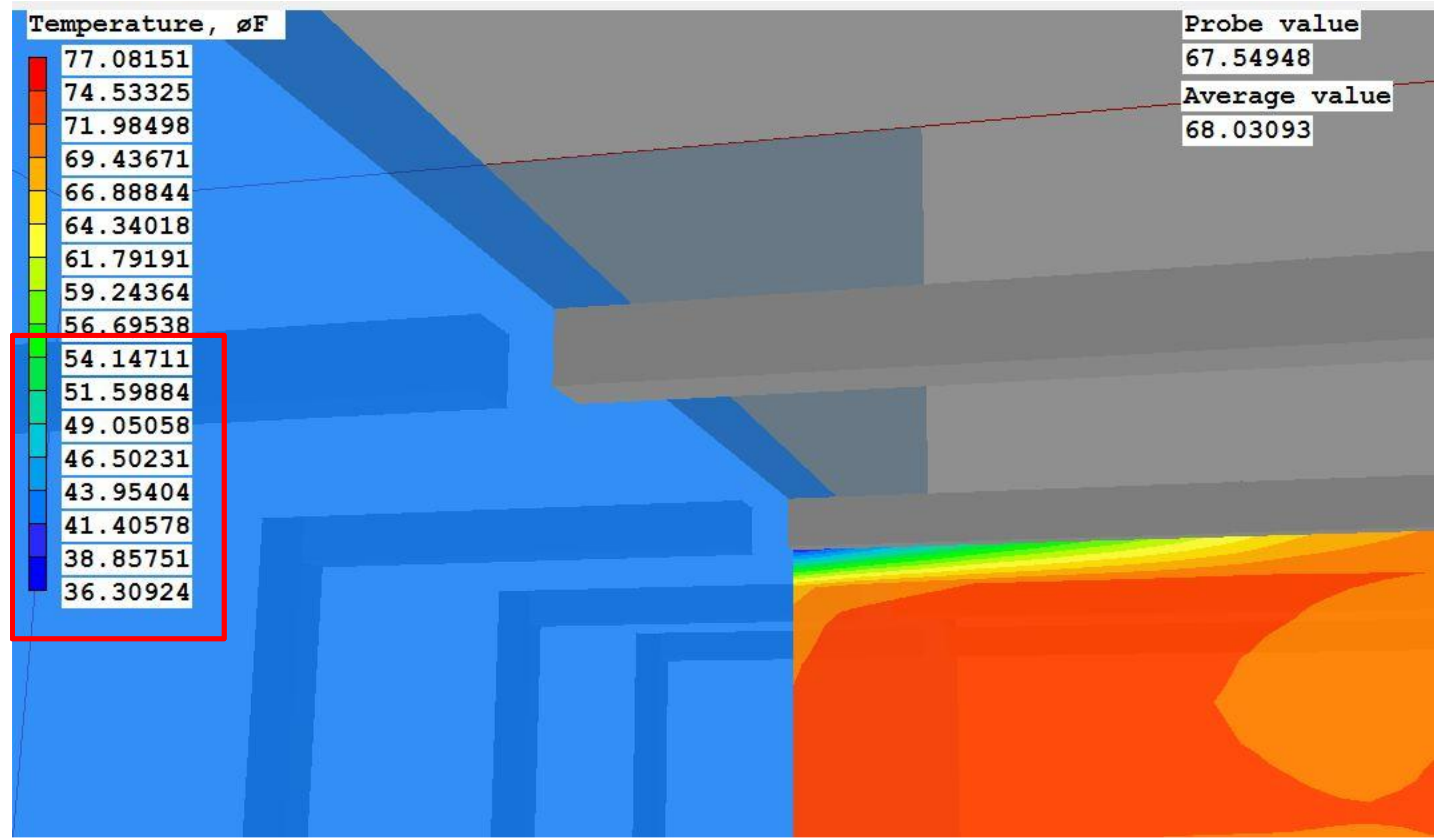
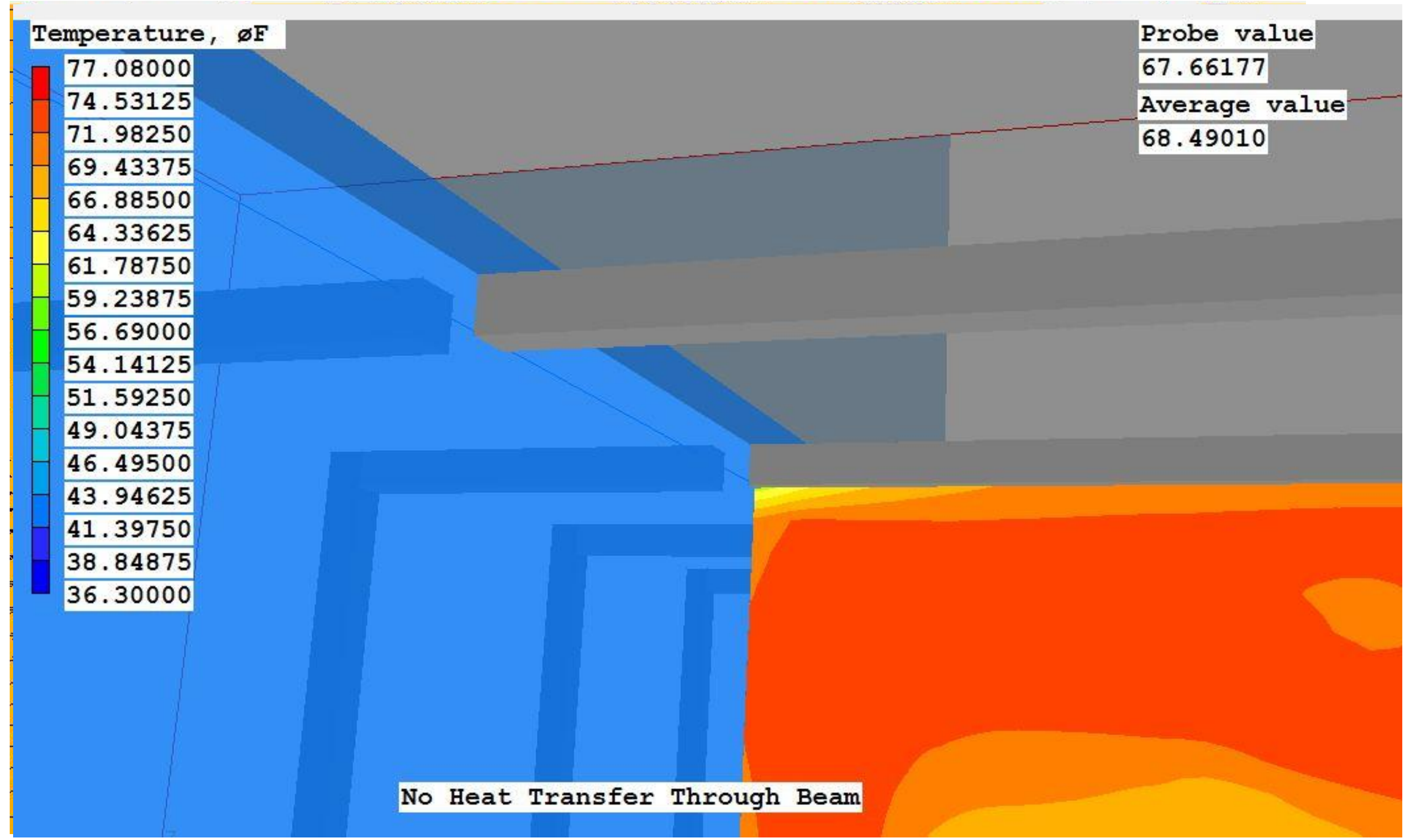
PHOENICS





