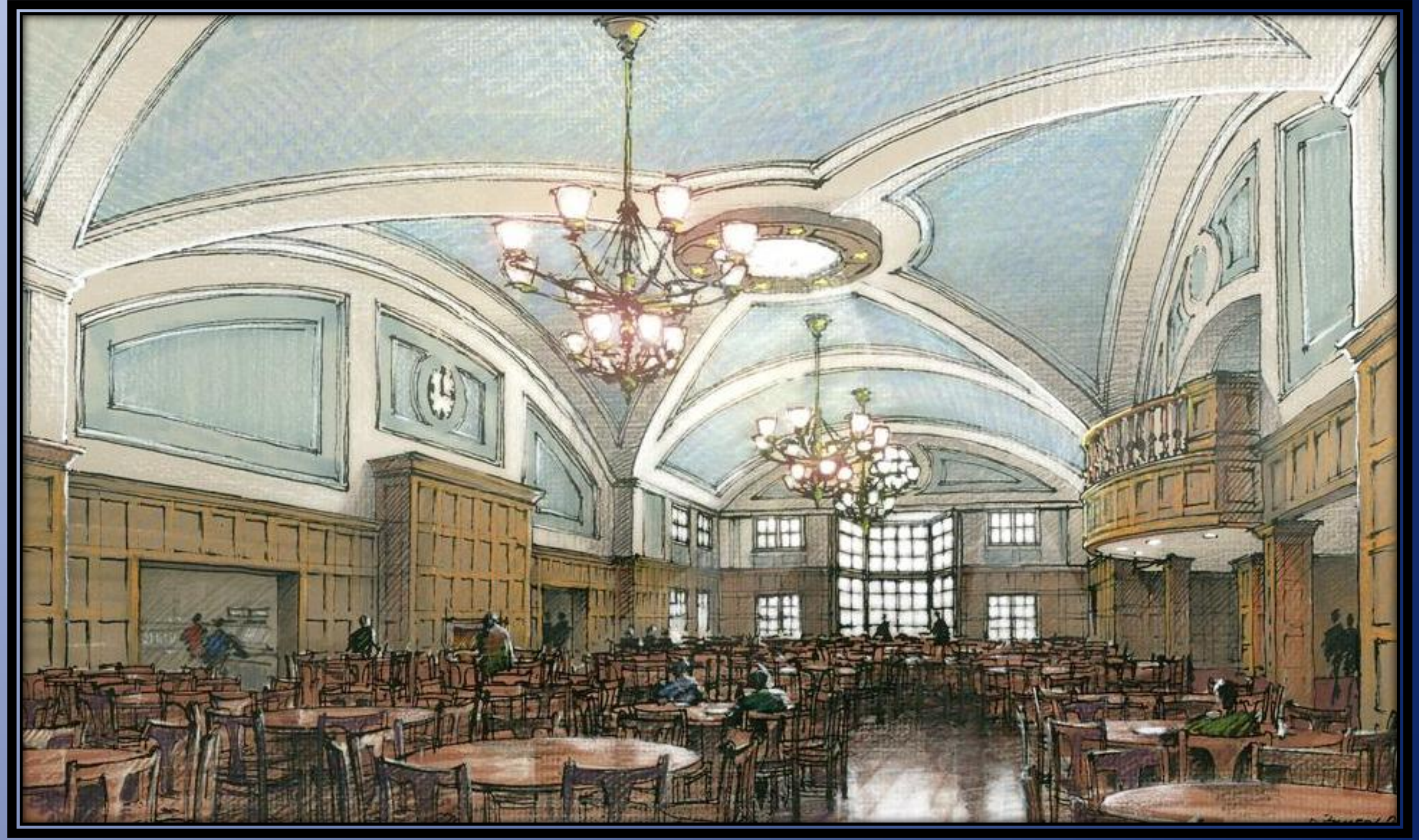
The Edward St. John Student Center

Zachary Haupt

Faculty Advisor: Dr. William Bahnfleth
11 April 2011

Presentation Outline

- Project Background
- Existing Mechanical Summary
- Design Objectives
- Alternative Descriptions
- Ground Source Heat Pumps
- Enthalpy Wheel
- Solarban 70XL Glass
- System Comparison
- Final Recommendations



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Project Information:
Delivery Method - Design-Bid-Build
Operational Date - September 2012
Occupancy - K-12 Boarding School
Size - 68,000 SF
Cost - $16,000,000

Primary Project Team:
Owner - McDonogh School
Architect - Bowie Gridley Architects
Civil Engineer - Matis Warfield
MEP Engineer - James Posey Associates, Inc
Structural Engineer - Linton Engineers, LLC

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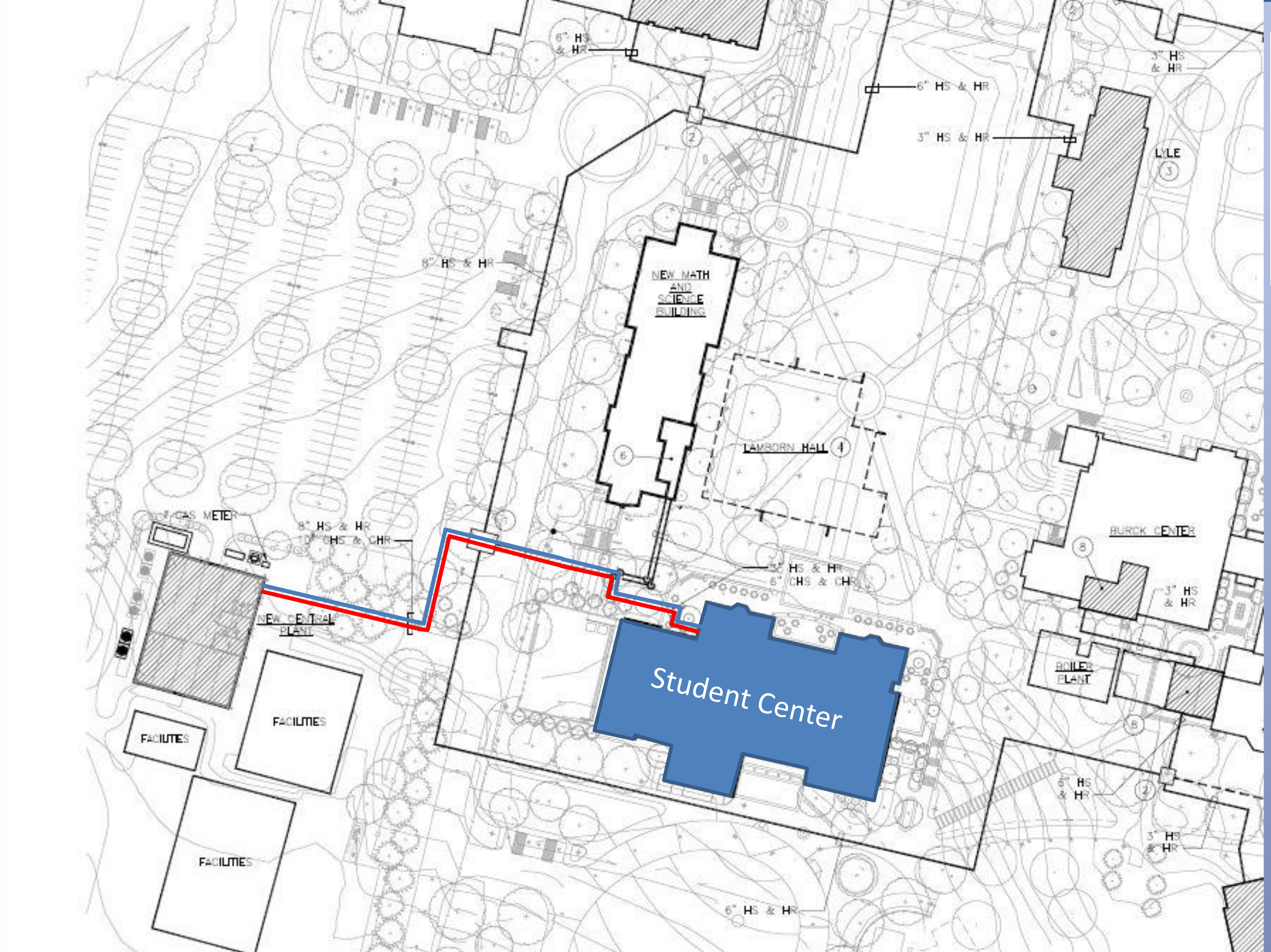


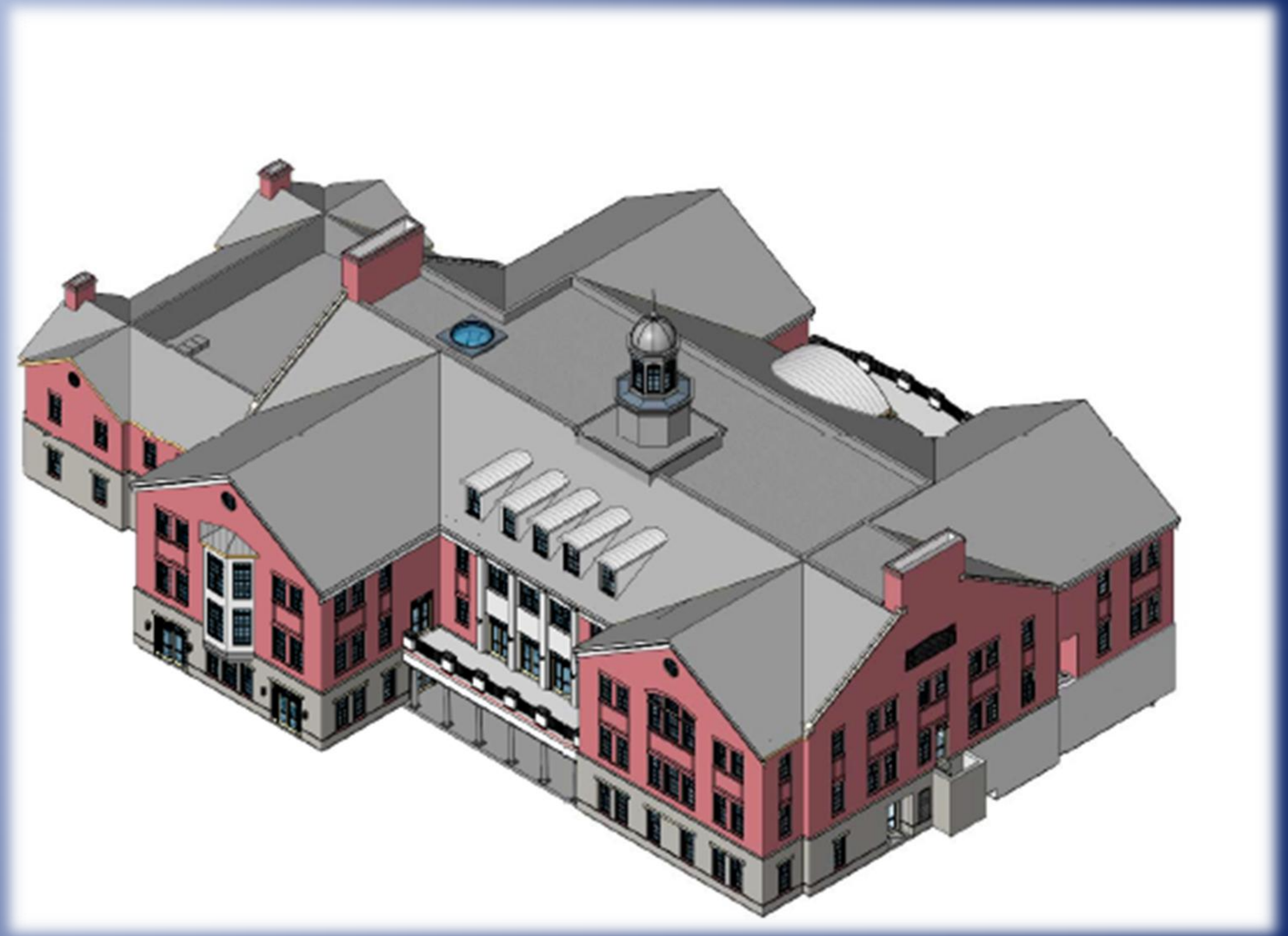
Mechanical System:
- 8 indoor AHUs
  - 7 VAV units
    - 5 single zone VAV units
    - 2 multizone VAV units
  - 1 single zone CAV unit

