- **Introduction**
- University Medical Center of Princeton Overview
    - Building
    - Current systems
- Goals
- Depth
    - Replace HRUs with GSHP/GHX
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    - Implement Micro Steam Turbines
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- Summary and Highlights
- Appendices

University Medical Center of Princeton Replacement Hospital

Turner

PENNSTATE

Timothy Berteotti

Pennsylvania State University
Architectural Engineering Department

Mechanical Option

Advisor: Dr. Treado

May 9, 2012

Princeton Health Care Systems

PENNSTATE *University Medical Center of Princeton*

Timothy Berteotti • Mechanical Option • Dr. Treado

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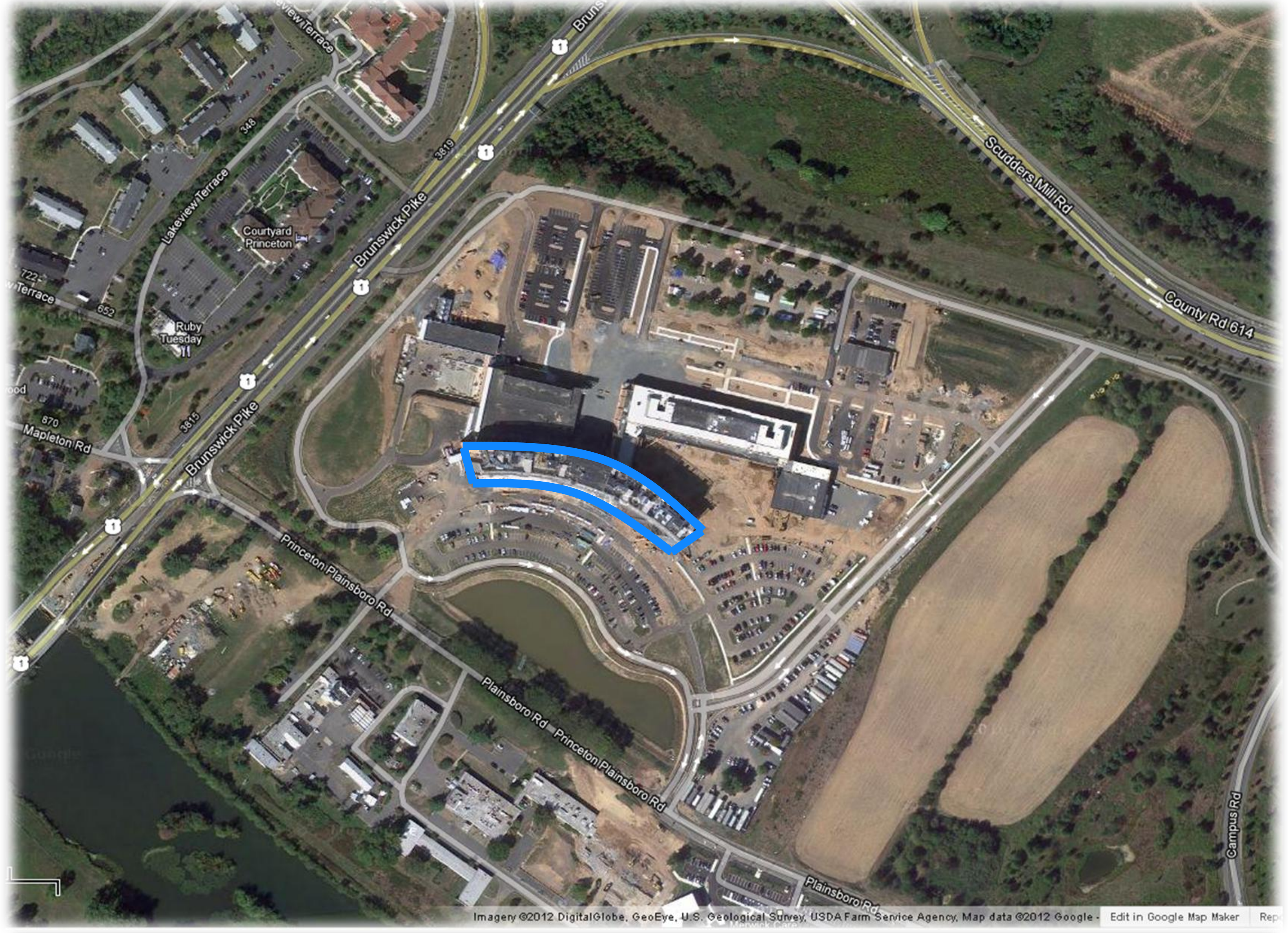
Building Stats