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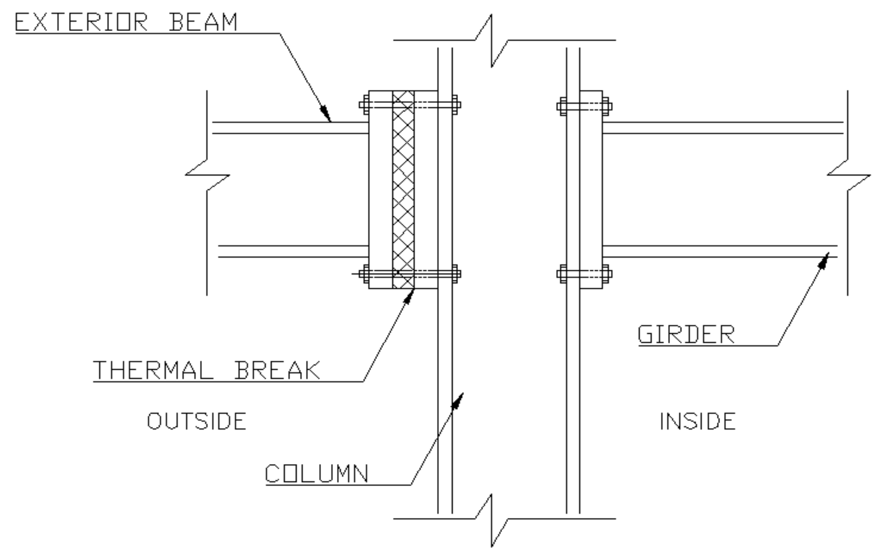
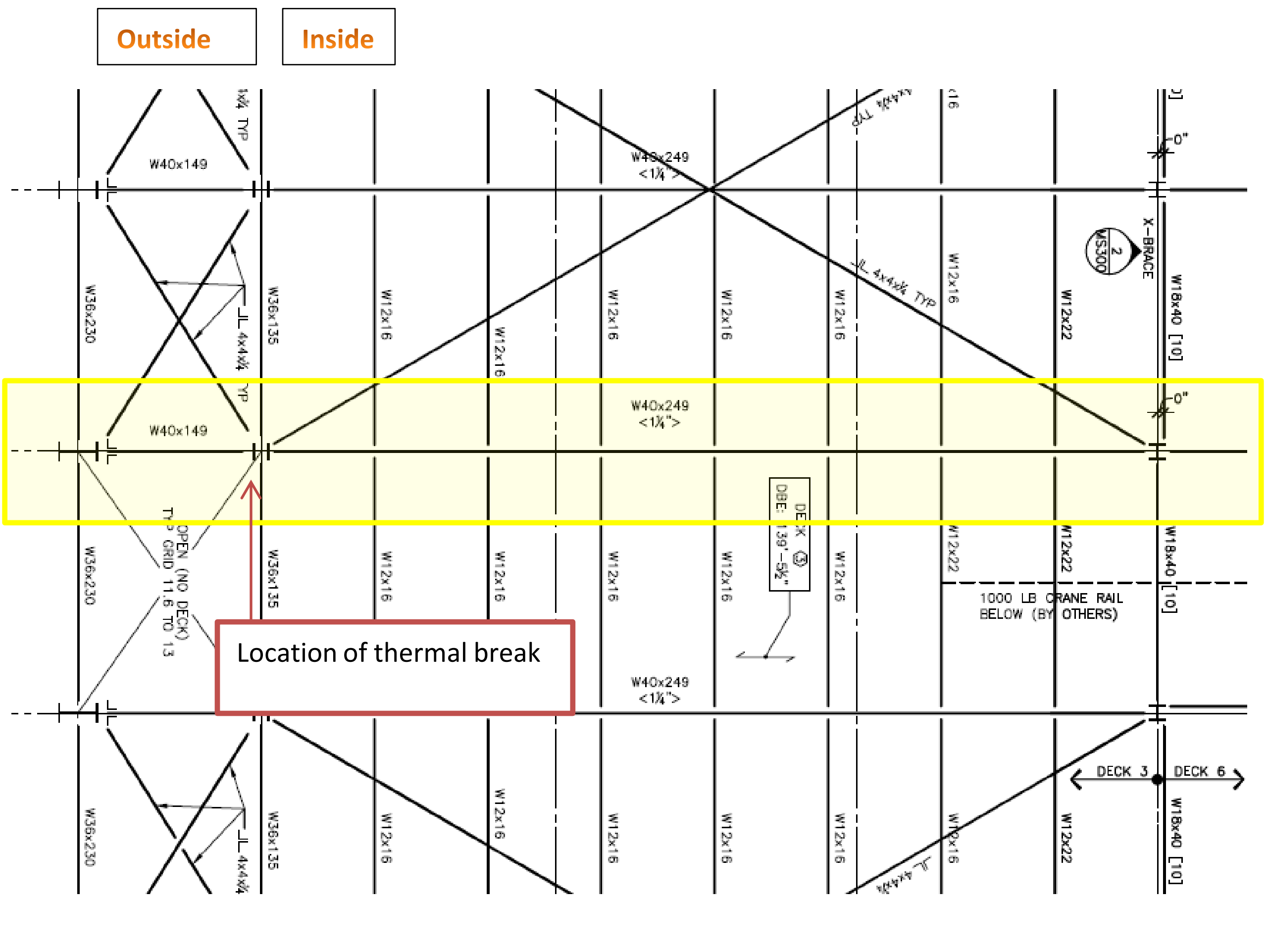


Structural Analysis



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**

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  - **Air vs. Water**
  - Cooling Tower vs. River Water
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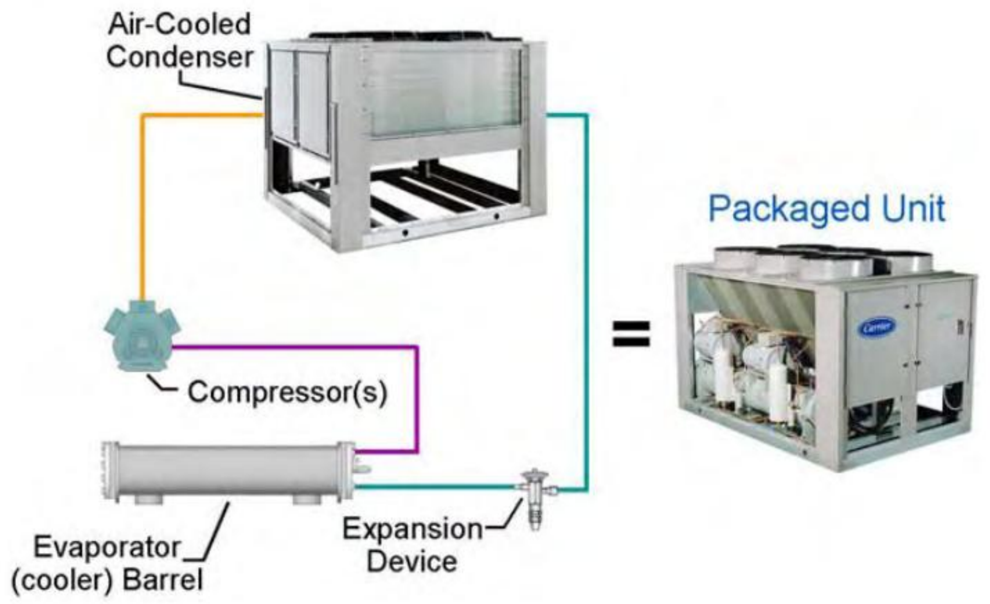
AIR VS. WATER

Two 300 Ton Air Cooled Chillers
EER 9.4



Carrier

Carrier

EPA

AIR VS. WATER

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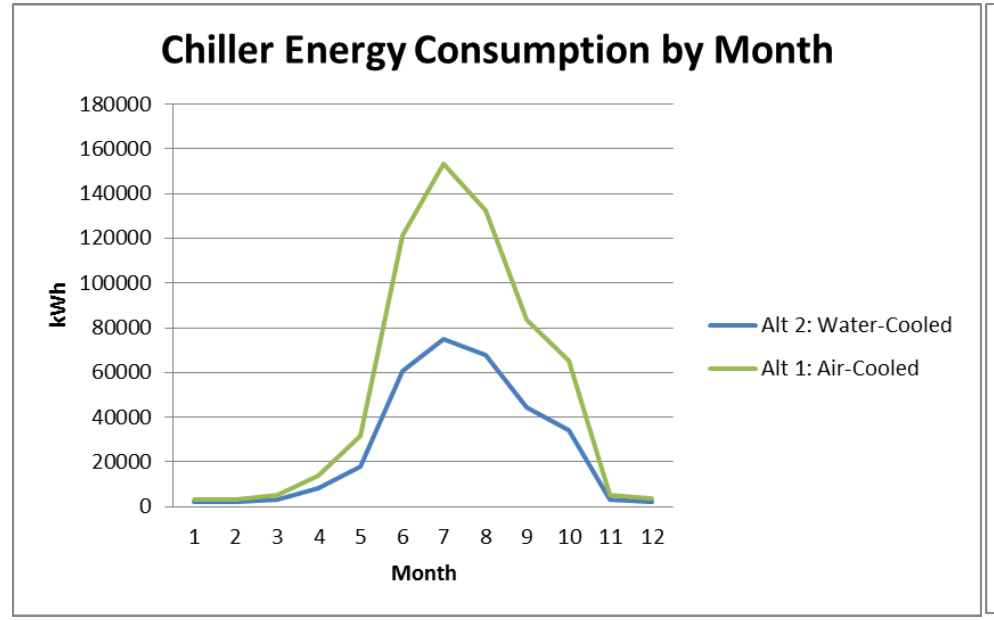
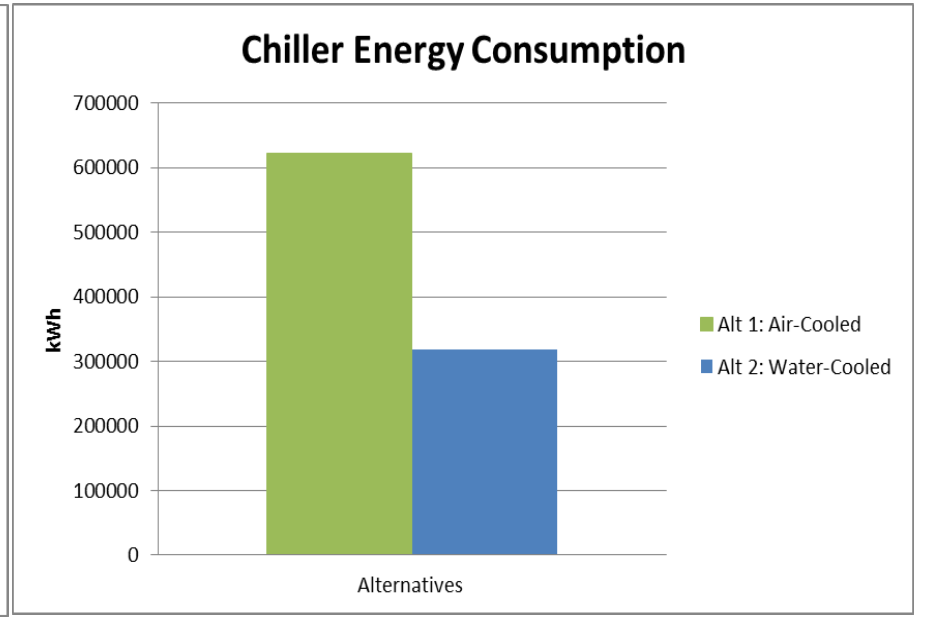
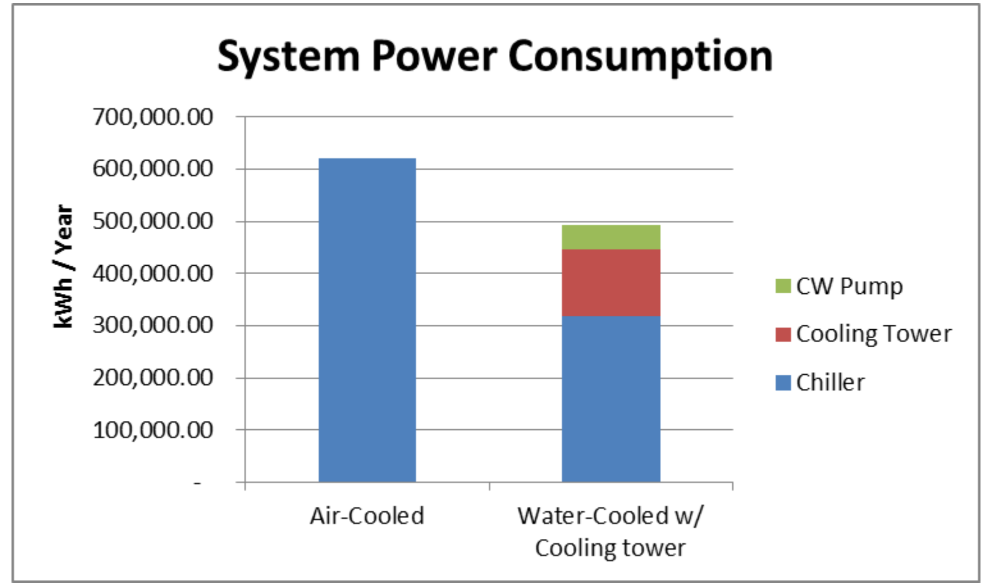