Central Plant:
- Located on campus
- 3 Boilers
- 2 Chillers

Building Layout

Lower Level

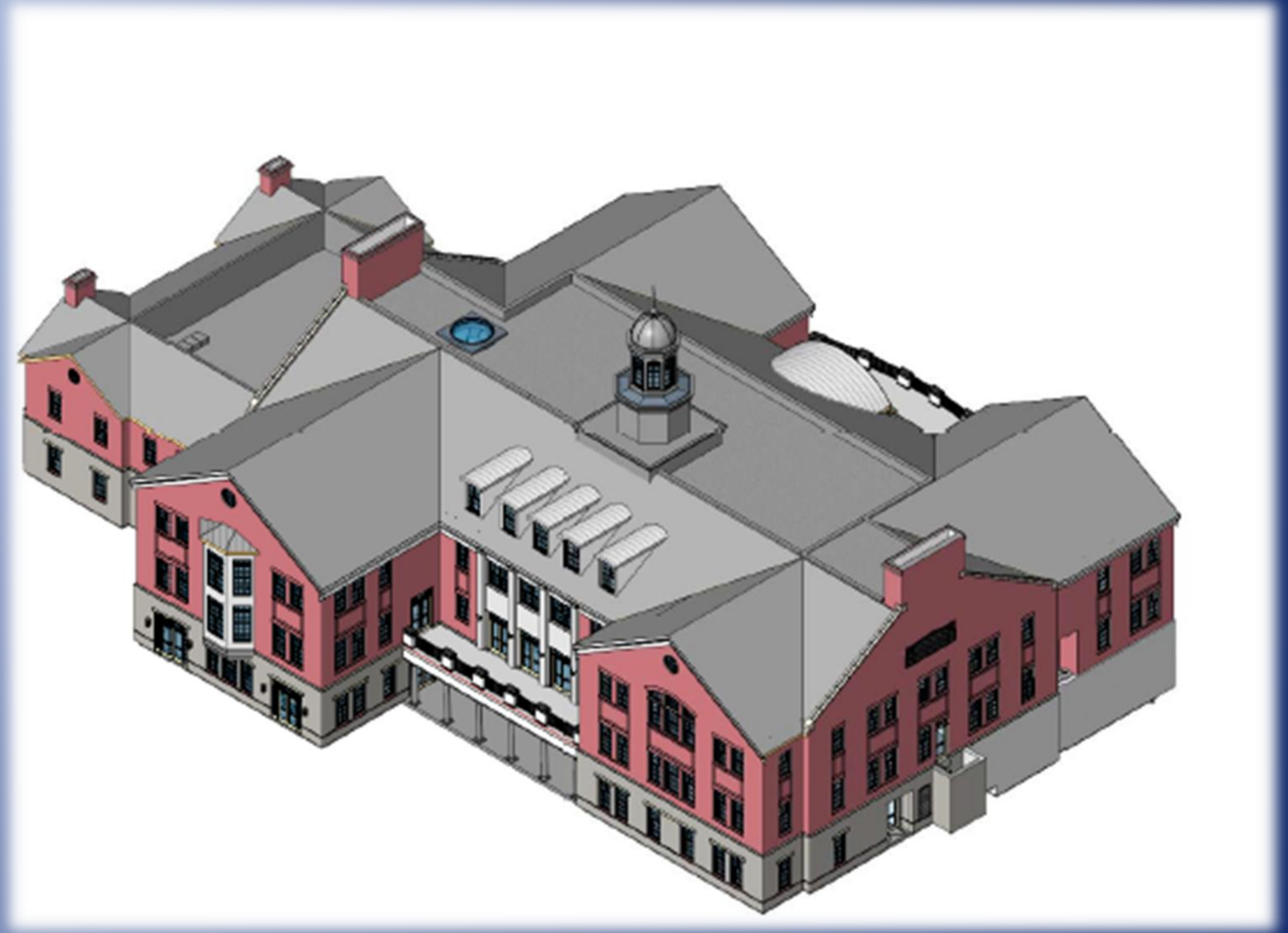
- AHU – 3 Serves Lecture Hall
- AHU – 4 Serves Dance Studio
- AHU – 5 Serves LS Dining
- AHU – 1 Serves Lower & Quad Levels



Building Layout

Quad Level

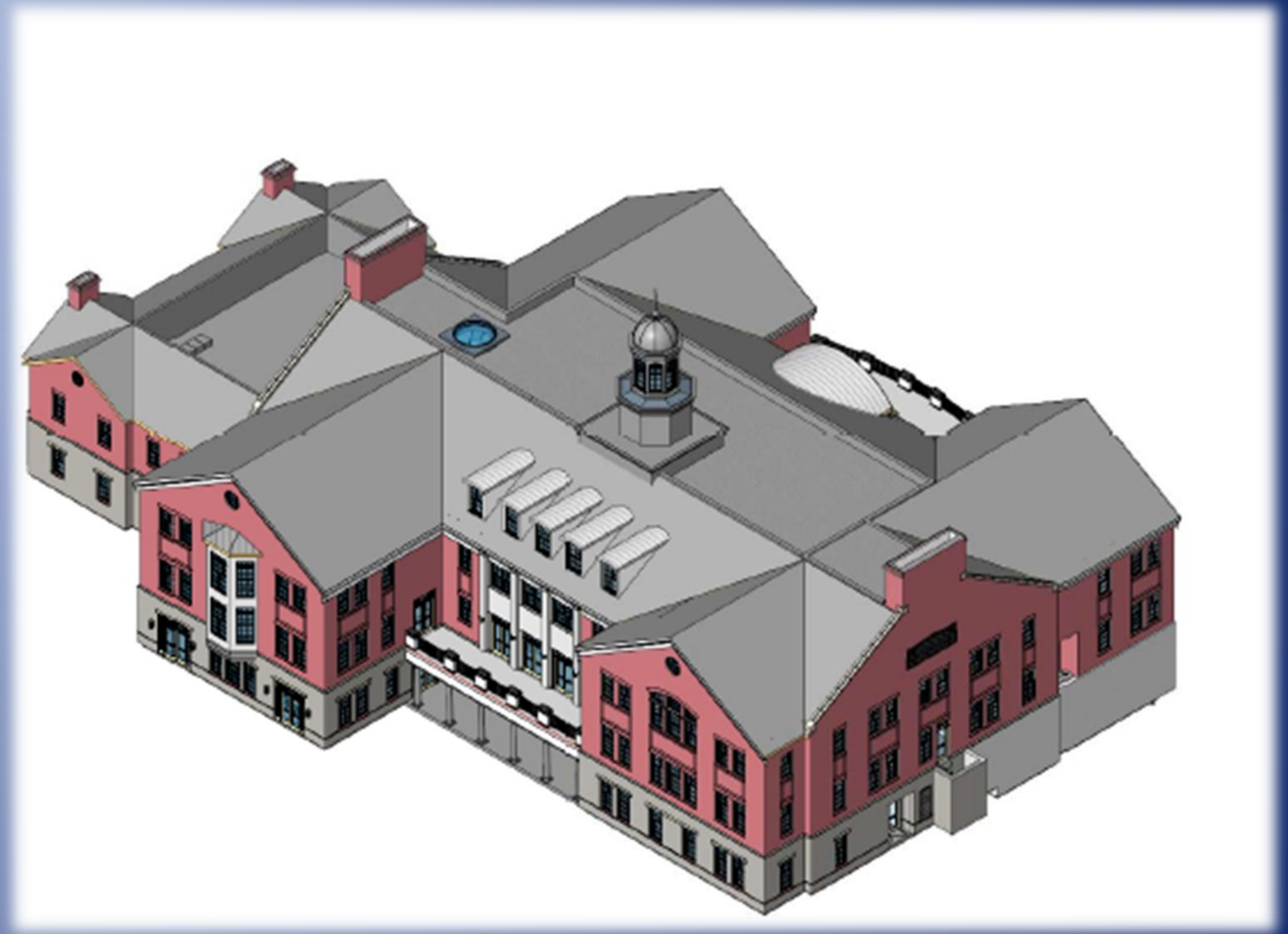
- AHU 6 & 7 Serve US Dining
- AHU – 2 Serves Senior Dining
- AHU – 1 Serves Lower & Quad Levels



Building Layout

Upper Level

- AHU – 8 Serves Entire Floor



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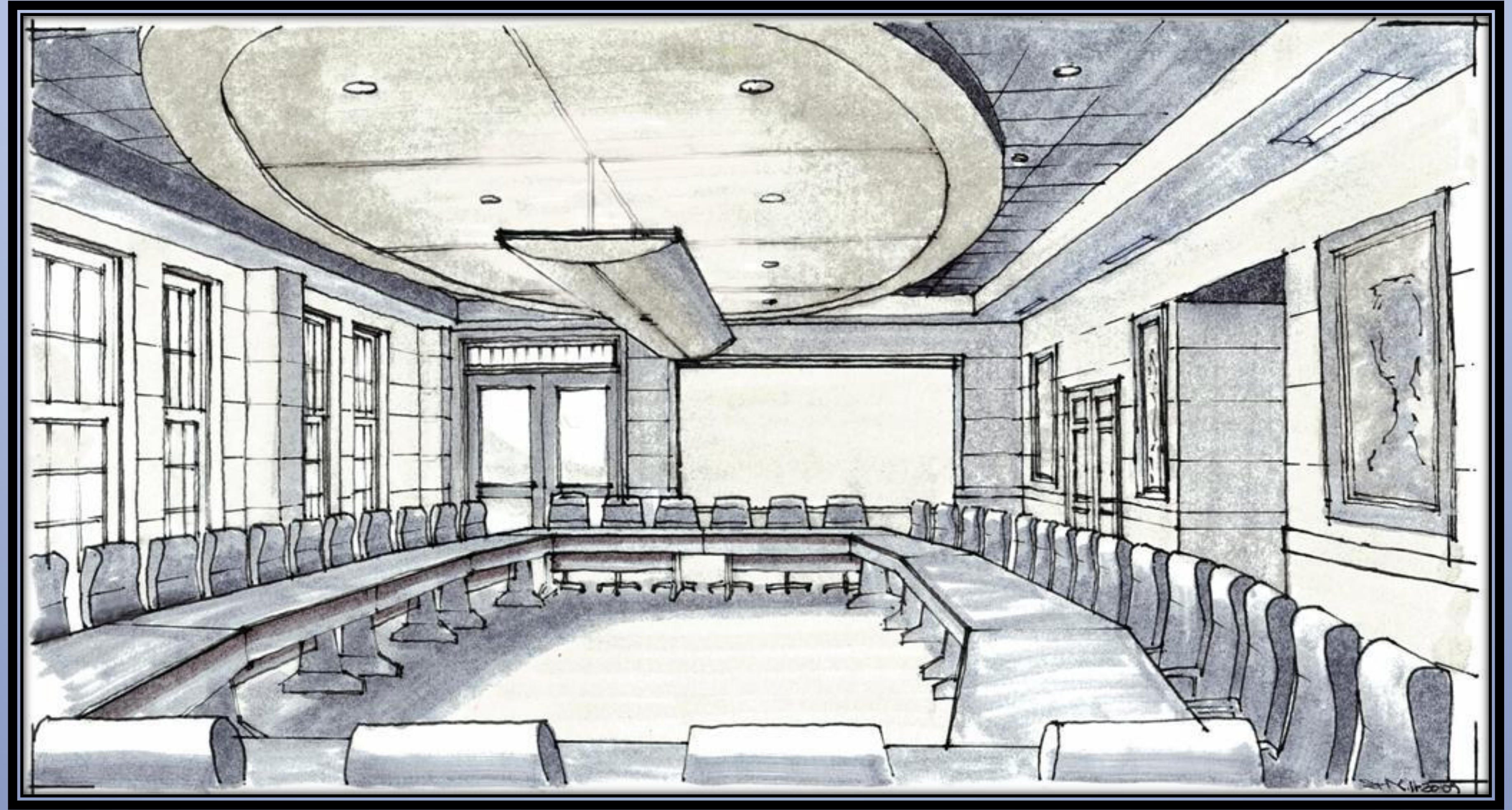

Improve System Performance

- Energy Consumption
- Emissions
- Total System Costs
- Minimize Payback Periods

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Ground Source Heat Pumps / Enthalpy Wheel / Solarban 70XL

The Good

- ✓ Higher System Efficiencies
- ✓ Decentralized System / No Added Maintenance / Lower Greenhouse Gas Emissions
- ✓ Lower Greenhouse Gas Emissions / Large Variety of Shading Choices
- ✓ Low Air Pressure Drop

Ground Source Heat Pumps / Enthalpy Wheel / Solarban 70XL

The Bad

- ❑ Increased Capital Cost / Increased Construction Costs
- ❑ Increased Construction Time / Slightly Larger Size and Weight of AHU
- ❑ Impact of Loop on Ecosystem