- Princeton Healthcare Systems
- Turner Construction
- Plainsboro, NJ
- 639,000 SF Total
- $425 Million
- May 2012
- Patient Tower
  - 269 Patient Rooms
- D&T
- Building 2

Princeton Health Care Systems



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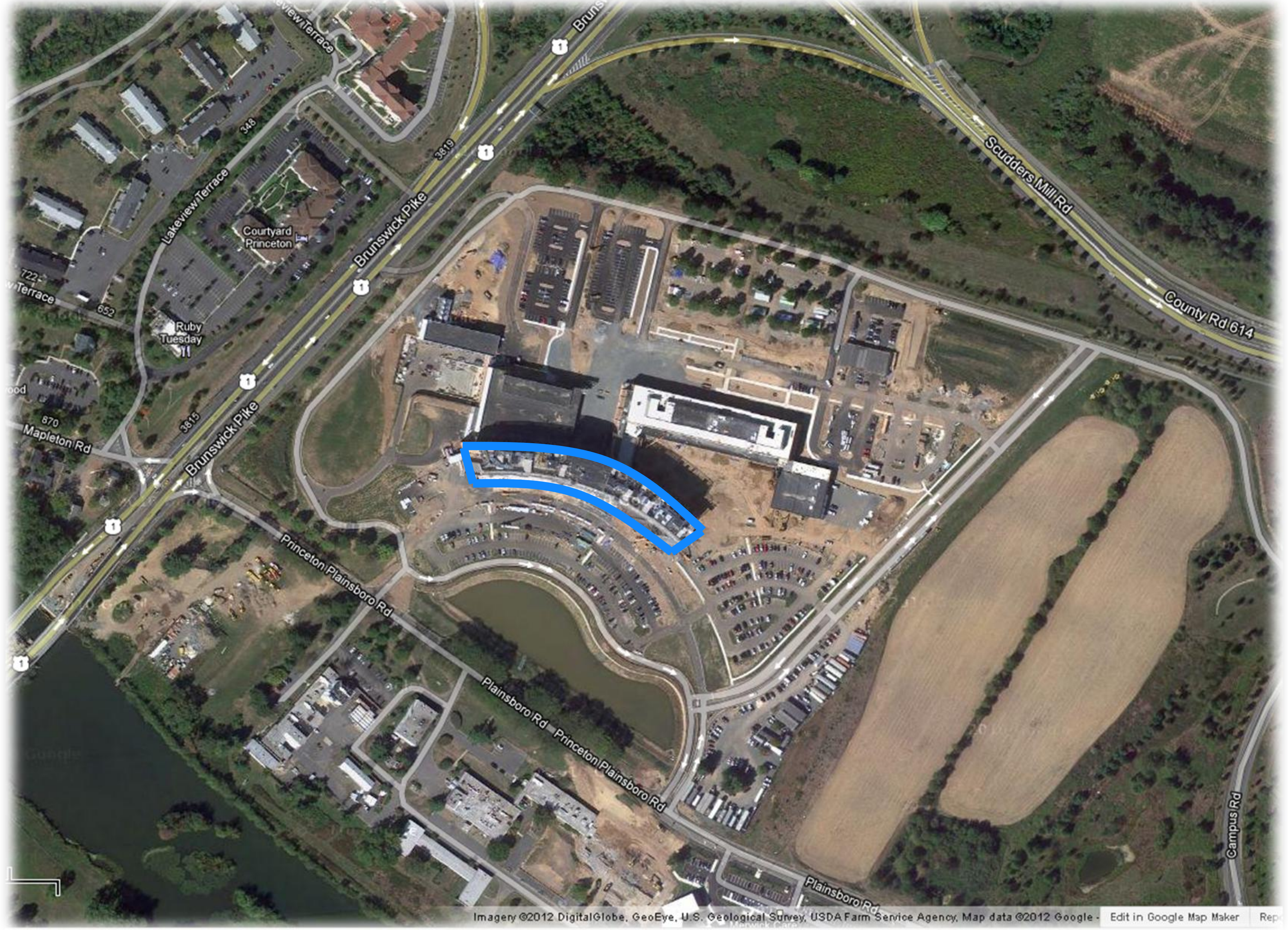
Princeton Health Care Systems