Additional Water: 2,500 1000gal
Cost : $5,500.00 / year

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**

Capital: -$42,850

AIR VS. WATER

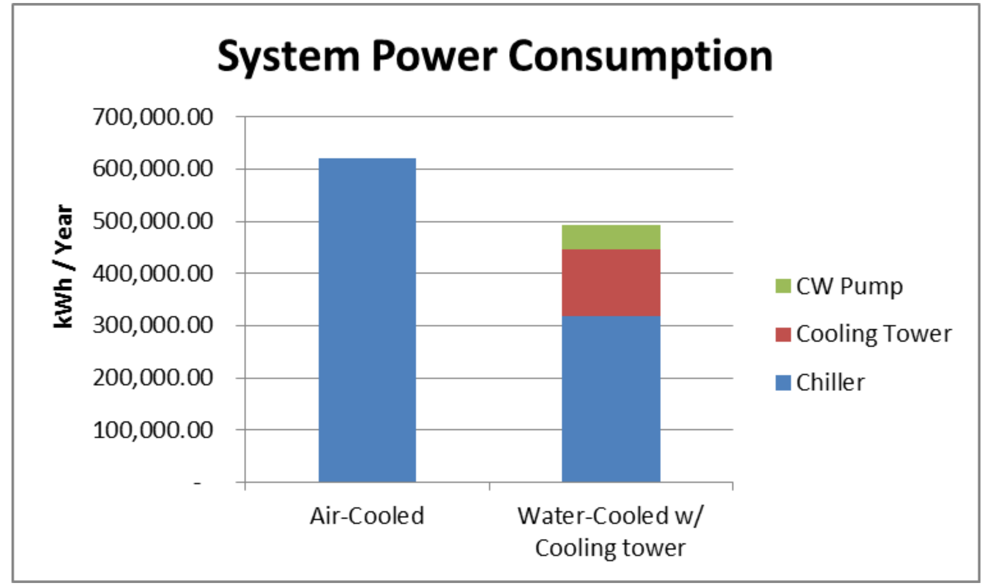
<u>30 Year LCC</u>

Existing Air-Cooled System: $4,045,288.09

Alternative 2; Water-Cooled System: $3,861,471.04

Savings: **$183,817.05**

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

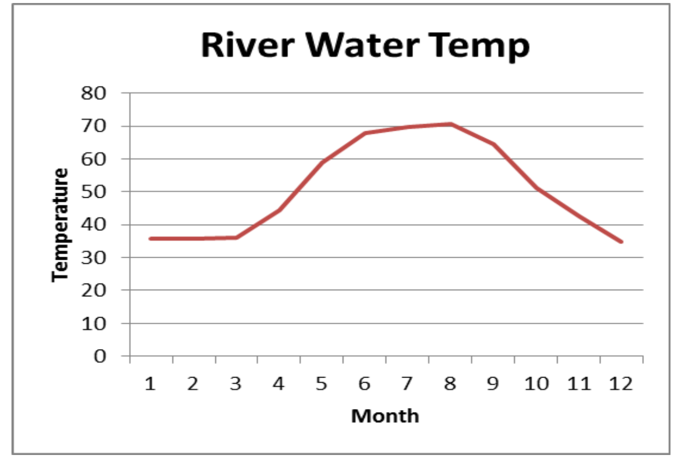


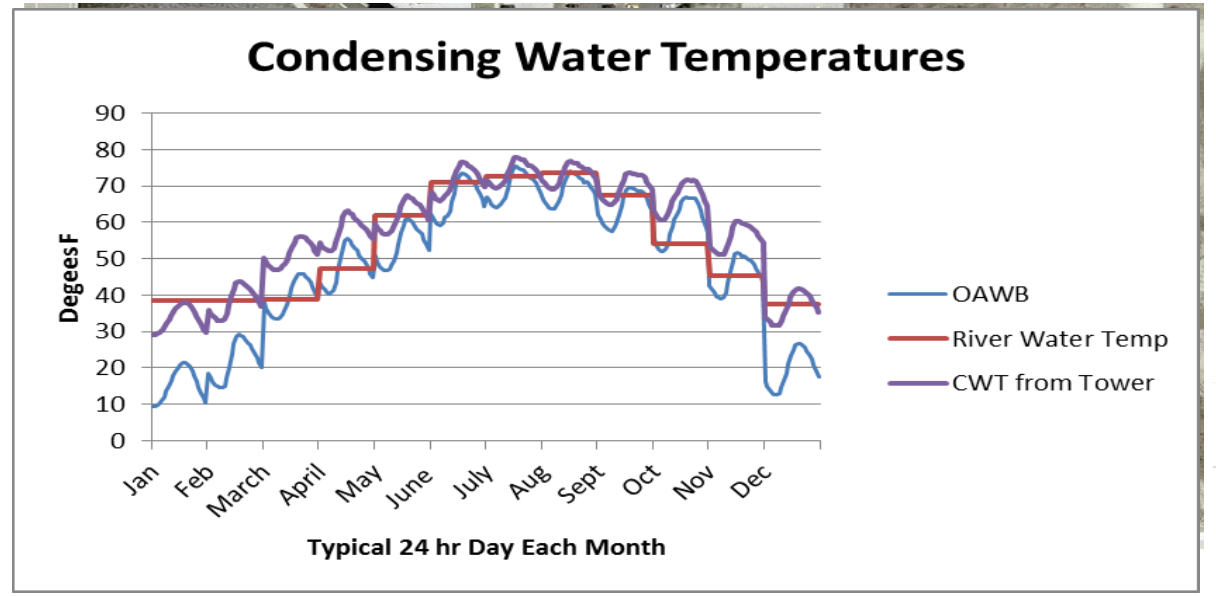
CAPITAL				
Alternative 1: Air- Cooled			Alternative 2: Water-Cooled	
Equipment	Price		Equipment	Price
AC Chiller 1	$215,000.00		WC Chiller 1	$140,500.00
AC Chiller 2	$215,000.00		WC Chiller 2	$140,500.00
			Cooling Tower 1	$ 37,000.00
			Cooling Tower 2	$ 37,000.00
			CW Pump 1	$ 5,575.00
			CW Pump 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**

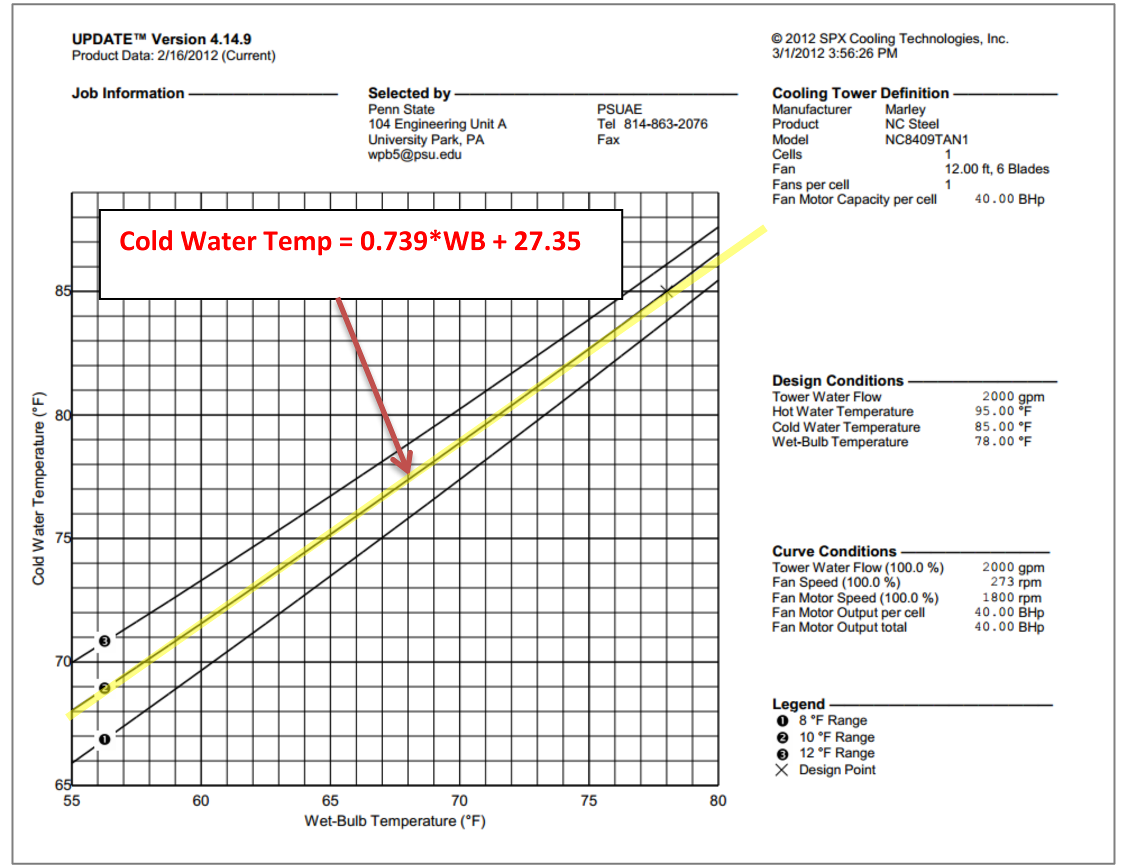
Capital: -$42,850

COOLING TOWER VS. RIVER WATER

- Project Background
- Thesis Goals
- Existing Conditions
- Structural Breadth
- Mechanical Depth
  - Air vs. Water
  - Cooling Tower vs. River Water
  - Conclusion
- Electrical Breadth
- Conclusion