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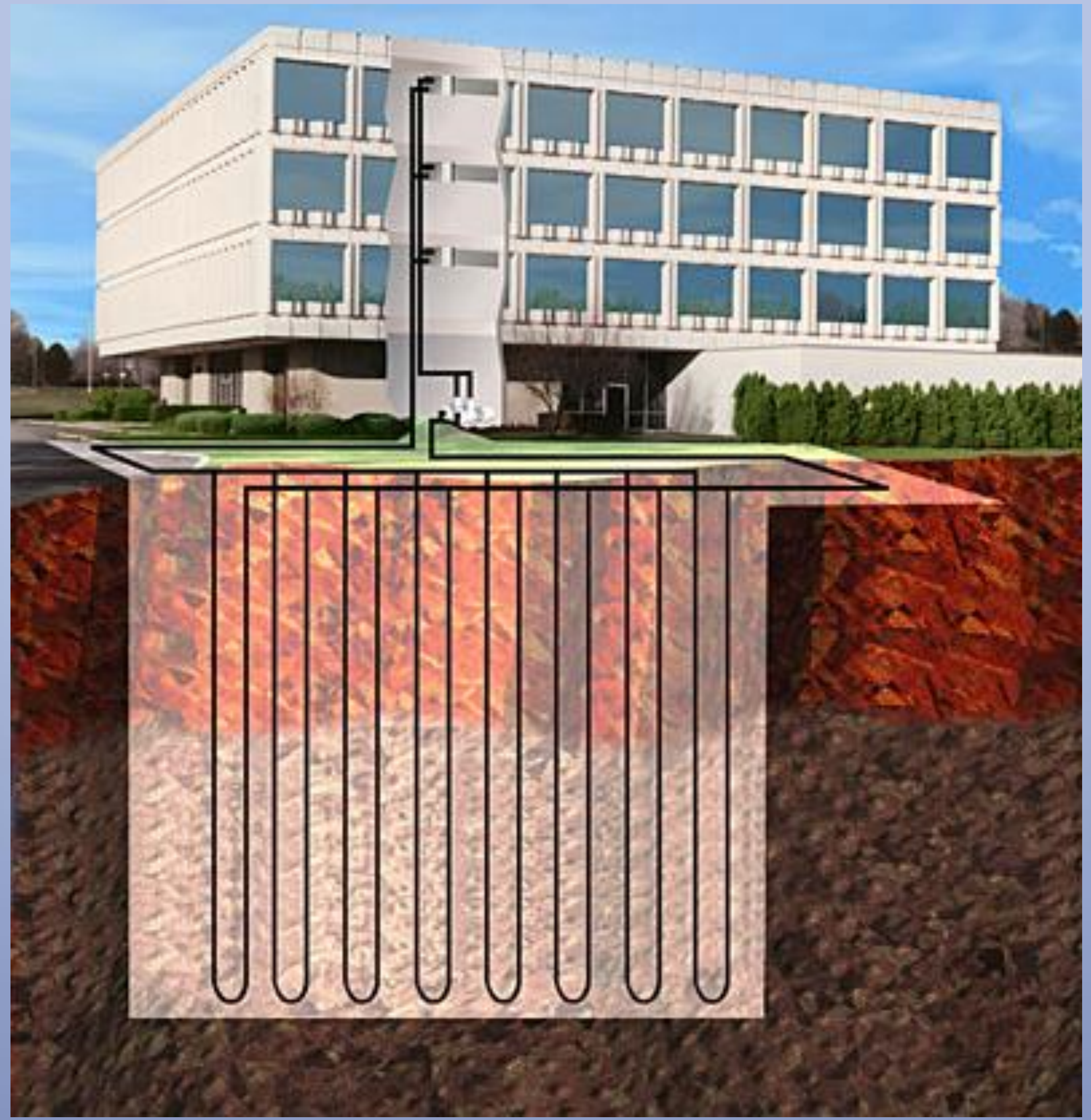

Implementing a GSHP

- Site Geology Study
- Calculations
- Pipe Sizing
- Pump & System Layout
- Results

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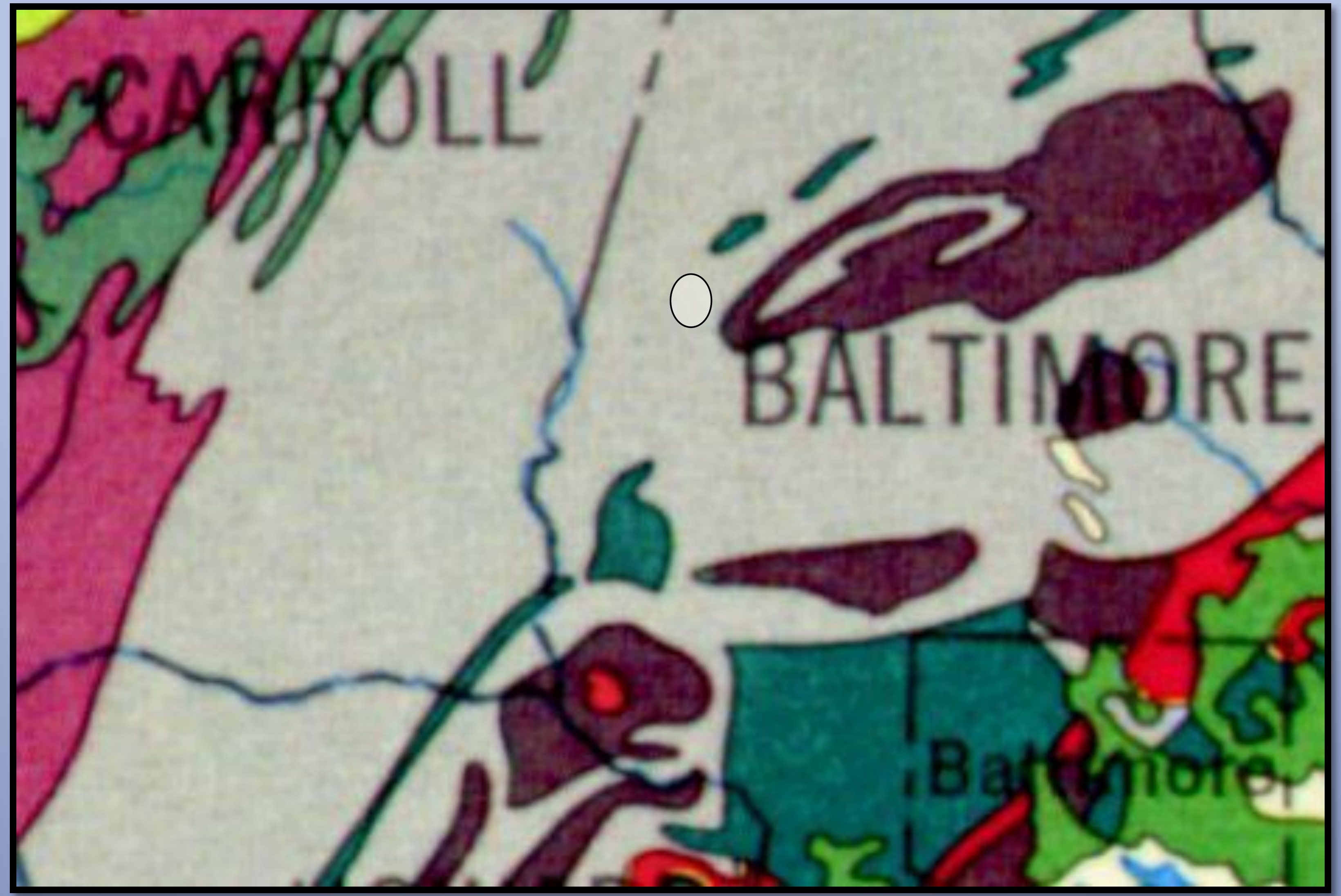
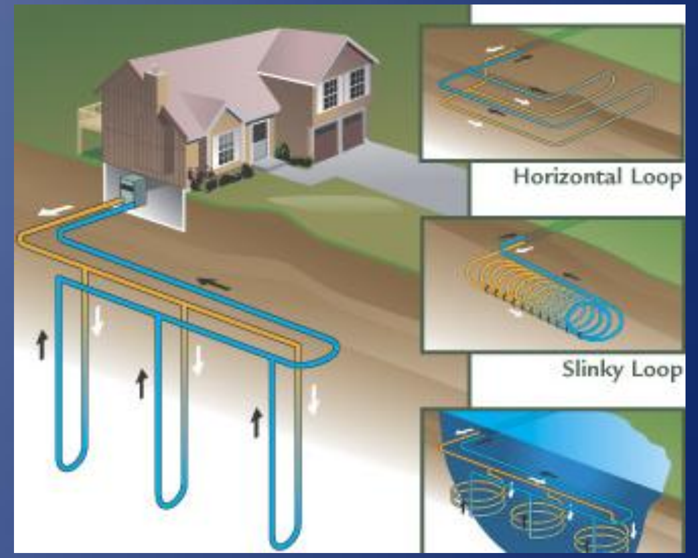


Located in Baltimore County

- Precambrian Soil Type
- 15% Water and Sandstone
- Soil Resistivity ≈ 0.6 BTU/hr · ft · °F



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Project: St. John Student Center
Job Number:
Date: 04/04/11
User: Haupt

INPUT DATA

Total Building Load (Ton)=	247.4	Bldg Area	68000	Sq Ft
Outdoor Design Temp. (°F)=	95	Sq. Ft / Ton	275	
Indoor Design Temp. (°F)=	75			
Balance Temp. (°F)=	65			

- Cooling Length

$$L_C = \frac{q_c R_a + (q_{lc} - 3.41 W_c)(R_b + PLF_m R_m + R_{gm} + R_{ga} F_{sc}}{t_g - \frac{t_{wi} - t_{wo}}{2} - t_p}$$

- Heating Length

$$L_C = \frac{q_c R_a + (q_{lc} - 3.41 W_c)(R_b + PLF_m R_m + R_{gm} + R_{ga} F_{sc}}{t_g - \frac{t_{wi} - t_{wo}}{2} - t_p}$$

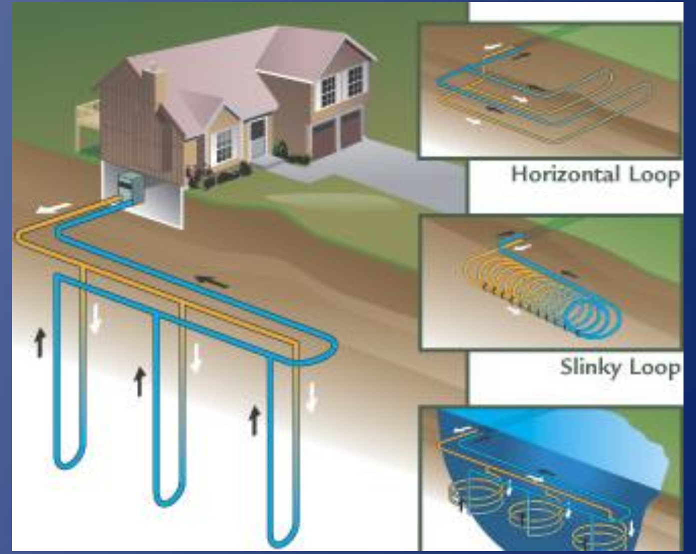
90/95	333.99	8.11
85/90	272.14	15.42
80/85	210.29	75.77
75/80	148.44	58.90
70/75	86.59	43.82
65/70	24.74	14.02
		216.05

nd Loop Heat Exchanger Length(Ft/Ton)= 201.71
Total Ground Loop Length= 49904.02

Bores Required: Depth (Ft)	Number
400	125
375	133
350	143
325	154
300	166
250	200
200	250
600	83

McClure Company Spreadsheet & ASHRAE

- Vertical Loop Analysis
- Used to Determine # of Bores + Depths
- Cross Checked With ASHRAE



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Selected Pump Model

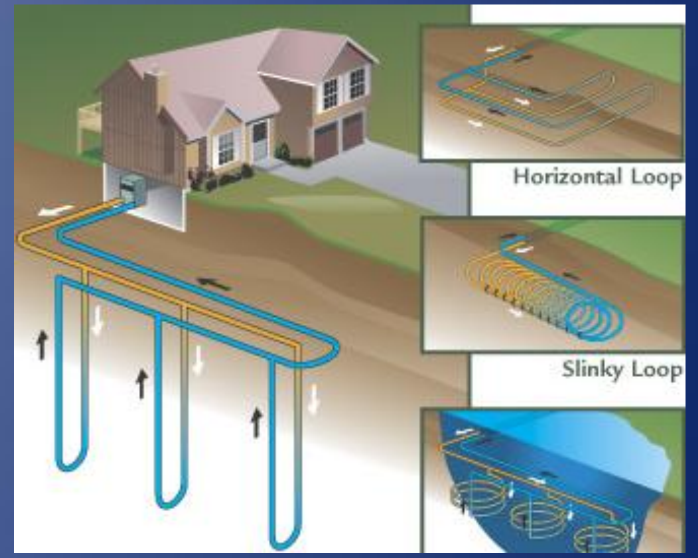
Manufacturer	Model	TC (MBtuh)	Power (kW)	THR (MBtuh)	LWT	EER
Carrier	50PSW360	313	16.08	367.9	61.1	19.5

Cost Of Pipe

Pipe Size	Length Of Pipe	Cost Of Pipe/Ft	Cost Of Pipe
3	64000	$ 0.033	$2,112
2	16000	$ 0.0275	$440
1.5	8000	$ 0.0165	$132
1.25	16000	$ 0.0125	$200
			$2,884