googlemaps.com

Current System

- CUP

Solar Mars 90 Combustion Gas Turbine						
Fuel Input (MMBH)	Electrical Output (MW)	Steam Output Unfired (kpph)	Steam Output Fired (kpph)	**Electrical Efficiency**	**Thermal Efficiency Unfired**	**Total Efficiency Unfired**
100.4	9.5	46.8	113.3	**32%**	**56%**	**88%**

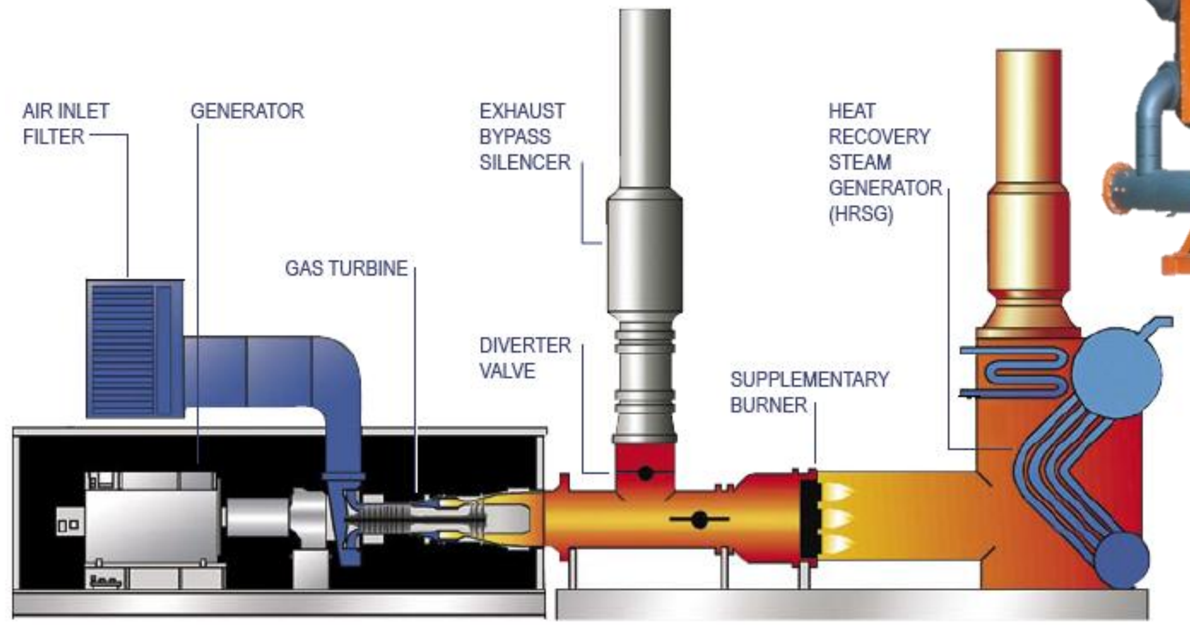