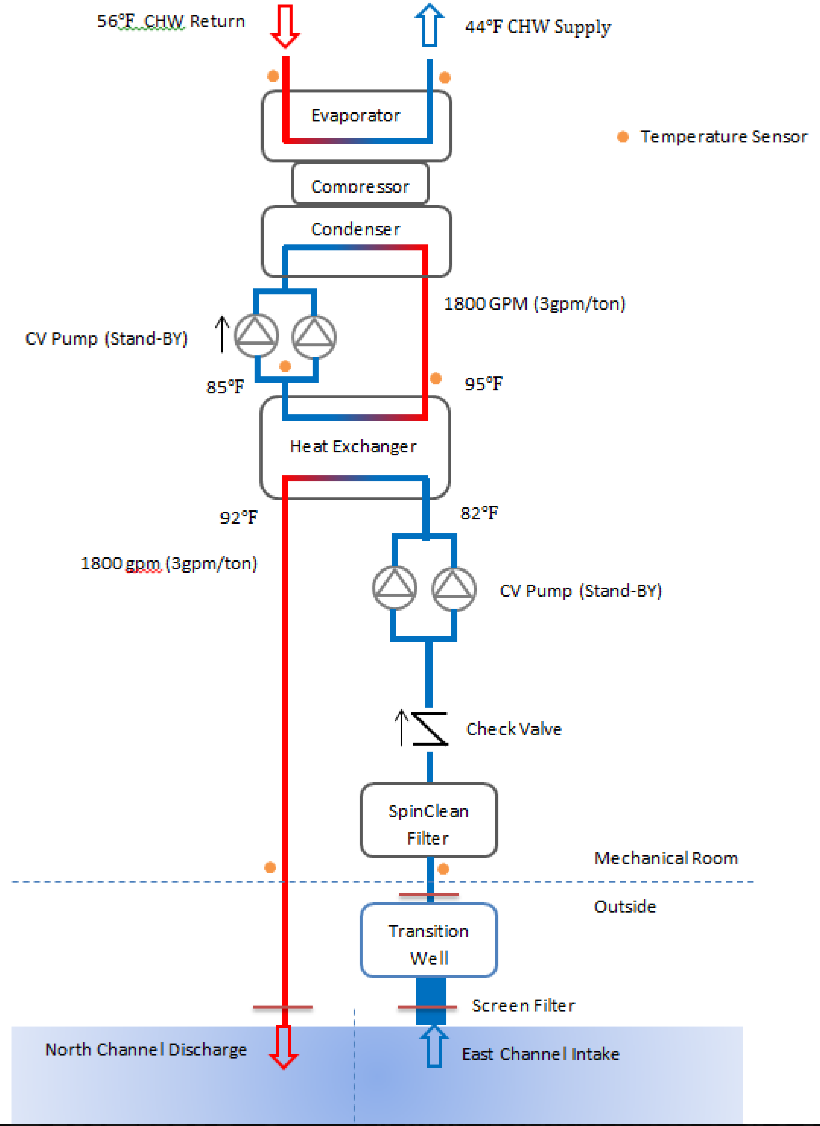




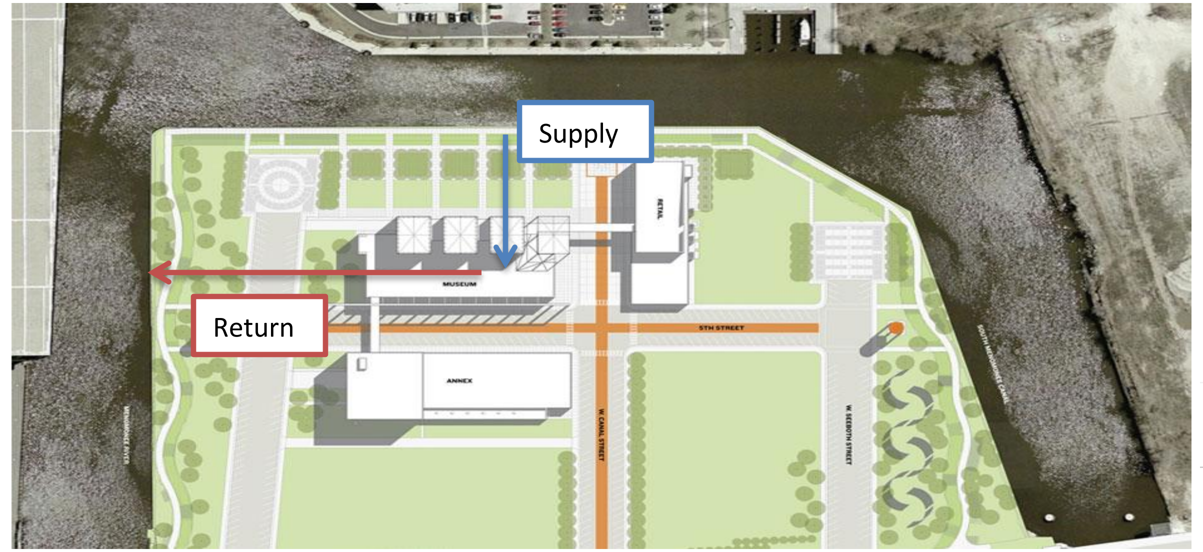


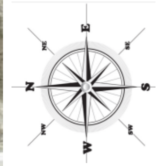
Project Depth

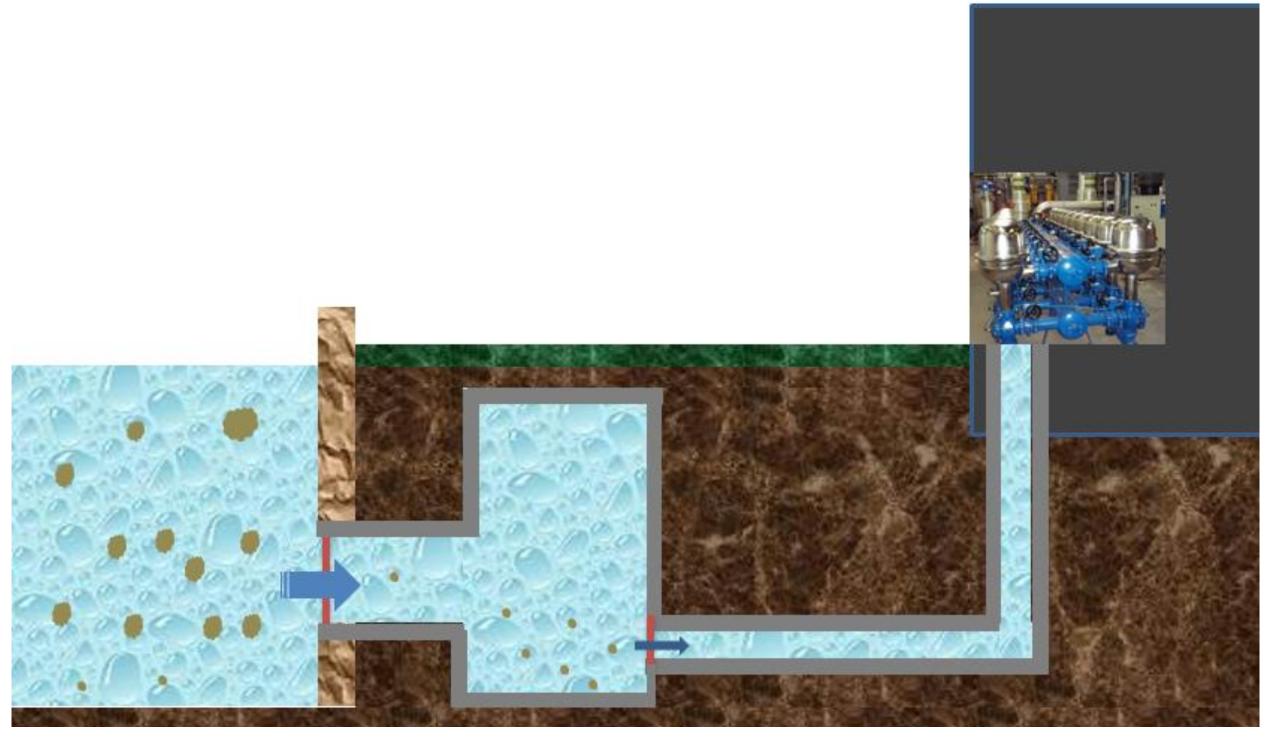
- Project Background
- Thesis Goals
- Existing Conditions
- Structural Breadth
- **Mechanical Depth**
  - Air vs. Water
  - **Cooling Tower vs. River Water**
  - Conclusion
- Electrical Breadth
- Conclusion