Bores Per Pump

- 750 Total GPM – 125 Total Bores
- 6 GPM Per Bore



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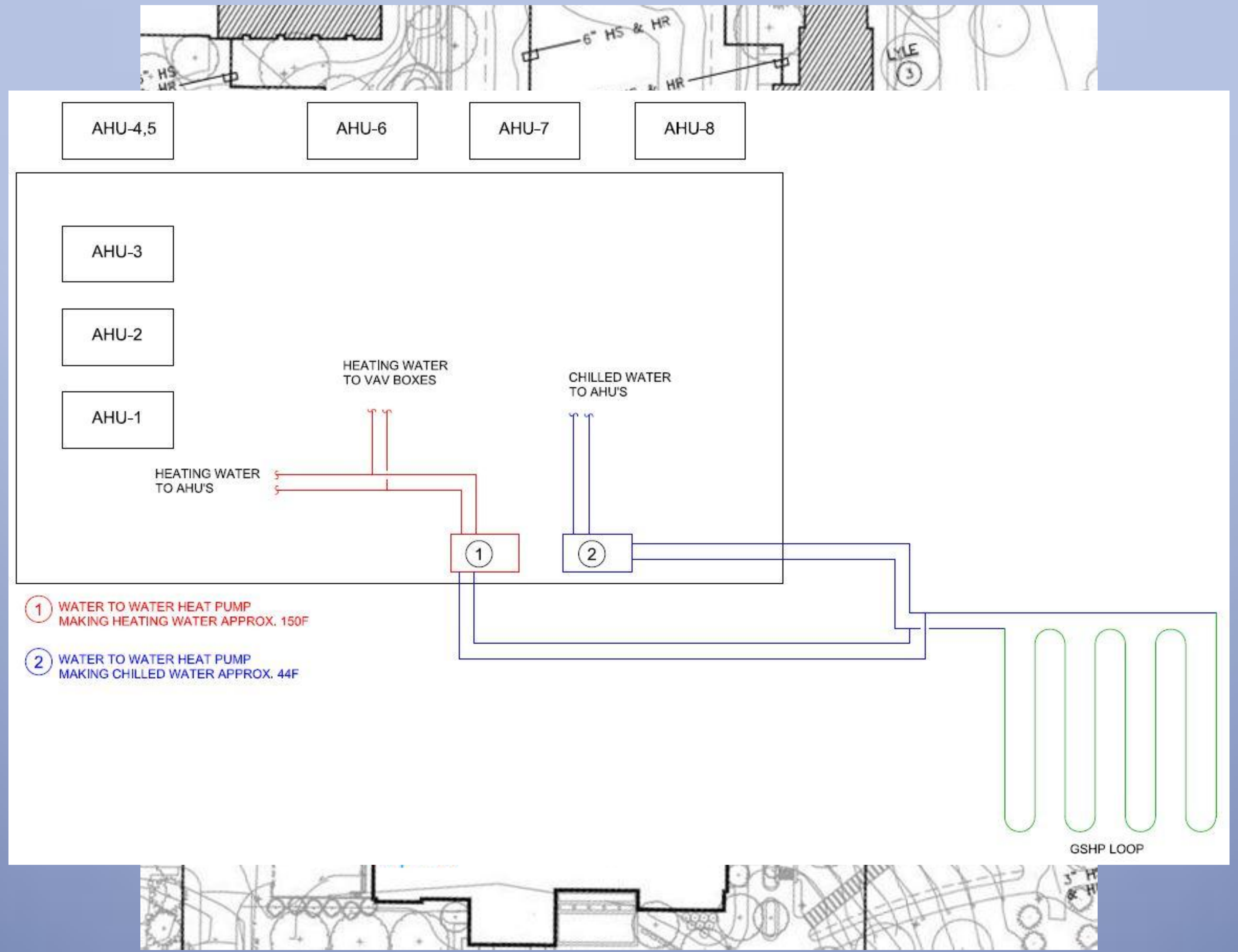
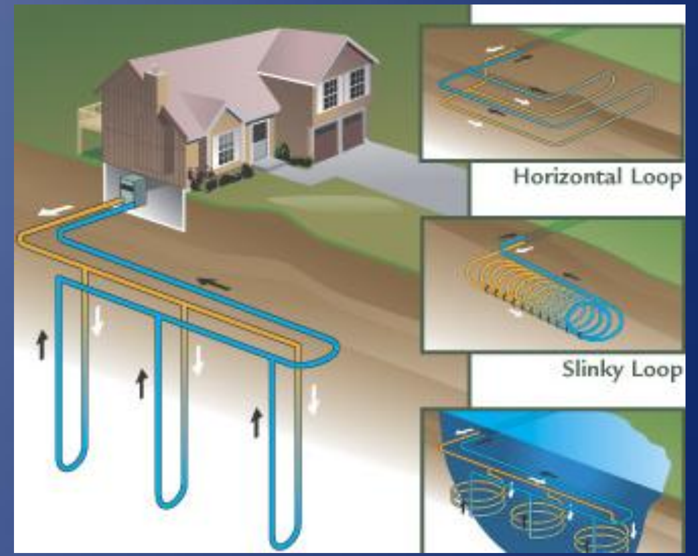


Layout of System

- 5 Pumps
  - Each Pump Serves 12 Bores
- 5 Pumps
  - Each Pump Serves 13 Bores



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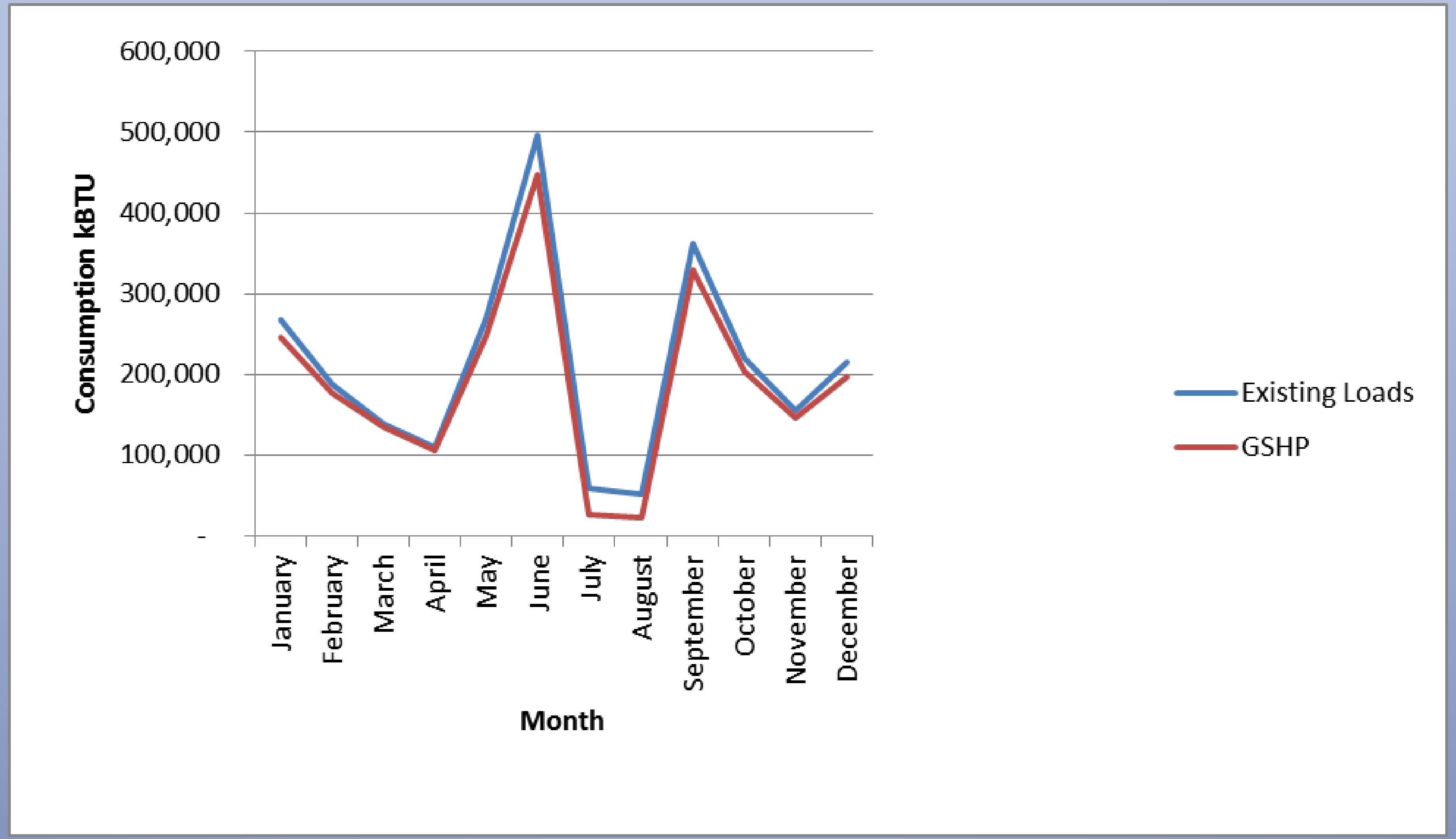
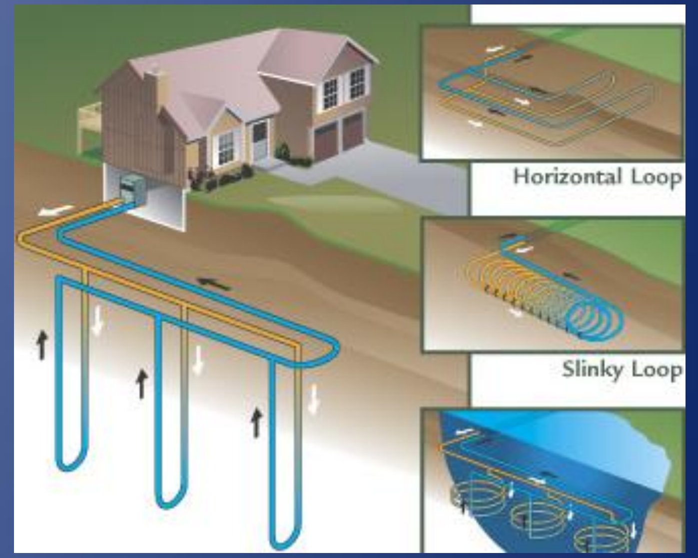
Annual Energy Consumption (Existing vs. GSHP)



Energy Savings

- 5.7 % Annual Heating Savings
- 12.4 % Annual Cooling Savings
- 9.9 % Total Annual Energy Savings



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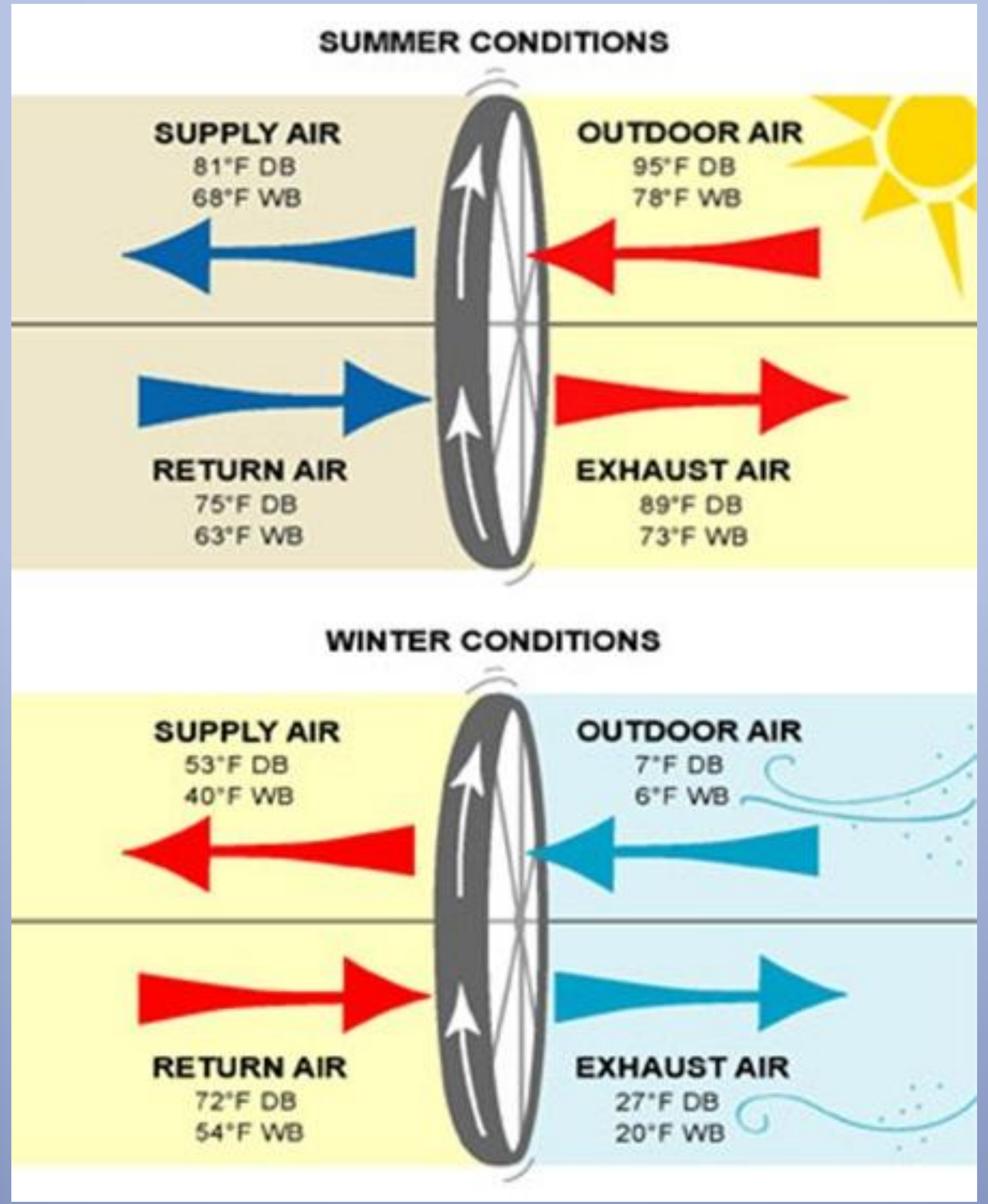

Selecting a Wheel

- Determine supply air total flow (CFM)
- Use SEMCO wheel chart
  - Keep face velocity ≈ 800 (FPM)
- Calculate unit effectiveness
- Results

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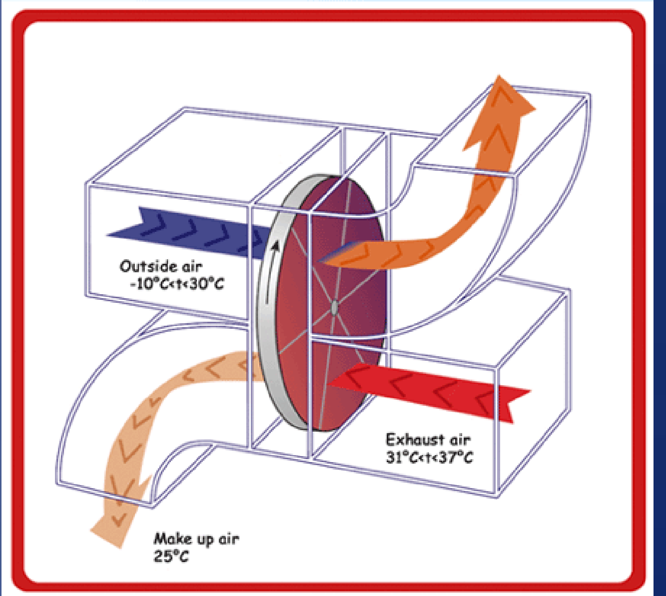
AHU - 8