CUP

- Chilled Water
- 150 psi Steam
- Electricity

Steam

- 150 psi → 15 psi
- Domestic HW
- Heating HW
- Sterilization

masdar.daralriyadh.com



Solar.com

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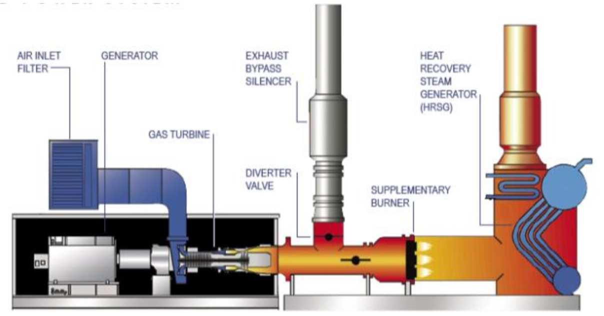
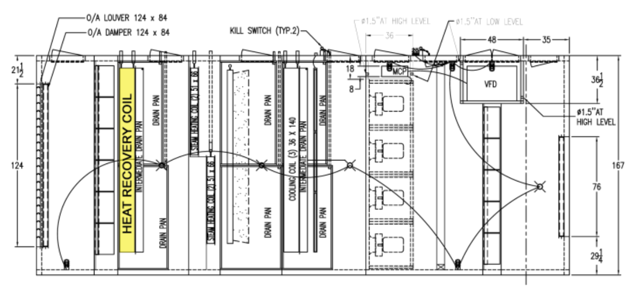
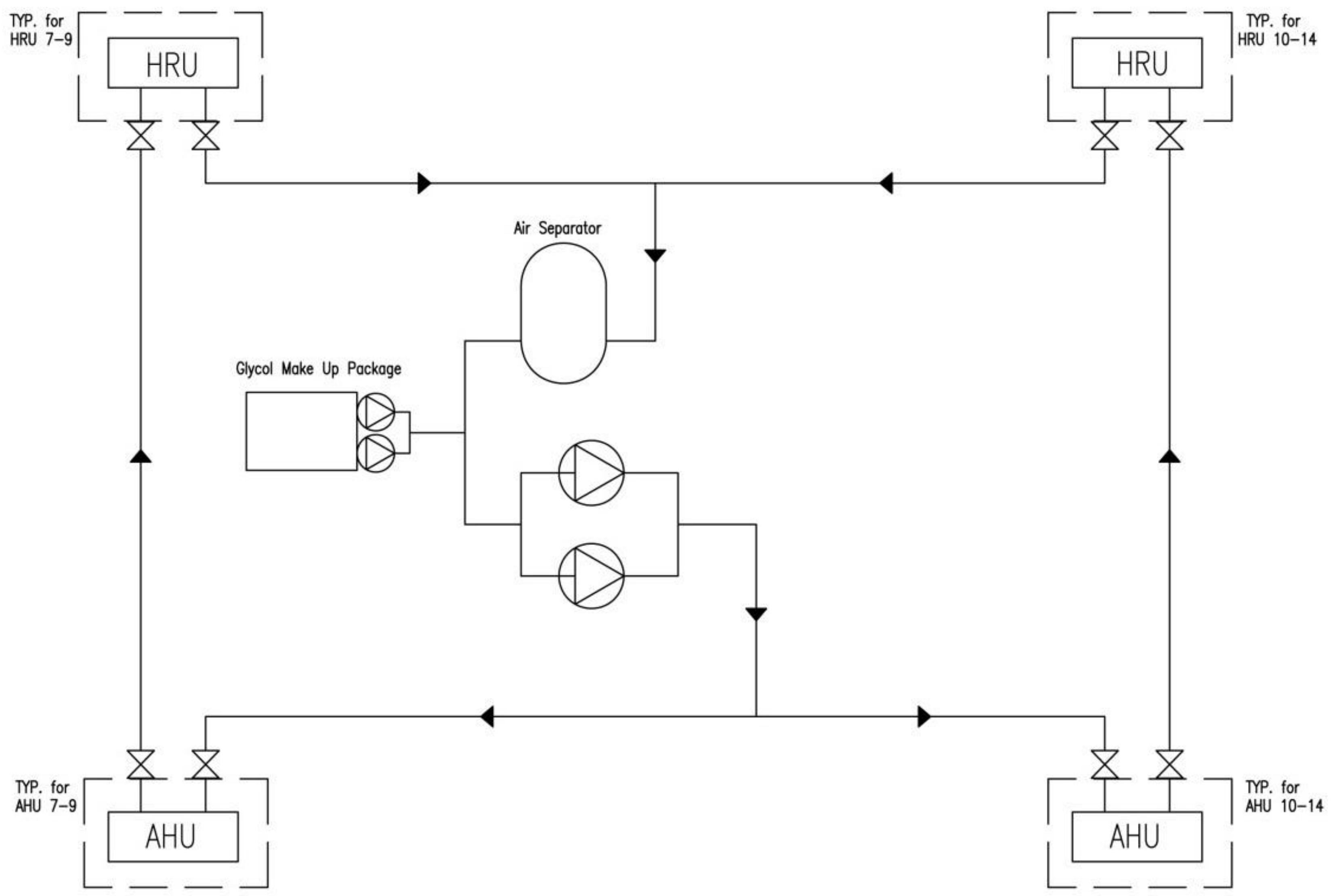
Current System