Cooling tower vs. River Water





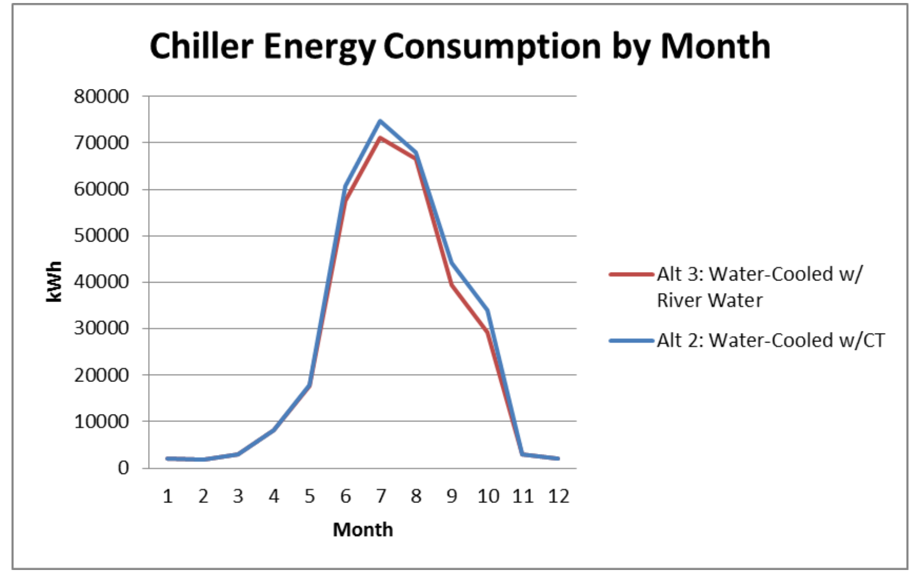


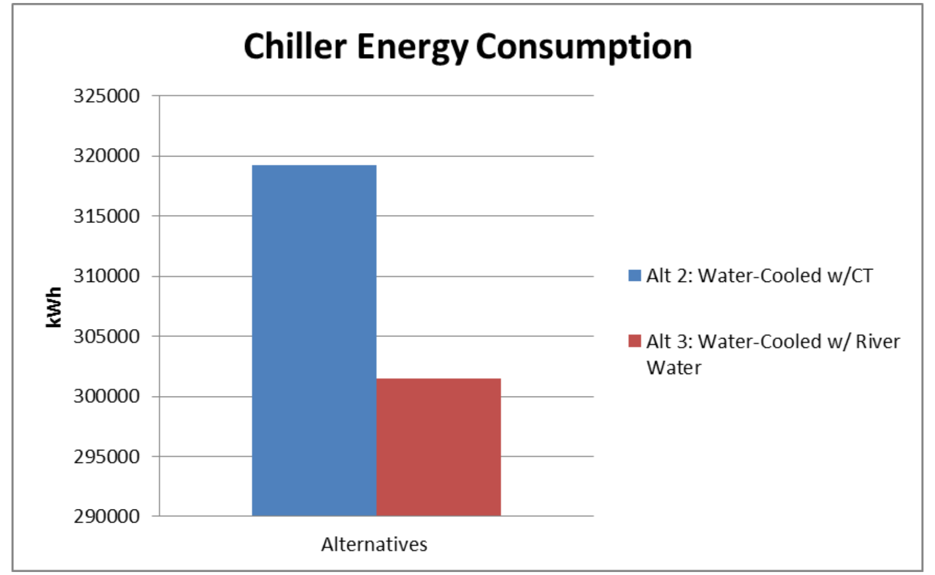
$$v = 0.4085\frac{q}{d^2}$$

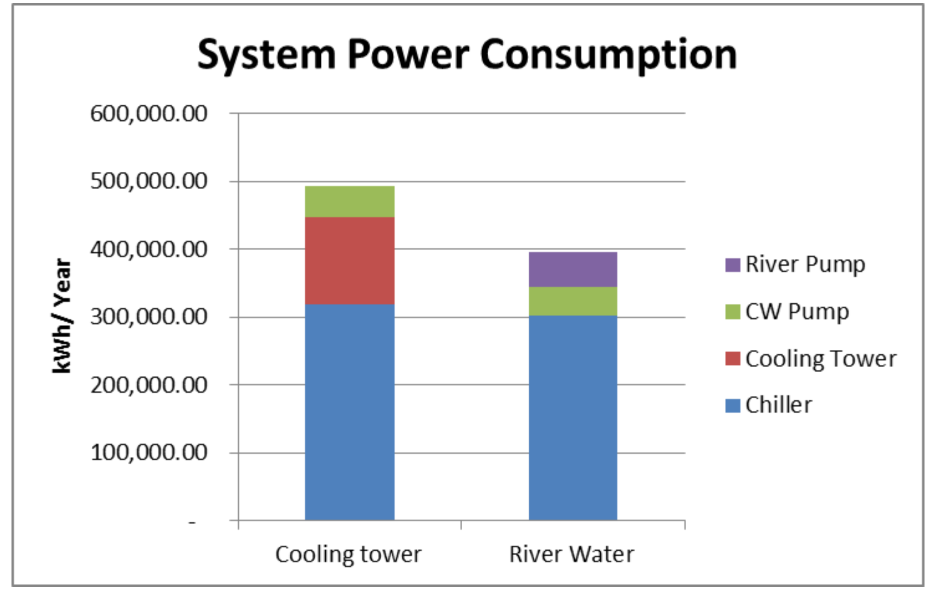
$v = velocity\ \left(\frac{ft}{s}\right),\ q = volume\ flow\ rate\ \left(US\frac{gal}{min}\right),$
$d = pipe\ inside\ diameter\ (inches)$

COOLING TOWER VS. RIVER WATER

- Project Background
- Thesis Goals
- Existing Conditions
- Structural Breadth
- **Mechanical Depth**
  - Air vs. Water
  - **Cooling Tower vs. River Water**
  - Conclusion
- Electrical Breadth
- Conclusion







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**

Capital: +$104,255

- Project Background
- Thesis Goals
- Existing Conditions
- Structural Breadth
- **Mechanical Depth**
  - Air vs. Water
  - **Cooling Tower vs. River Water**
  - Conclusion
- Electrical Breadth
- Conclusion

COOLING TOWER VS. RIVER WATER

Simple Payback: **2.8 years**
Discount payback : **3.0 years**

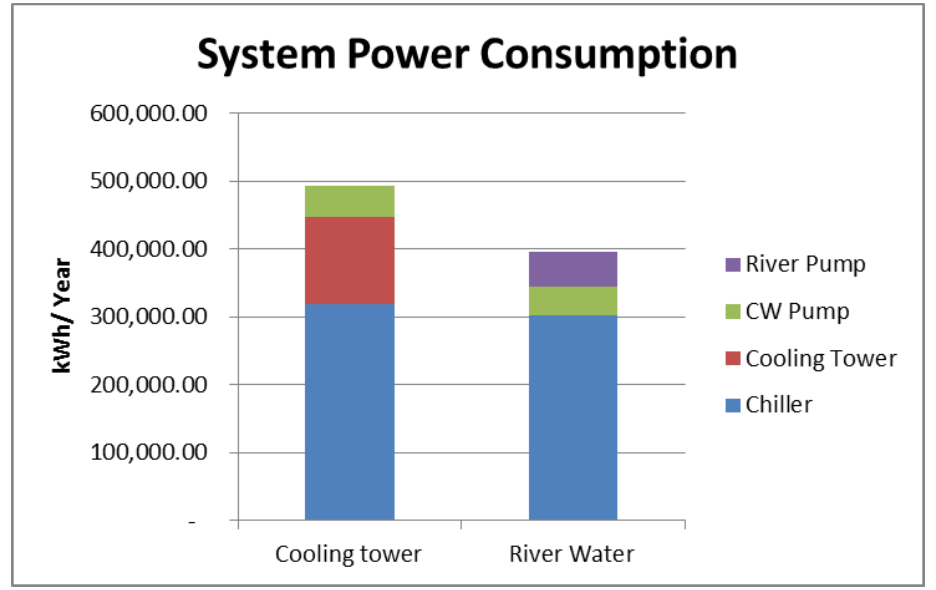
30 Year LCC

Alternative 2; Cooling Tower System: $3,861,471.04

Alternative 3; River Water System: $3,641,264.61

Savings: **$220,206.43**

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



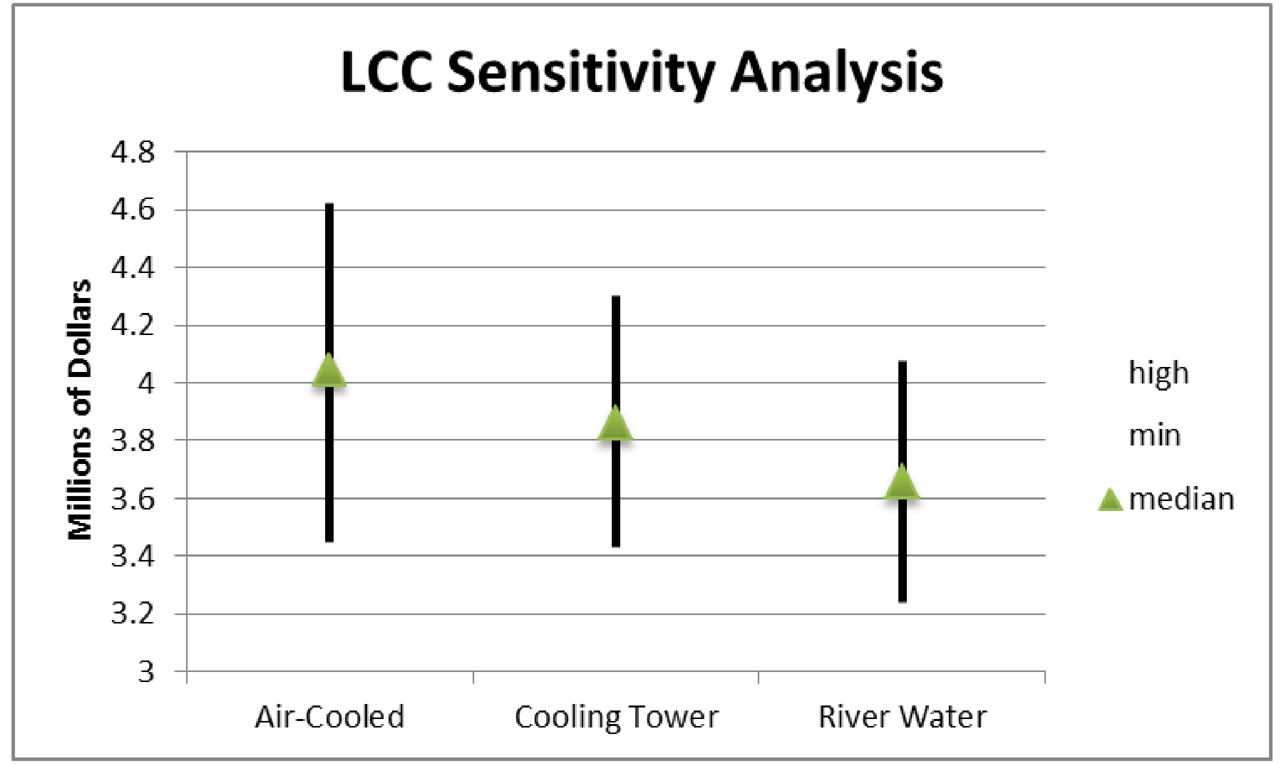
CAPITAL				
Alternative 2: Water-Cooled Cooling Tower			Alternative 3: Water-Cooled River Water	
Equipment	Price		Equipment	Price
WC Chiller 1	$140,500.00		WC Chiller 1	$140,500.00
WC Chiller 2	$140,500.00		WC Chiller 2	$140,500.00
			River Pump 1	$ 12,000.00
Cooling Tower 1	$ 37,000.00		River Pump 2	$ 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