- Serves art classrooms
- Scheduled at 15,000 CFM



A diagram of a rotary heat exchanger, or "heat wheel" (From Uptime Technology BV)

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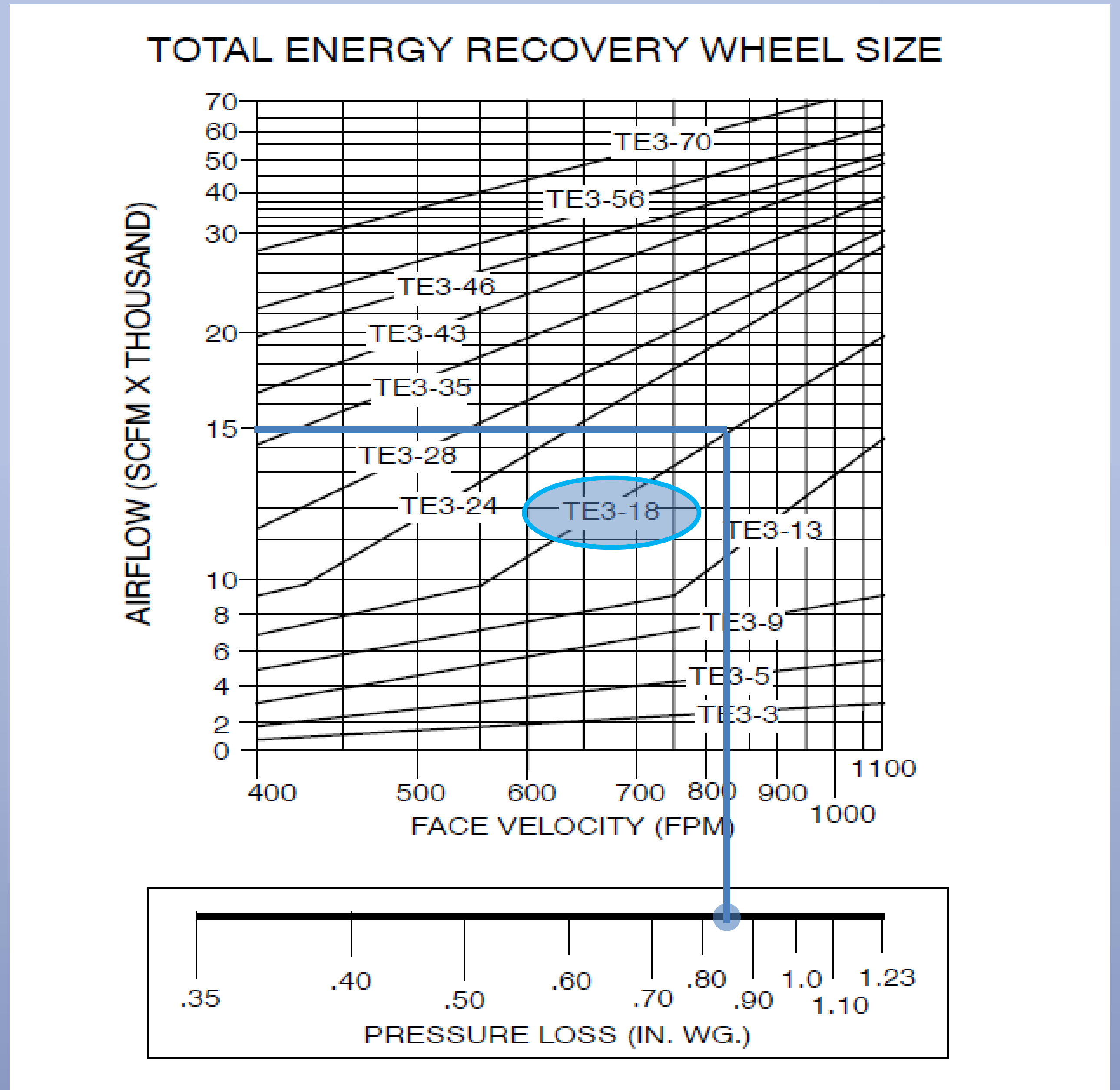
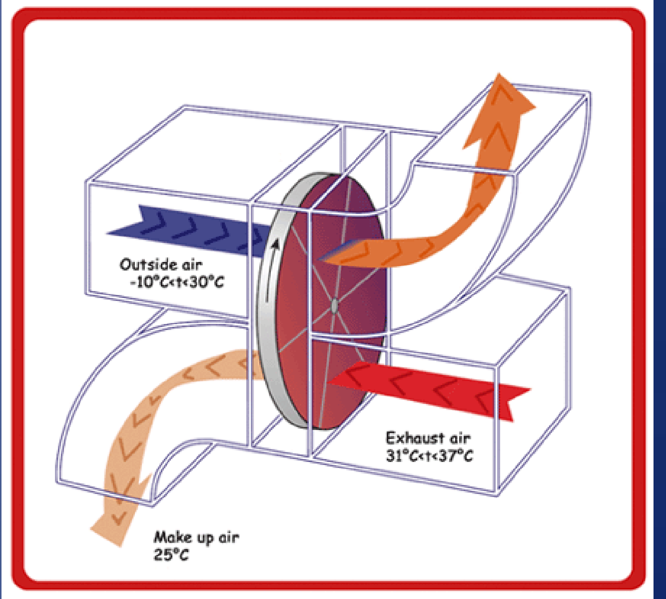


AHU - 8

- Find desired CFM
- Read directly right until model intersection (closest to 800 FPM)
- Mark model # down
- Read directly down to find associated pressure loss



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The exchanger heat transfer effectiveness e is defined as the amount of energy recovered, e.g. sensible or latent, divided by the maximum amount of energy that could theoratically be recovered.

The supply air volume heat transfer effectiveness e_s is defined as

$$e_s = \frac{V_s\,(X_1 - X_2)}{V_{min}\,(X_1 - X_3)}$$

The return air volume heat transfer effectiveness e_r is defined as

$$e_r = \frac{V_r\,(X_4 - X_3)}{V_{min}\,(X_1 - X_3)}$$

Based on the above definitions, the supply air condition X_2 can be calculated from

$$X_2 = X_1 - e_s \frac{V_{min}}{V_s}(X_1 - X_3)$$

and the exhaust air condition X_3 can be calculated from

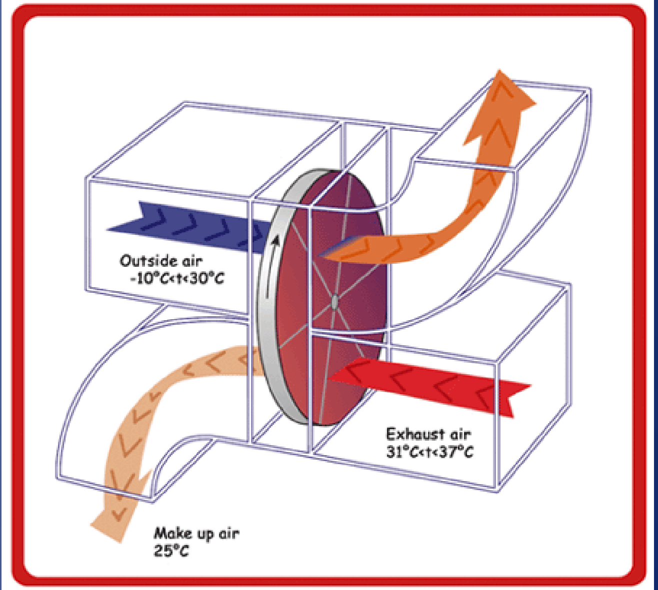
$$X_4 = X_3 + e_s \frac{V_{min}}{V_r}(X_1 - X_3)$$

where V_s = Supply air volume, scfm
V_r = Return air volume, scfm
V_{min} = V_r if V_r is smaller than V_s or V_{min} = V_s if V_s is smaller than V_r
X = dry bulb temperture (°F) or moisture content (gr/lb) or enthalpy (Btu/lb)

The indices refer to the following airstreams, as indicated in the figure below:
1 = Outdoor air condition
2 = Supply air condition
3 = Return air condition
4 = Exhaust air condition

AHU - 8

- Use calculations to determine unit effectiveness
- ≈ 80% Good



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Selecting a Wheel

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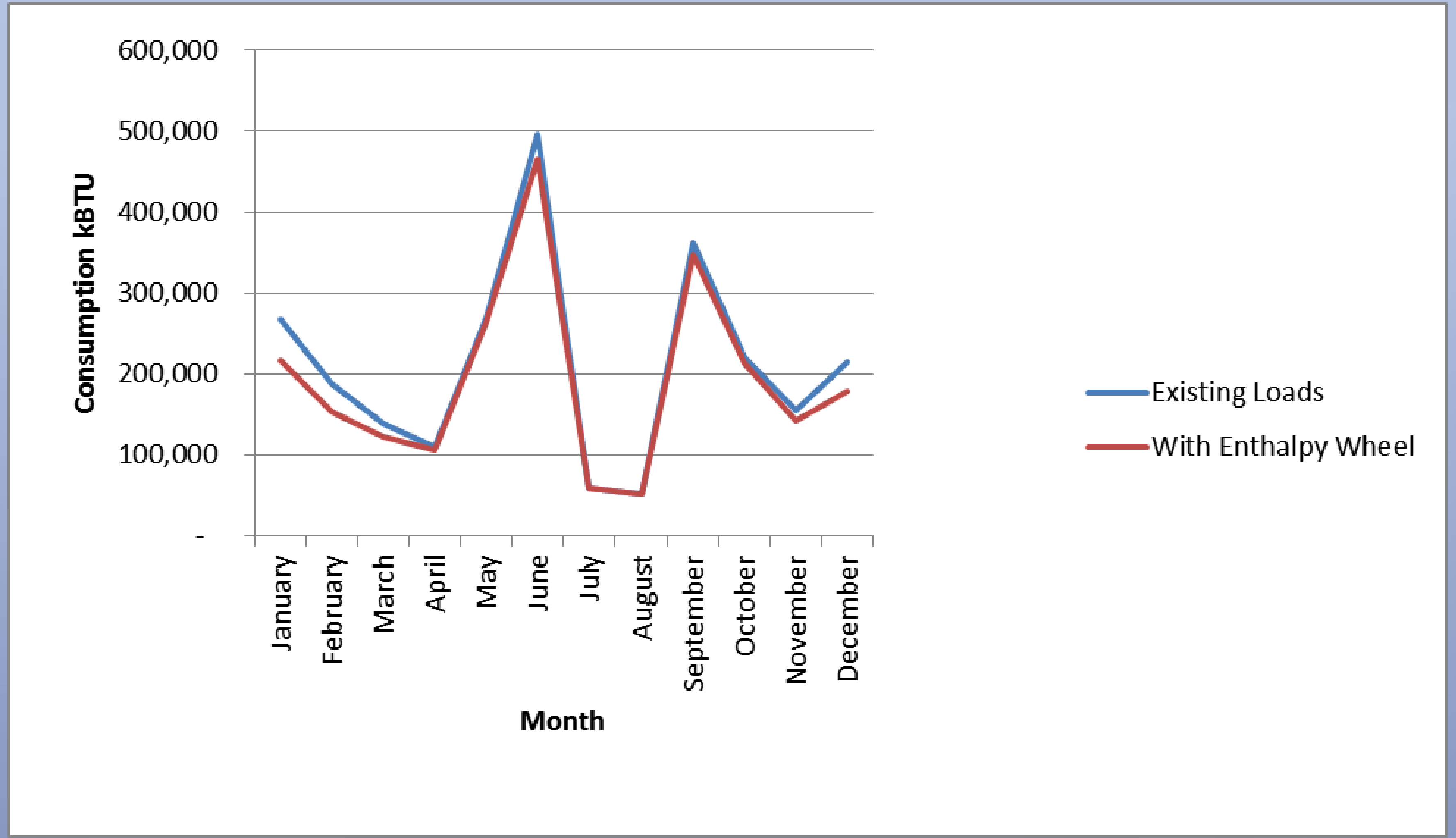
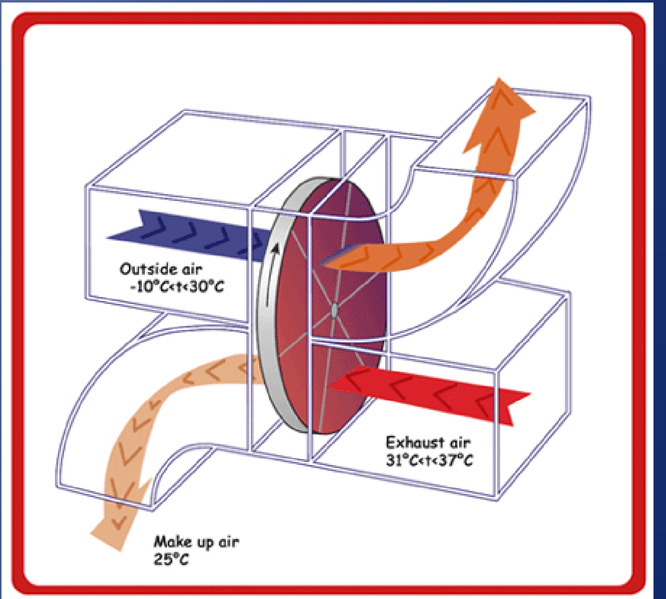
Annual Energy Consumption (Existing vs. Wheel)