- CUP
- 8 Roof Top AHU
- CAV and VAV with Reheat
- HRU







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- CUP
- 8 Roof Top AHU
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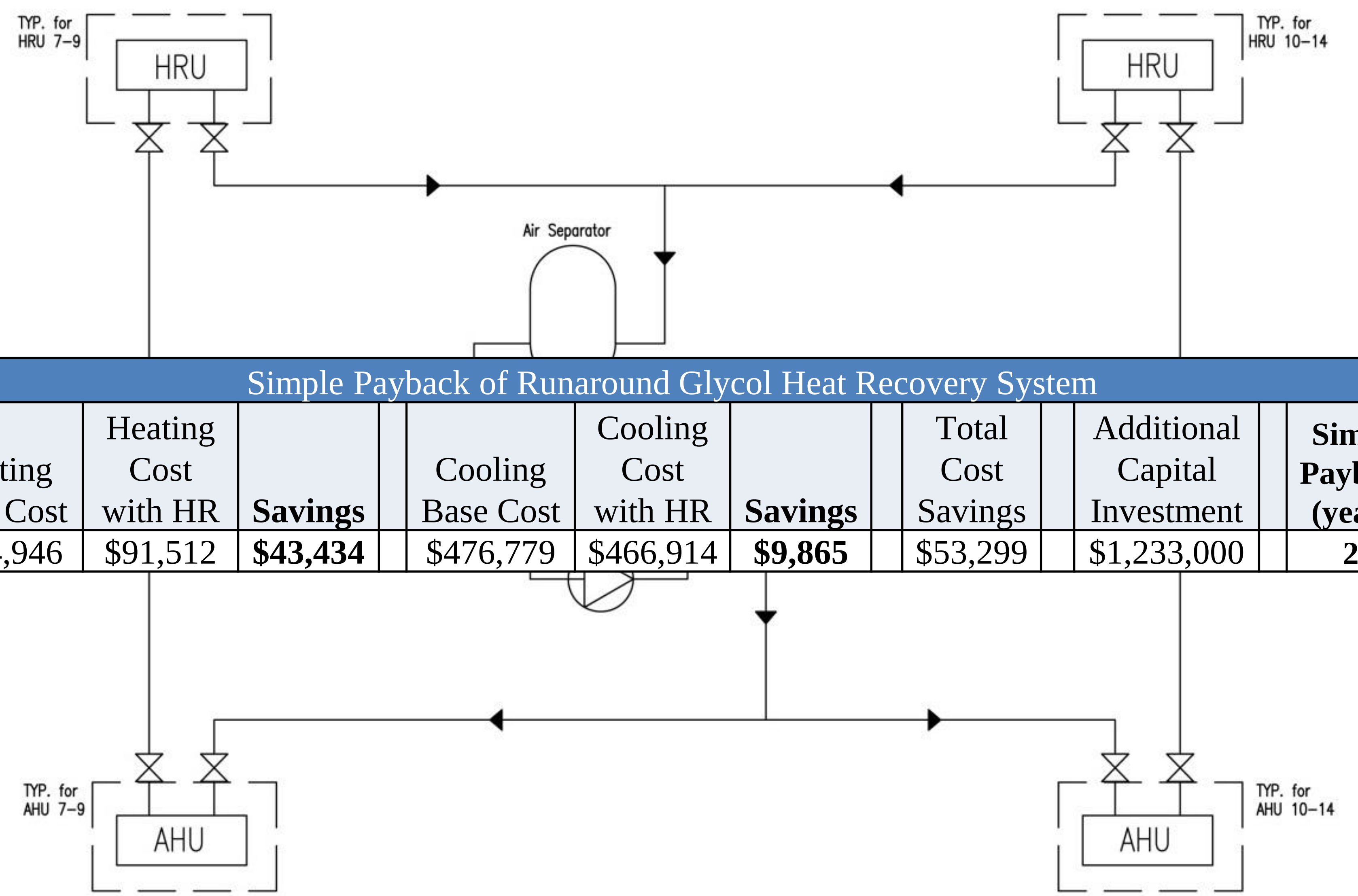
- HRU