Capital: +$104,255

CONCLUSION

Air-Cooled vs. Water-Cooled with River Water

- Capital cost increased 10% [$61,400.00]
- Annual operating cost reduced by 14% [$21,732.00]
- 30 year LCC reduced 10% [$389,986.00]
- Simple payback 3 years



CHP FEASIBILITY

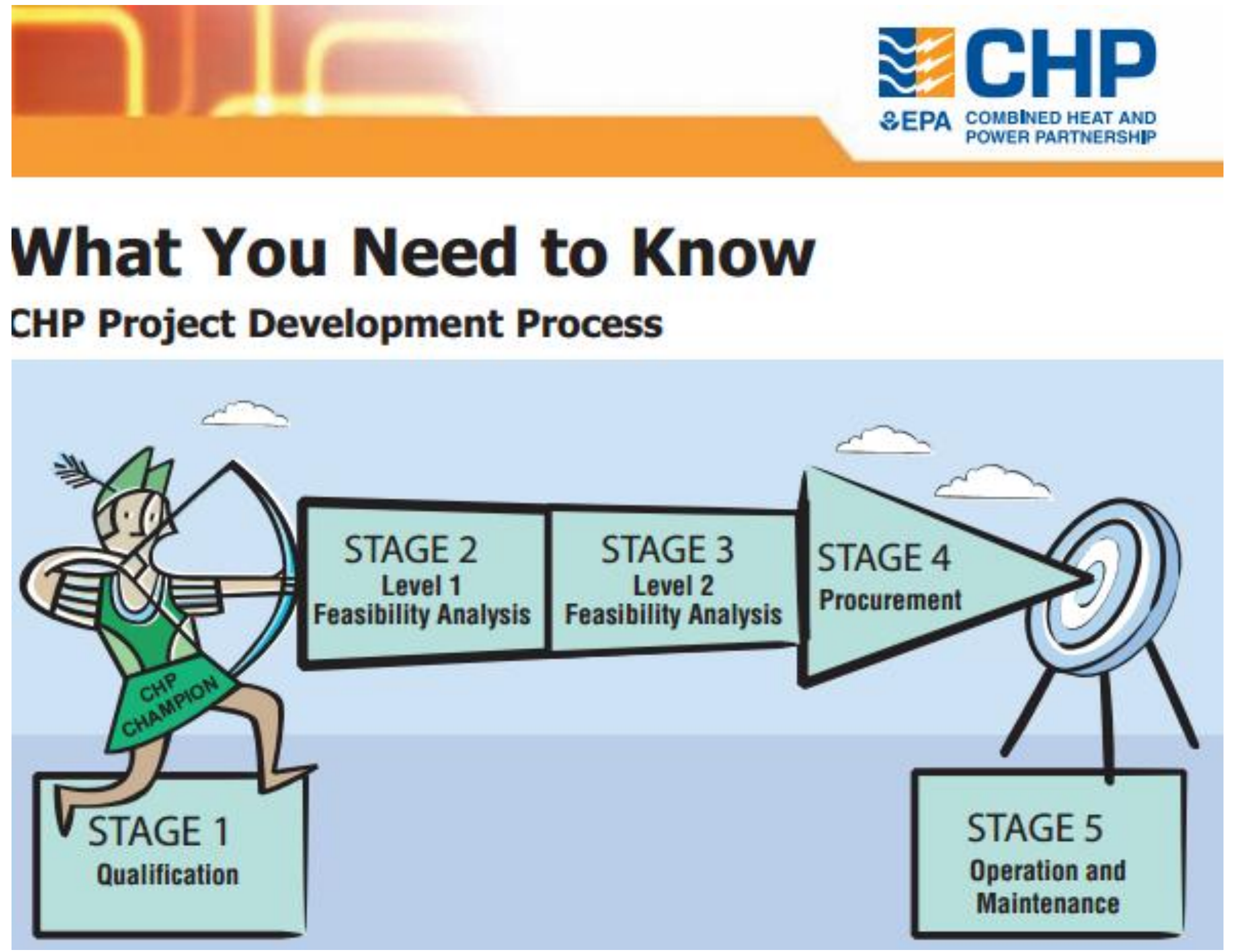
- Project Background
- Thesis Goals
- Existing Conditions
- Structural Breadth
- Mechanical Depth
- Electrical Breadth
  - CHP Feasibility
  - Conclusion
- Conclusion

Spark Gap

Electric Cost: $0.10/kWh = $29.30/MMBTU

Gas Cost: : $0.80/therm = $8.00/MMBTU

1 : 3.7 Ratio , 1 : 4 [rule of thumb]



ELECTRICAL BREADTH

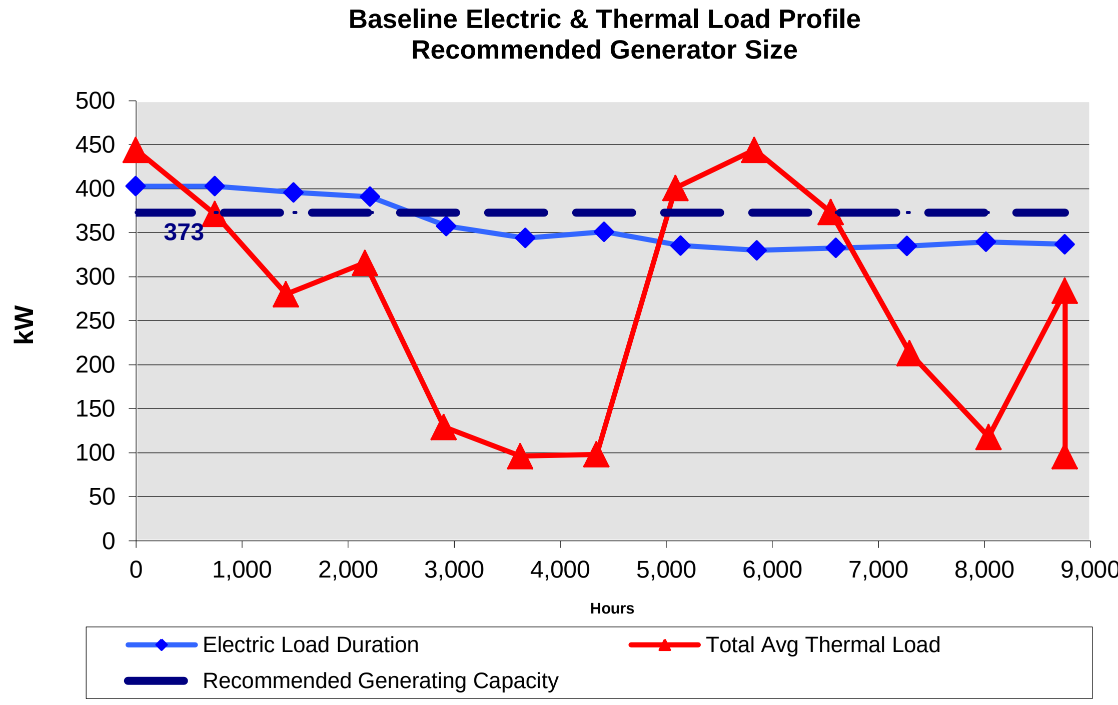
- Project Background
- Thesis Goals
- Existing Conditions
- Structural Breadth
- Mechanical Depth
- **Electrical Breadth**
  - **CHP Feasibility**
  - Conclusion
- Conclusion