Energy Savings

- 17.0 % Annual Heating Savings
- 3.4 % Annual Cooling Savings
- 8.4 % Total Annual Energy Savings



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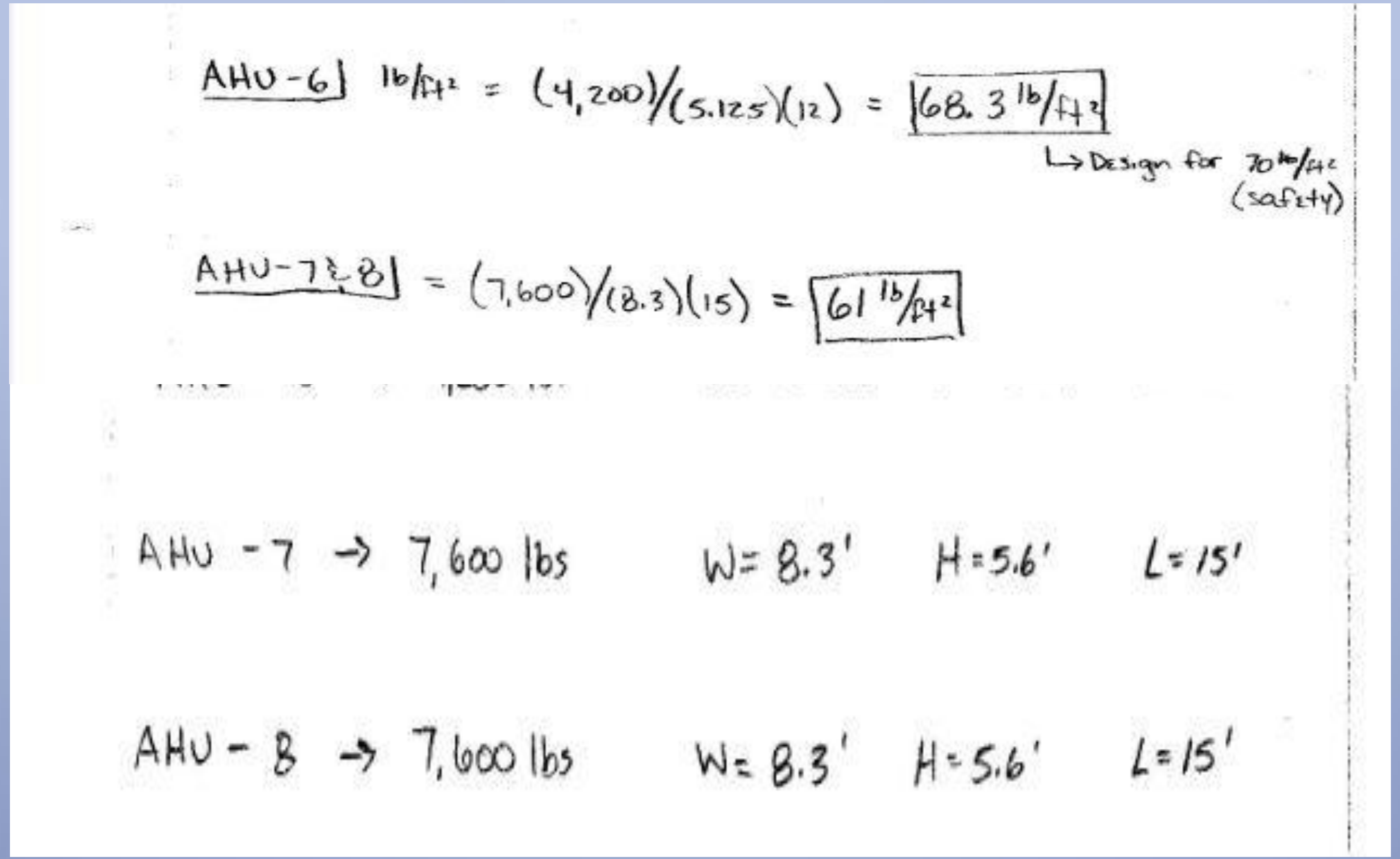
Structural Check

- Calculate lb/ft^2 for each AHU
- Calculate new lb/ft^2 for AHU 8
- Check slab strength
  - Adjust accordingly
- Check beam strength
  - Adjust accordingly

Structural Check

- Calculate lb/ft² for each AHU
- Calculate new lb/ft² for AHU 8
- Check slab strength
  - Adjust accordingly
- Check beam strength
  - Adjust accordingly



AHU-6 lb/ft² = (4,200)/(5.125)(12) = 68.3 lb/ft²
→ Design for 70 lb/ft² (safety)

AHU-7 & 8 = (7,600)/(8.3)(15) = 61 lb/ft²

AHU-7 → 7,600 lbs W= 8.3' H=5.6' L=15'

AHU-8 → 7,600 lbs W= 8.3' H=5.6' L=15'

Calculations

- Locate AHU Schedule
- Mark Weight, Width, & Length of each AHU Located in Room
- Calculate lb/ft² of Each AHU

Structural Check

- Calculate lb/ft^2 for each AHU
- Calculate new lb/ft^2 for AHU 8
- Check slab strength
  - Adjust accordingly
- Check beam strength
  - Adjust accordingly

AHU-7&8 $= (7{,}600)/(8.3)(15) = 61\ lb/ft^2$

Enthalpy wheel will add 2' in length & 1300 lbs.

AHU-8 w/ wheel $lb/ft^2 = (8{,}900lb)/(8.3')(17') = 63.1\ lb/ft^2$

↳ $65\ lb/ft^2$ (safety)

Calculations

- AHU 6 Dropped
- Wheel Adds
  - 2' in Length
  - 1,300 lbs

Structural Check

- Calculate lb/ft^2 for each AHU
- Calculate new lb/ft^2 for AHU 8
- Check slab strength
  - Adjust accordingly
- Check beam strength
  - Adjust accordingly

Structural | Breadth | Final Report

ASCE 7-10

Slab Check

$F_y = 60$

$f'_c = 5000$ psi

live load = 40 lb/ft^2

Slab load = 87.5 lb/ft^2

AHU - 8 = 63.1 lb/ft^2

$\text{Load} = 1.2(D) + 1.6(L) \Rightarrow (65 + 87.5)(1.2) + (40)(1.6) = 247 \text{ lb/ft}$

#5 @ 14" o.c. 14"

$(247 \text{ lb/ft})\left(\frac{14}{12}\right) = 288 \text{ lb/ft}$

$\sim 7 - 3/4 - 1/2 \cdot 5/8 = 5.94"$

$m = \frac{wL^2}{8} \Rightarrow \frac{(0.288 \text{ klb/ft})(16)^2}{8} = 9.216 \text{ ftk}$

$A_s = 0.31 \text{ in}^2$ $D = 5.94$

$a = \frac{A_s \times F_y}{0.85 \times F'_c \times b} \Rightarrow \frac{(0.31)(60)}{(0.85)(5)(14)} = 0.3126$ (F_y = 60)

$\phi M_n = 0.9(A_s)(F_y)(d - a/2)/12 = 8.07 \text{ ftk}$

$8.07 \text{ ftk} < 9.216 \text{ ftk} \rightsquigarrow$ Slab fails.

Calculations

- Rebar Spaced Every 14" O.C.
- Slab Fails Under New Load
- Space Rebar Every 12" O.C.
- Recheck Slab

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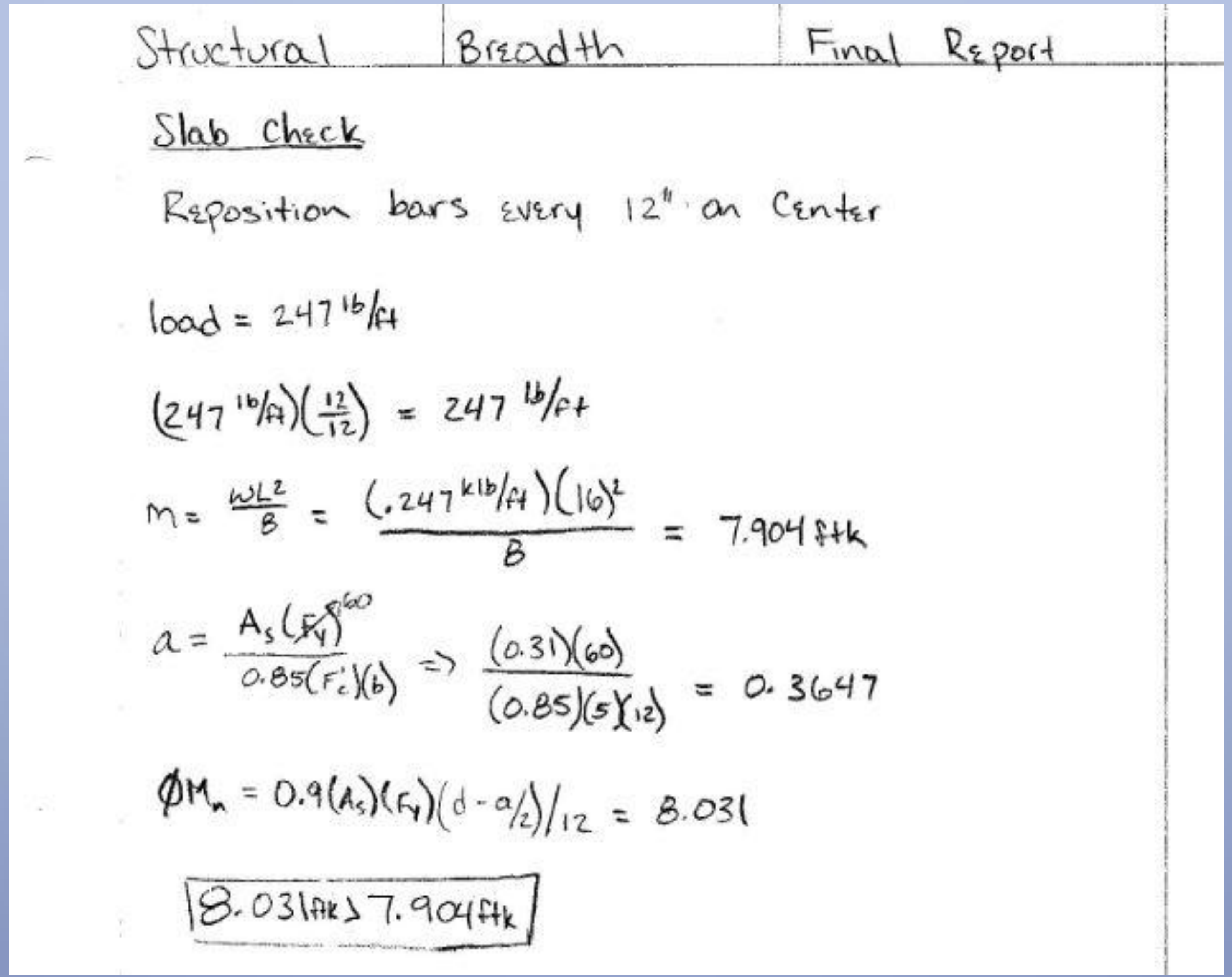
- Calculate lb/ft^2 for each AHU
- Calculate new lb/ft^2 for AHU 8
- Check slab strength
    - Adjust accordingly
- Check beam strength
    - Adjust accordingly



Structural | Breadth | Final Report

Slab Check

Reposition bars every 12" on Center

load = 247 lb/ft

$(247\ lb/ft)\left(\frac{12}{12}\right) = 247\ lb/ft$

$M = \frac{wL^2}{8} = \frac{(.247\ klb/ft)(16)^2}{8} = 7.904\ ftk$

$a = \frac{A_s(F_y)}{0.85(F'_c)(b)} \Rightarrow \frac{(0.31)(60)}{(0.85)(5)(12)} = 0.3647$

$\phi M_n = 0.9(A_s)(F_y)(d - a/2)/12 = 8.031$

8.031 ftk > 7.904 ftk

Calculations

- Slab Does Not Fail
- Adjust Rebar Spacing
- Analyze Beam

Structural Check

- Calculate lb/ft^2 for each AHU
- Calculate new lb/ft^2 for AHU 8
- Check slab strength
  - Adjust accordingly
- Check beam strength
  - ~~Adjust accordingly~~

[2] DESIGN RESULTS

Top Reinforcement

Units: Width (ft), Mmax (k-ft), Xmax (ft), As (in^2), Sp (in)

Span	Zone	Width	Mmax	Xmax	AsMin	AsMax	SpReq	AsReq	Bars	
1	Left	2.70	105.26	0.833	0.954	14.477	8.933	0.692	4-#7	*3 *5
	Middle	2.70	0.00	13.500	0.000	14.477	0.000	0.000	---	
	Right	2.70	105.26	26.167	0.954	14.477	8.933	0.692	4-#7	*3 *5

NOTES:
*3 - Design governed by minimum reinforcement.
*5 - Number of bars governed by maximum allowable spacing.

Top Bar Details

Units: Length (ft)

Span	Left				Continuous		Right			
	Bars	Length	Bars	Length	Bars	Length	Bars	Length	Bars	Length
1	2-#7	5.45	2-#7	3.67	---		2-#7	5.45	2-#7	3.67

Bottom Reinforcement

Units: Width (ft), Mmax (k-ft), Xmax (ft), As (in^2), Sp (in)

Span	Width	Mmax	Xmax	AsMin	AsMax	SpReq	AsReq	Bars	
1	1.67	309.57	13.500	2.409	44.722	3.600	2.030	5-#7	*3

NOTES:
*3 - Design governed by minimum reinforcement.