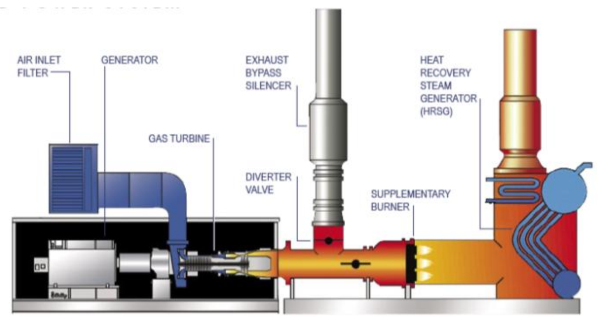
Peak Heating and Cooling Savings from HR

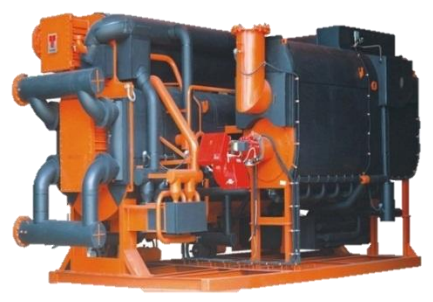
Heating Base Load (MBH)	Load With HR (MBH)	**Savings (MBH)**		Cooling Base Load (Tons)	Load with HR (Tons)	**Savings (Tons)**
10,537	5,431	**5,106**		1,431	1,424	**7**

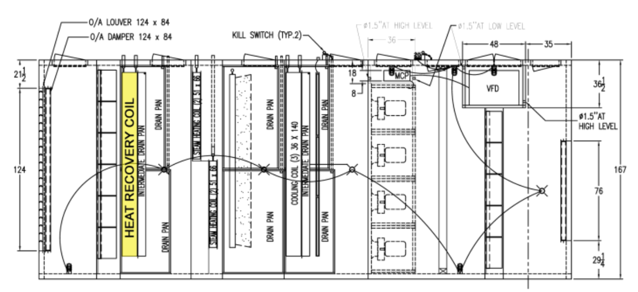


Simple Payback of Runaround Glycol Heat Recovery System

Heating Base Cost	Heating Cost with HR	**Savings**		Cooling Base Cost	Cooling Cost with HR	**Savings**		Total Cost Savings		Additional Capital Investment	**Simple Payback (years)**
$134,946	$91,512	**$43,434**		$476,779	$466,914	**$9,865**		$53,299		$1,233,000	**23**







PHS Design Objectives

- Optimum Healing Environment
- Improved Performance
- Environmental Responsibility

Project Objectives

- Provide Alternative
- Discover Unique Options
- Compare Energy/Cost

Electrical Breadth

Redesign of Power Distribution

Acoustical Breadth

Evaluate Current Room Acoustics
Recommend Solution

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Size heat pump to match precooling load
Need one 8 Ton

Size to match water flow of 900 gpm
need 13 in parallel
Additional 367 Tons Peak Cooling Savings

Size to match preheating
Need 30 units

What if no HP and only GHX?