CHP FEASIBILITY

CHP Results

Thermal-to-Electric Ratio = 0.74

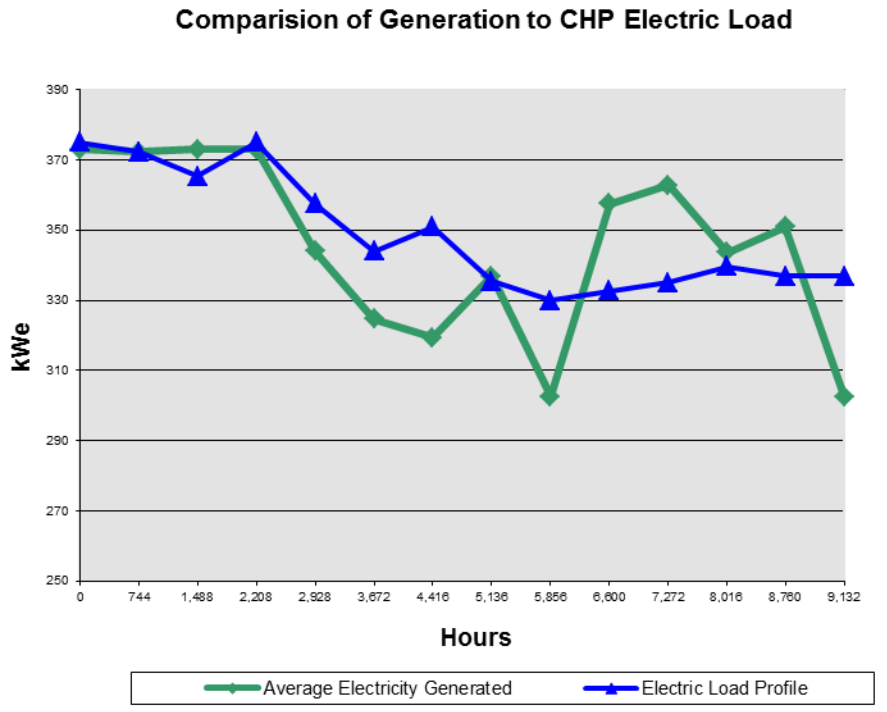
Recommended: 373 kWe Gas Engine

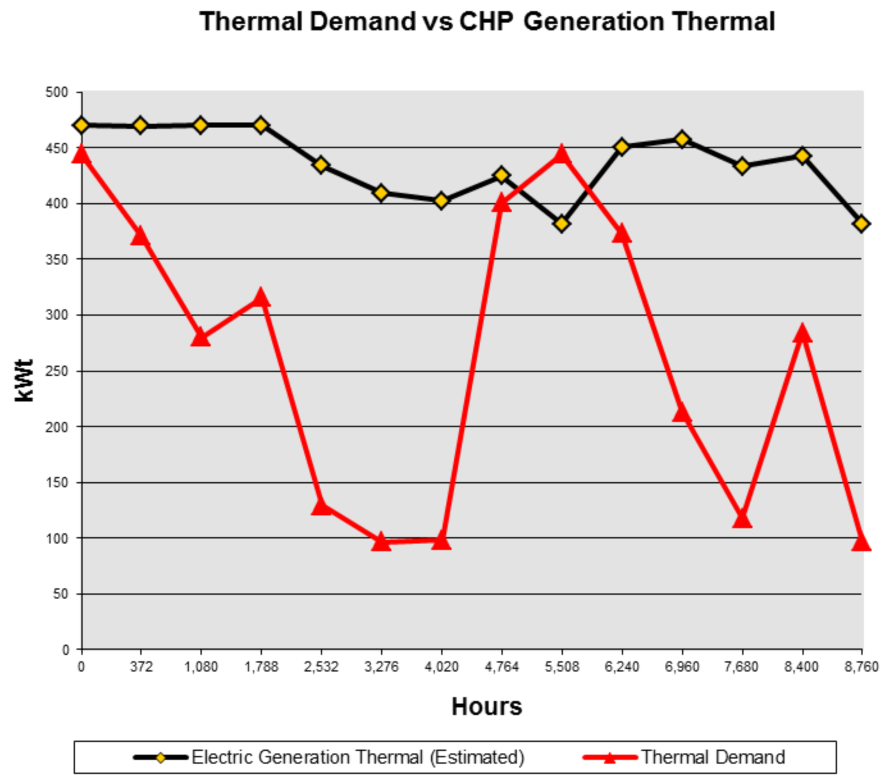


CHP CONCLUSION

- Additional Cost $564,000
- Generation Cost $0.088 /kWh
  1.2 cents less than purchased
- Total Savings: $140,000 /year
- Simple Payback: 4.04 Years
- CO_2 reduction of 62%

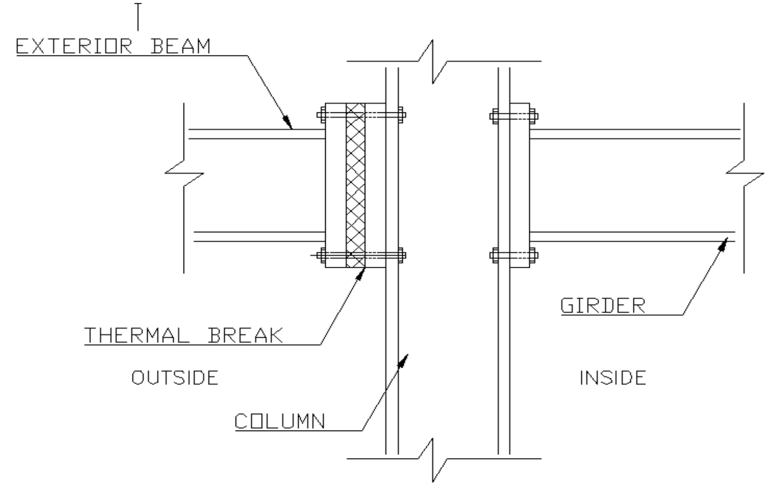
CHP Results





CONCLUSION

- Project Background
- Thesis Goals
- Existing Conditions
- Structural Breadth
- Mechanical Depth
- Electrical Breadth
- **Conclusion**



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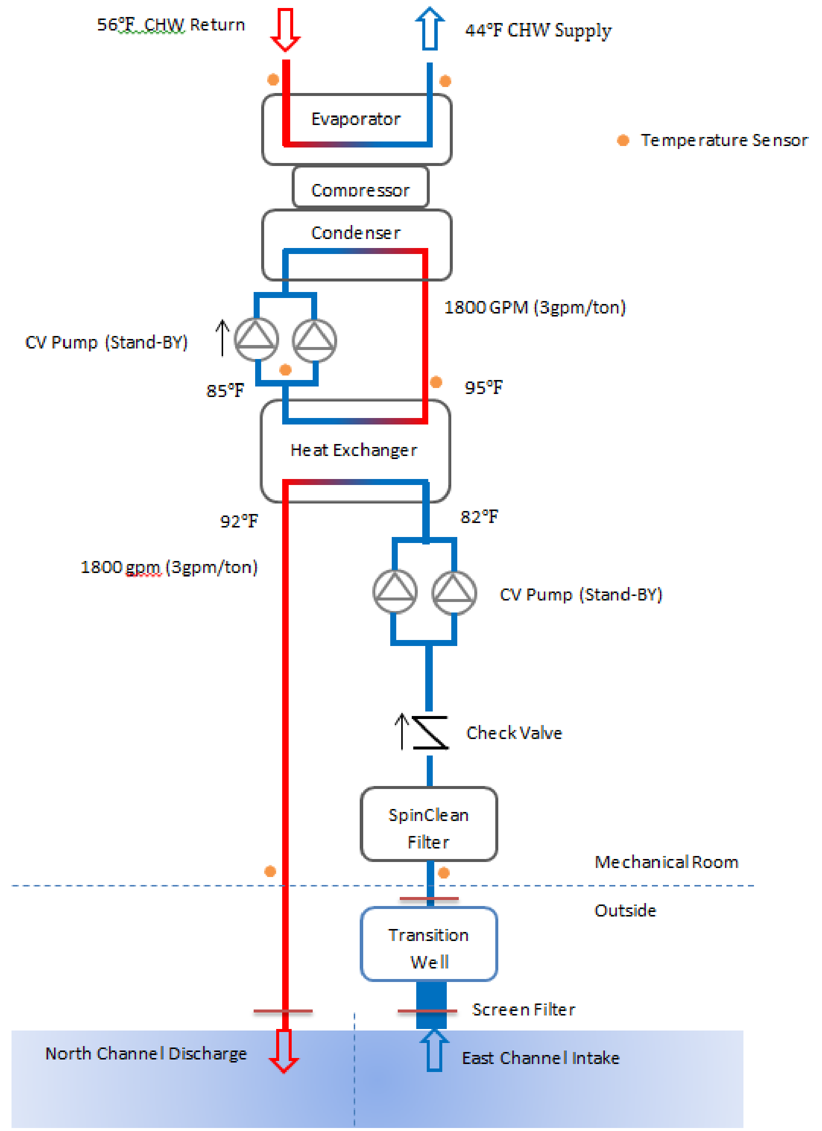

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CHP
EPA COMBINED HEAT AND POWER PARTNERSHIP

=

Total

- **$160,000 Annually**
- **4 Year Payback**
- **65% Reduction of CO_2**

- Project Background
- Existing Conditions
- Thesis Goals
- Structural Breadth
- Mechanical Depth
- Electrical Breadth
- **Conclusion**

Thank You

HGA

Kevin Pope, P.E.	Associate Vice President, HGA
Jeff Harris, P.E.	Director of Mechanical Engineering, HGA, Penn State Alumni
Steve Mettlach	Mechanical Engineer, HGA