Bottom Bar Details

Units: Start (ft), Length (ft)

Span	Long Bars			Short Bars		
	Bars	Start	Length	Bars	Start	Length
1	5-#7	0.00	27.00	---		

Flexural Capacity

Units: x (ft), As (in^2), PhiMn (k-ft)

Span	x	AsTop	AsBot	PhiMn-	PhiMn+
1	0.000	2.40	3.00	-358.73	456.31
	0.833	2.40	3.00	-358.73	456.31
	2.672	2.40	3.00	-358.73	456.31
	3.672	1.20	3.00	-181.65	456.31
	4.445	1.20	3.00	-181.65	456.31
	5.445	0.00	3.00	0.00	456.31
	9.700	0.00	3.00	0.00	456.31
	13.500	0.00	3.00	0.00	456.31
	17.300	0.00	3.00	0.00	456.31
	21.555	0.00	3.00	0.00	456.31
	22.555	1.20	3.00	-181.65	456.31
	23.328	1.20	3.00	-181.65	456.31
	24.328	2.40	3.00	-358.73	456.31
	26.167	2.40	3.00	-358.73	456.31
	27.000	2.40	3.00	-358.73	456.31

Calculations

- Beam Analyzed in spBeam
- Sized Beam Cross Checked With Scheduled Beam
- Scheduled Beam Well Oversized
- Beam Holds New Load

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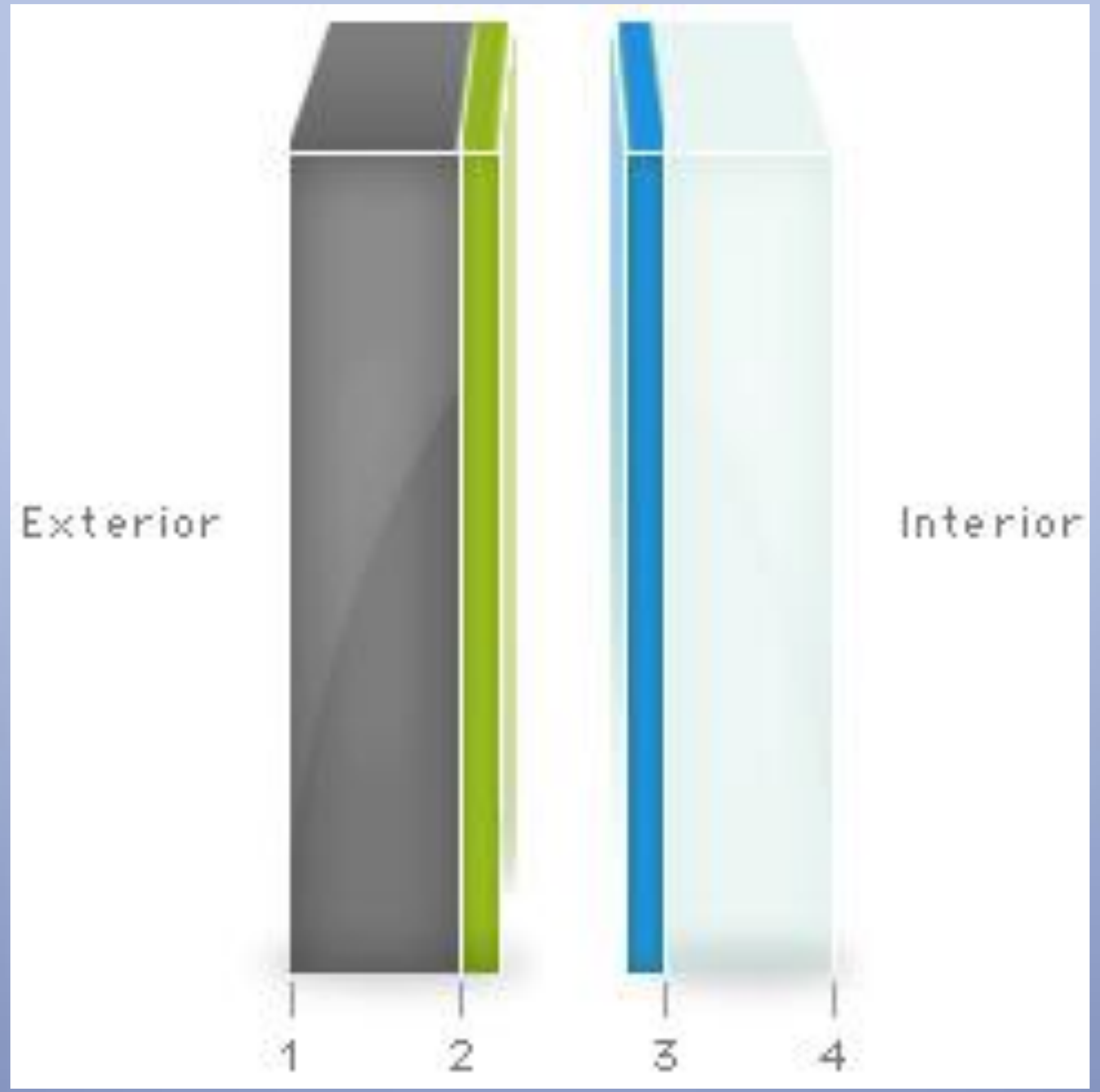

Installing Solarban 70XL Glass

- Calculate Total Amount of Glazing
- Calculate Cost of Glazing
- Analyze Glazing Properties
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Fenestration Area			
Floor	Glass (SF)	Gross Wall (SF)	Percentage Glass
Lower Level:	736	12992	6
First Floor:	3842	12643	30
Second Floor:	2630	7462	35
Overall Total:	**7208**	**33096**	**22**

Total Glazing

- Review Architectural Drawings

Installing Solarban 70XL Glass

- Calculate Total Amount of Glazing
- Calculate Cost of Glazing
- Analyze Glazing Properties
- Results

Type	Cost/SF	Total SF	Cost
1" clear/clear	$4.95	7208	$35,679.60
1" Solarban 60	$6.45	7208	$46,491.60
1" Solarban 70 XL	$7.45	7208	$53,699.60

	1" Solarban 70 XL	1" Solarban 60	1" clear/clear
1st Floor	$5,483.20	$4,747.20	$3,643.20
2nd Floor	$28,622.90	$24,780.90	$19,017.90
3rd Floor	$19,593.50	$16,963.50	$13,018.50
Total	$53,699.60	$46,491.60	$35,679.60

Cost

- Multiply Glass SF By $/SF
- Analyze 3 Types of Glass

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Glass	U-Value	Shading Coefficient
Installed	0.588	0.811
Solarban 60	0.29	0.44
Solarban 70XL	0.26	0.27

Performance

- Installed Values Obtained From Drawings
- Upgraded Values Obtained From PPG Industries

Installing Solarban 70XL Glass

- Calculate Total Amount of Glazing
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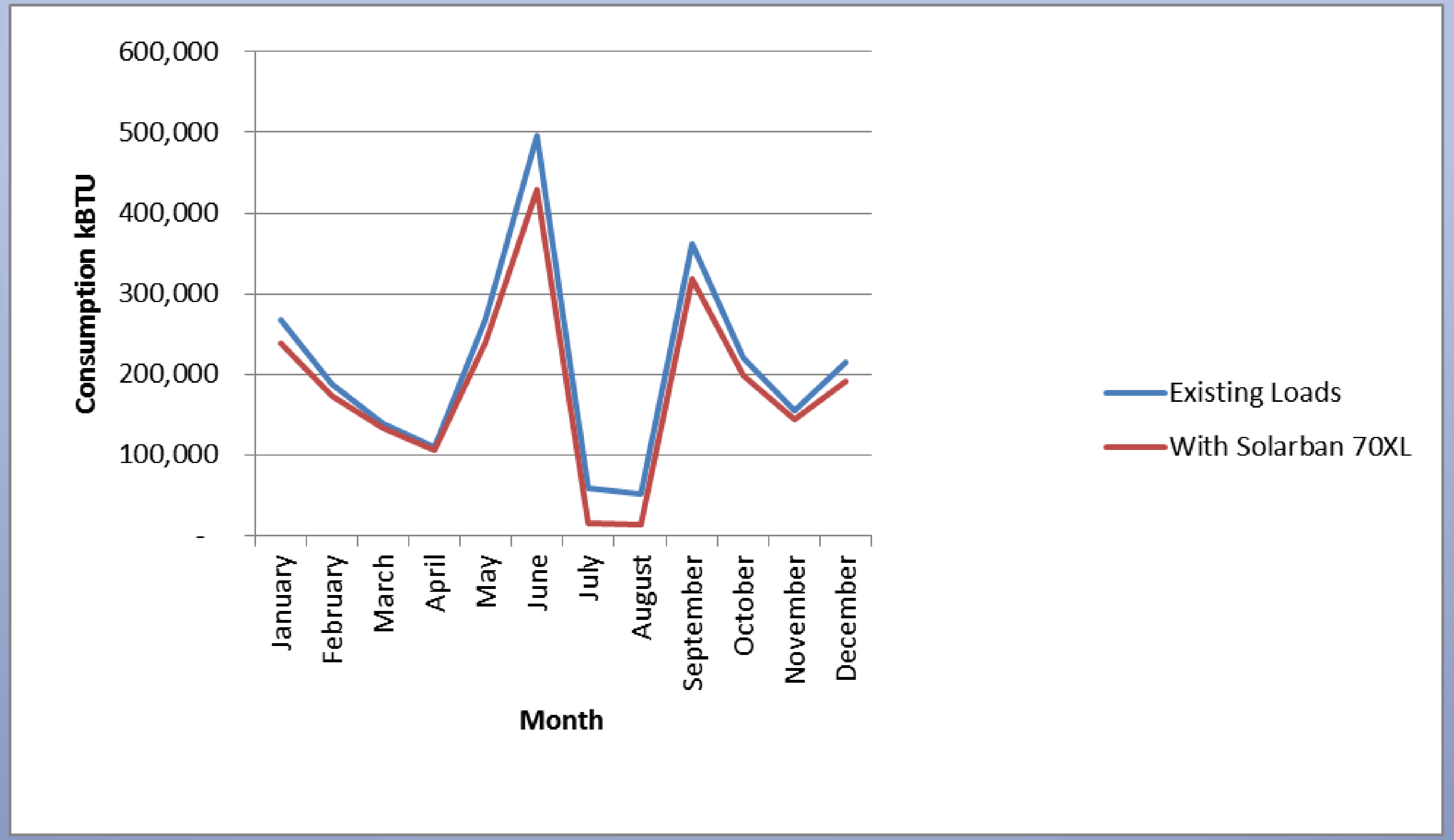
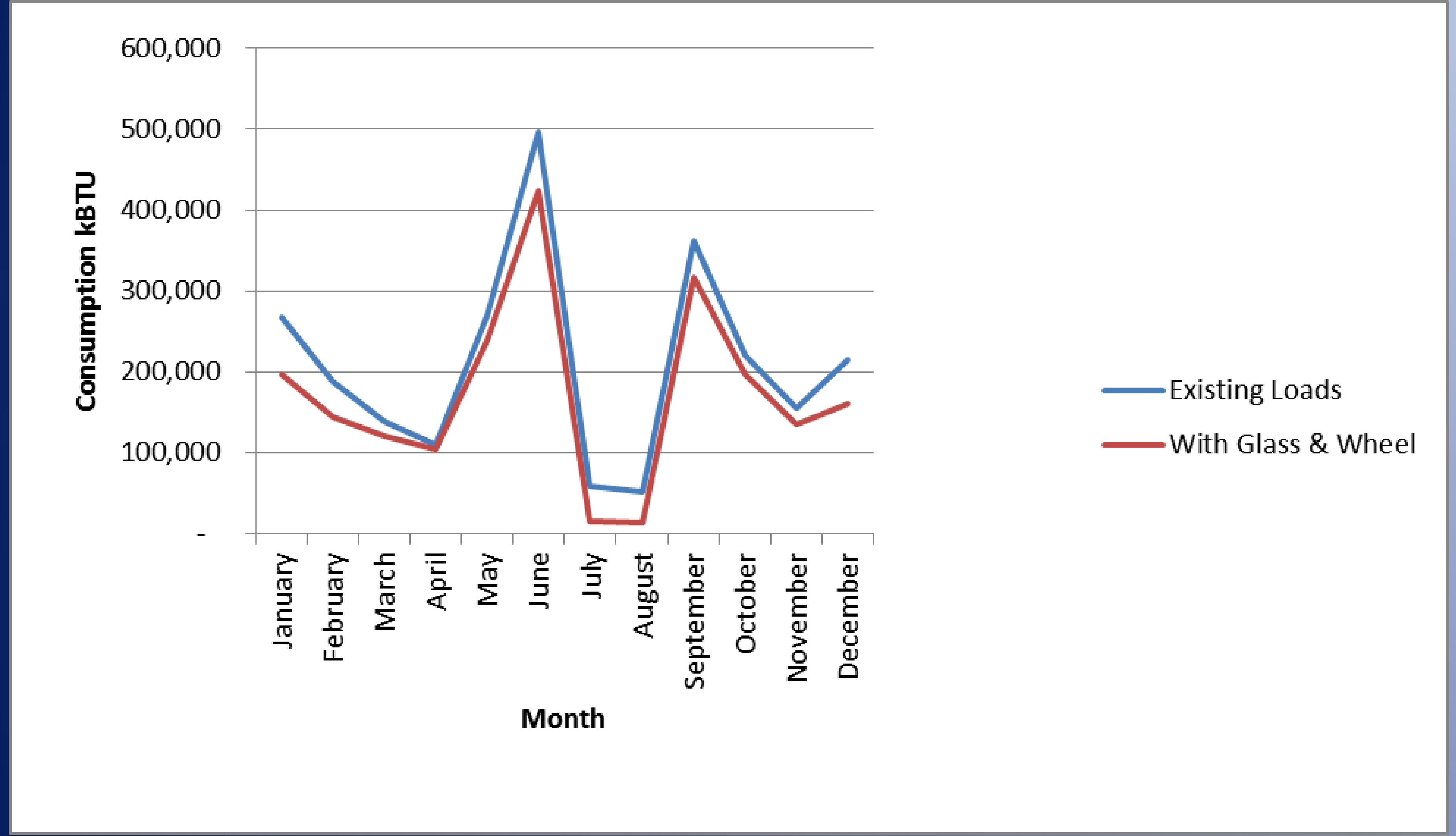
- Results