Lc = 25,637 ft / HP => 333,281 feet total

8,008 MBH Heating Capacity

Additional 2,902 MBH Peak Heating Savings

Peak Heating and Cooling Savings from HR						
Heating Base Load (MBH)	Load With HR (MBH)	**Savings (MBH)**		Cooling Base Load (Tons)	Load with HR (Tons)	**Savings (Tons)**
10,537	5,431	**5,106**		1,431	1,424	**7**

SOURCE COIL				LOAD COIL																					
					Flow 35.0 gpm							Flow 53.0 gpm							Flow 70.0 gpm						
EWT (F)	gpm	Pressure Drop psig	Pressure Drop ft wg	EWT (F)	TC (MBtuh)	Power (kW)	THR (MBtuh)	LWT (F)	EER	Pressure Drop psig	Pressure Drop ft wg	TC (MBtuh)	Power (kW)	THR (MBtuh)	LWT (F)	EER	Pressure Drop psig	Pressure Drop ft wg	TC (MBtuh)	Power (kW)	THR (MBtuh)	LWT (F)	EER	Pressure Drop psig	Pressure Drop ft wg
50	35	1.19	2.75	50	129.3	6.84	152.7	35.2	18.6	0.54	1.20	271.2	13.86	318.5	39.8	19.6	3.60	8.30	277.3	13.94	324.9	42.1	19.9	6.50	15.00
				60	141.0	6.90	164.5	43.9	20.1	0.30	0.70	294.1	13.92	341.6	48.9	21.1	3.44	7.94	299.9	13.97	347.5	51.4	21.5	6.18	14.28
				70	151.3	7.00	175.2	52.7	21.3	0.17	0.40	313.9	14.09	362.0	58.2	22.3	3.29	7.60	319.0	14.14	367.3	60.9	22.6	5.91	13.64
				80	160.2	7.08	184.4	61.7	22.4	0.15	0.30	330.2	14.24	378.8	67.5	23.2	3.15	7.28	334.5	14.28	383.2	70.4	23.4	5.67	13.09
				90	167.5	7.14	191.9	70.9	23.3	0.12	0.30	342.7	14.35	391.6	77.1	23.9	3.02	6.97	345.8	14.38	394.8	80.1	24.0	5.47	12.64
	53	3.59	8.30	50	131.1	6.34	152.8	35.0	20.2	0.54	1.20	275.0	12.76	318.5	39.6	21.5	3.60	8.30	281.1	12.80	324.8	42.0	22.0	6.50	15.00
				60	142.7	6.41	164.6	43.7	21.9	0.30	0.70	297.6	12.90	341.6	48.8	23.1	3.44	7.94	303.3	12.93	347.4	51.3	23.4	6.18	14.28
				70	152.9	6.47	175.0	52.5	23.3	0.17	0.40	316.8	13.01	361.2	58.0	24.3	3.29	7.60	321.9	13.04	366.4	60.8	24.7	5.91	13.64
				80	161.6	6.53	183.8	61.5	24.5	0.15	0.30	332.6	13.11	377.4	67.4	25.4	3.15	7.28	336.8	13.13	381.6	70.4	25.6	5.67	13.09
				90	168.6	6.57	191.0	70.7	25.5	0.12	0.30	344.8	13.18	389.8	77.0	26.2	3.02	6.97	347.9	13.20	392.9	80.1	26.4	5.47	12.64
	70	6.50	15.02	50	131.7	6.12	152.6	35.0	21.1	0.54	1.20	276.2	12.30	318.2	39.6	22.5	3.60	8.30	282.4	12.33	324.5	41.9	22.9	6.50	15.00
				60	143.4	6.18	164.4	43.6	22.8	0.30	0.70	298.9	12.41	341.2	48.7	24.1	3.44	7.94	304.6	12.43	347.0	51.3	24.5	6.18	14.28
				70	153.5	6.22	174.8	52.5	24.3	0.17	0.40	318.1	12.50	360.7	58.0	25.5	3.29	7.60	323.1	12.52	365.8	60.8	25.8	5.91	13.64
				80	162.2	6.26	183.5	61.5	25.6	0.15	0.30	333.7	12.57	376.6	67.4	26.6	3.15	7.28	337.8	12.59	380.8	70.3	26.8	5.67	13.09