Harley-Davidson

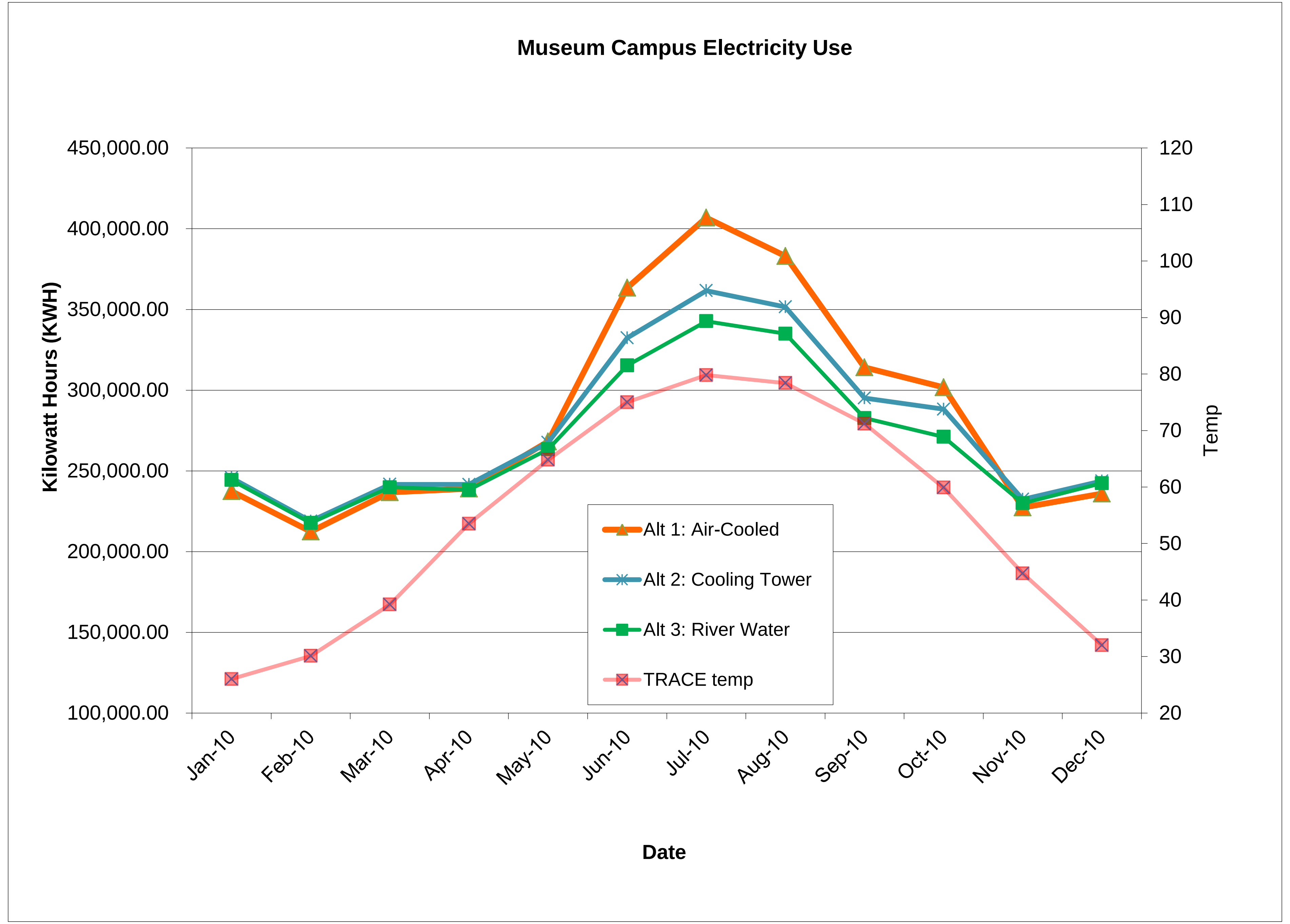
Joyce Koker, P.E.	Harley-Davidson Museum

Penn State

Dr. William Bahnfleth	Faculty Advisor
Dr. Jelena Srebric	AE Mechanical Professor
Dr. James Freihaut	AE Mechanical Associate Professor
Mr. David H. Tran	AE 5^{th} Year Structural, BAE/MS

Family and friends for their support

Questions?



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

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

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

	Alternative	LCC
Air-cooled	1	$4,046,288.09
Cooling Tower	2	$ 3,861,471.04
River	3	$ 3,656,301.16

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

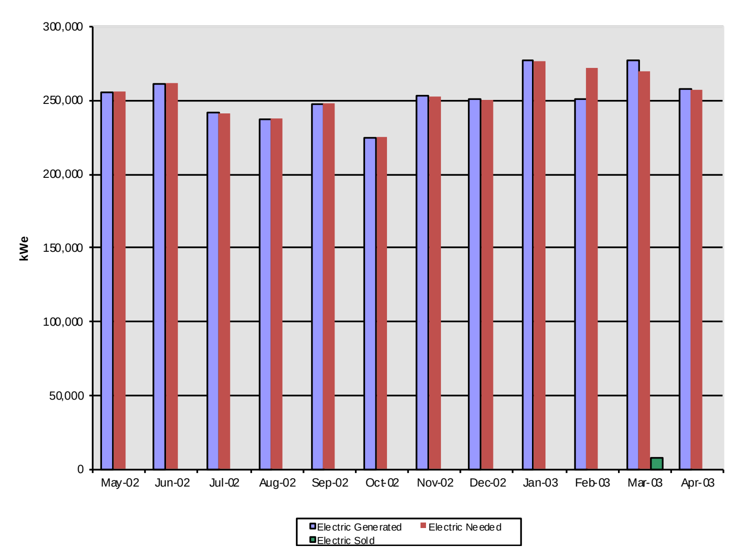
	Electricity				Fuels	
			% of Total Cost from Peak Demand		Gas	
	Energy	Peak Demand		Cost*	Energy	Cost*
	kWh	kW		$	Therms	$
Jan-03	252,717	611	10%	$25,272	12,113	$9,690
Feb-03	225,119	626	10%	$22,512	8,256	$6,605
Mar-03	247,492	631	10%	$24,749	4,217	$3,374
Apr-03	241,526	671	10%	$24,153	3,102	$2,482
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

Thermal-to-Electric Ratio	= 0.74	
Recommended Prime Mover(s)		
Gas Engine	Recommended	
Microturbine		
Gas Turbine (Simple Cycle)		
Phosphoric Acid Fuel Cells		
Select Prime Mover	Gas Engine	
Would backup generation have been installed anyway?	Yes	
If "Yes", indicated planned size	300	kWe
Recommended Generation	373	kWe
Chose Size (per Unit)	373	kWe
Chose Number of Units	1	Unit(s)
Total Selected Capacity	373	kWe
Electric Efficiency	34	%
Gross Heat Rate Exhaust (LHV)	6,623	BTU/kWhe
Recoverable Heat Rate (LHV)	4,305	BTU/kWhe
O&M Costs	$0.0120	$/kWh/yr
Electric Use	0.0000	kWe/kWe
Include Absorption Chiller	Yes	
Will the Absorption ChillerDisplace an Electric Chiller?	Yes	
Size	89	RT
Thermal Input	1,606	MBTU/hr
O&M Costs	$55	$/RT/yr
Electric Use	0.0300	kWe/RT
Electric Displaced	0.6000	kWe/RT
Select Desiccant	None	
Would a desicant have been installed	No	
Chose Size (per Unit)	10,000	SCFM
Chose Number of Units	1	Unit(s)
Total Selected Capacity		SCFM
Regeneration Requirements (200°F)		BTU/hr
O&M Costs		¢/SCFM/yr
Latent Heat Removal Rate		BTU/hr
Electric Use		kWe per kSCFM

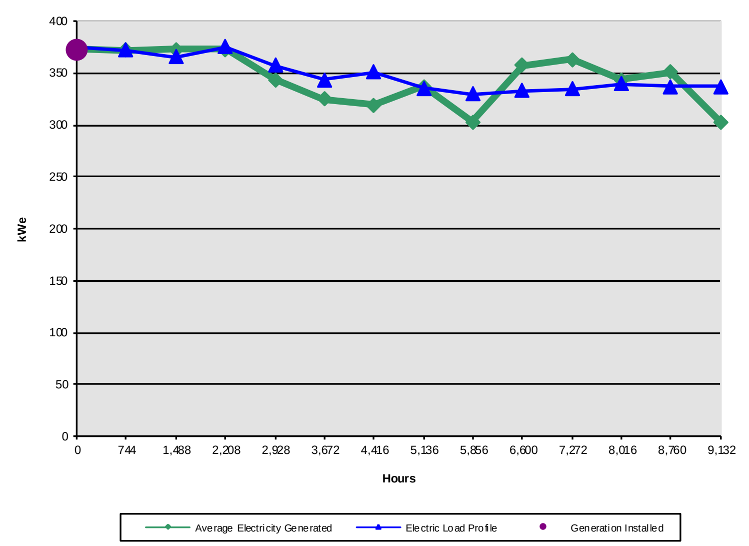
SITE		
MN Hospital		
1234 W. Main St		
Milwakee	WI	
ASSUMPTIONS		
Average Electric Cost	10.000	¢/kWh
Peak Averge Electric Cost	N/A	¢/kWh
Initial Electric Sell Back	1.500	¢/kWh
Supplemental Elect Cost	10.000	¢/kWh
Cogen Initial Fuel Cost	8.00	$/MMBTU
W/O Cogen Fuel Cost	8.00	$/MMBTU
Existing Boiler Efficiency	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**

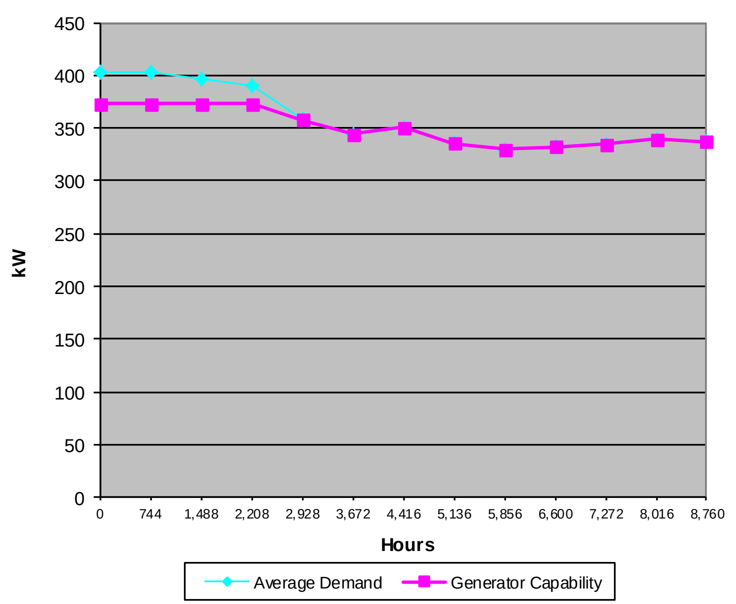
CHP Electric



Comparision of Generation to CHP Electric Load



Average Demand Profile



Thermal Demand vs CHP Generation Thermal