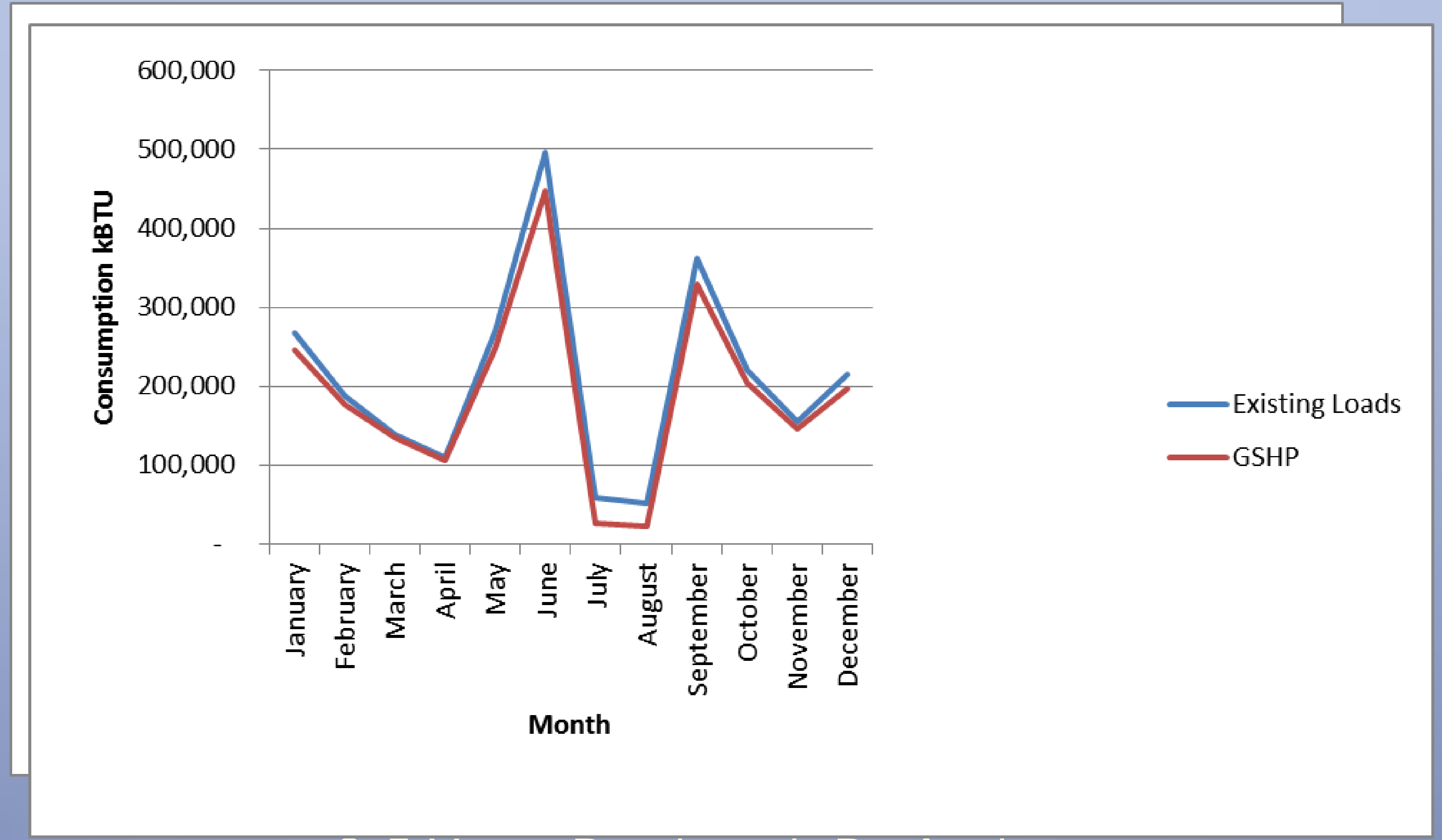
Energy Savings

- 6.6 % Annual Heating Savings
- 16.7 % Annual Cooling Savings
- 13 % Total Annual Energy Savings

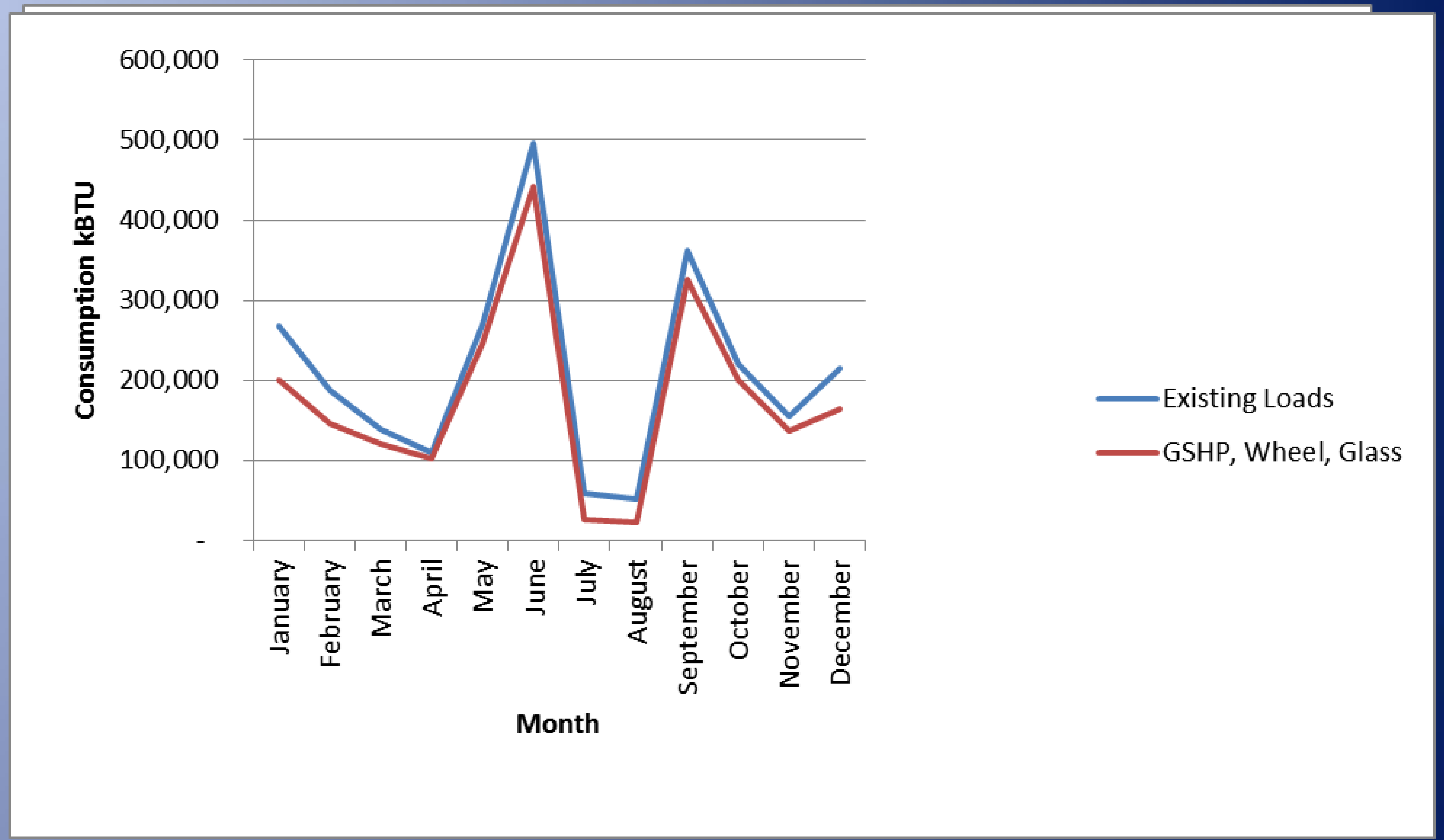
Presentation Outline



2.5 Year Payback Period



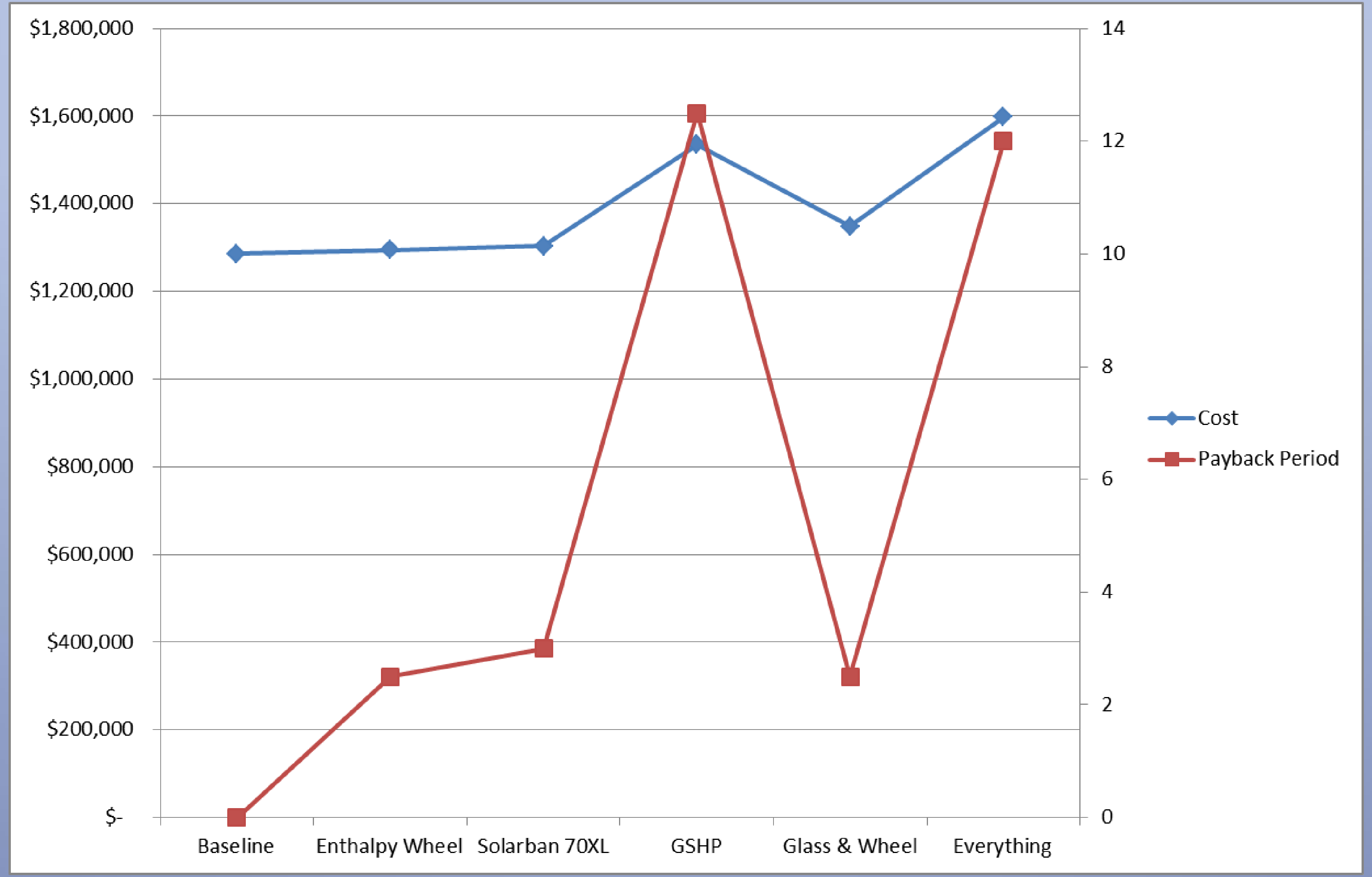
2.5 Year Payback Period
12.5 Year Payback Period



3 Year Payback Period
12 Year Payback Period

Presentation Outline

- Project Background
- Existing Mechanical Summary
- Design Objectives
- Alternative Descriptions
- Ground Source Heat Pumps
- Enthalpy Wheel
- Solarban 70XL Glass
- System Comparison
- **Final Recommendations**



Final Recommendations

- Maximize Distance Between Cost & Payback Period
- Analyze Owner's Intentions
- Make Suggestion

Special Thanks To:

- Justin Bem
- Dr. Bahnfleth
- Penn State AE Mechanical Faculty
- Family & Friends

Questions Or Comments