				90	169.1	6.29	190.6	70.7	26.7	0.12	0.30	345.6	12.67	388.7	77.0	27.4	3.02	6.97	348.6	12.63	391.7	80.0	27.6	5.47	12.64
70	35	1.01	2.34	50	118.9	8.26	147.0	36.4	13.9	0.54	1.20	251.5	16.64	308.3	40.5	15.1	3.60	8.30	258.3	16.70	315.3	42.6	15.5	6.50	15.00
				60	132.6	8.38	161.2	44.8	15.4	0.30	0.70	279.0	16.88	336.6	49.5	16.5	3.44	7.94	285.6	16.94	343.4	51.8	16.9	6.18	14.28
				70	144.9	8.49	173.9	53.4	16.7	0.17	0.40	302.7	17.10	361.1	58.6	17.7	3.29	7.60	308.7	17.15	367.2	61.2	18.0	5.91	13.64
				80	155.5	8.59	184.8	62.2	17.8	0.15	0.30	322.2	17.27	381.1	67.8	18.7	3.15	7.28	327.1	17.32	386.2	70.7	18.9	5.67	13.09
				90	164.0	8.66	193.6	71.3	18.7	0.12	0.30	336.8	17.40	396.2	77.3	19.4	3.02	6.97	340.3	17.43	399.8	80.3	19.5	5.47	12.64
	53	3.29	7.60	50	122.4	7.84	149.1	36.0	15.1	0.54	1.20	258.4	15.76	312.2	40.2	16.4	3.60	8.30	265.2	15.80	319.1	42.4	16.8	6.50	15.00
				60	135.7	7.92	162.7	44.5	16.7	0.30	0.70	284.8	15.91	339.1	49.3	17.9	3.44	7.94	291.2	15.95	345.6	51.7	18.3	6.18	14.28
				70	147.5	7.99	174.7	53.1	18.1	0.17	0.40	307.3	16.04	362.1	58.4	19.2	3.29	7.60	313.0	16.08	367.9	61.1	19.5	5.91	13.64
				80	157.5	8.04	184.9	62.0	19.3	0.15	0.30	325.5	16.15	380.6	67.7	20.2	3.15	7.28	330.1	16.17	385.3	70.6	20.4	5.67	13.09
				90	165.4	8.09	193.0	71.1	20.2	0.12	0.30	338.9	16.23	394.2	77.2	20.9	3.02	6.97	341.9	16.24	397.4	80.2	21.1	5.47	12.64
	70	5.91	13.64	50	124.0	7.64	150.0	35.8	15.7	0.54	1.20	261.5	15.34	313.9	40.1	17.0	3.60	8.30	268.2	15.37	320.6	42.3	17.5	6.50	15.00
				60	137.0	7.70	163.3	44.3	17.4	0.30	0.70	287.3	15.45	340.0	49.2	18.6	3.44	7.94	293.6	15.48	346.4	51.6	19.0	6.18	14.28
				70	148.5	7.75	175.0	53.0	18.8	0.17	0.40	309.2	15.55	362.3	58.3	19.9	3.29	7.60	314.8	15.57	367.9	61.0	20.2	5.91	13.64
				80	158.3	7.79	184.9	61.9	20.0	0.15	0.30	326.9	15.62	380.2	67.7	20.9	3.15	7.28	331.4	15.64	384.8	70.5	21.2	5.67	13.09
				90	166.1	7.82	192.7	71.0	21.0	0.12	0.30	339.9	15.68	393.4	77.2	21.7	3.02	6.97	343.0	15.69	396.5	80.2	21.9	5.47	12.64
				50	106.2	9.76	139.4	37.9	10.3	0.54	1.20	225.8	19.64	292.8	41.5	11.5	3.60	8.30	232.6	19.71	299.8	43.4	11.8	6.50	15.00
				60	121.2	9.90	154.9	46.2	11.7	0.30	0.70	256.2	19.94	324.3	50.3	12.8	3.44	7.94	263.1	20.01	331.4	52.5	13.1	6.18	14.28
	35	0.86	2.03	70	134.8	10.04	169.1	54.6	13.0	0.17	0.40	283.6	20.22	352.6	59.3	14.0	3.29	7.60	290.4	20.28	359.6	61.7	14.3	5.91	13.64

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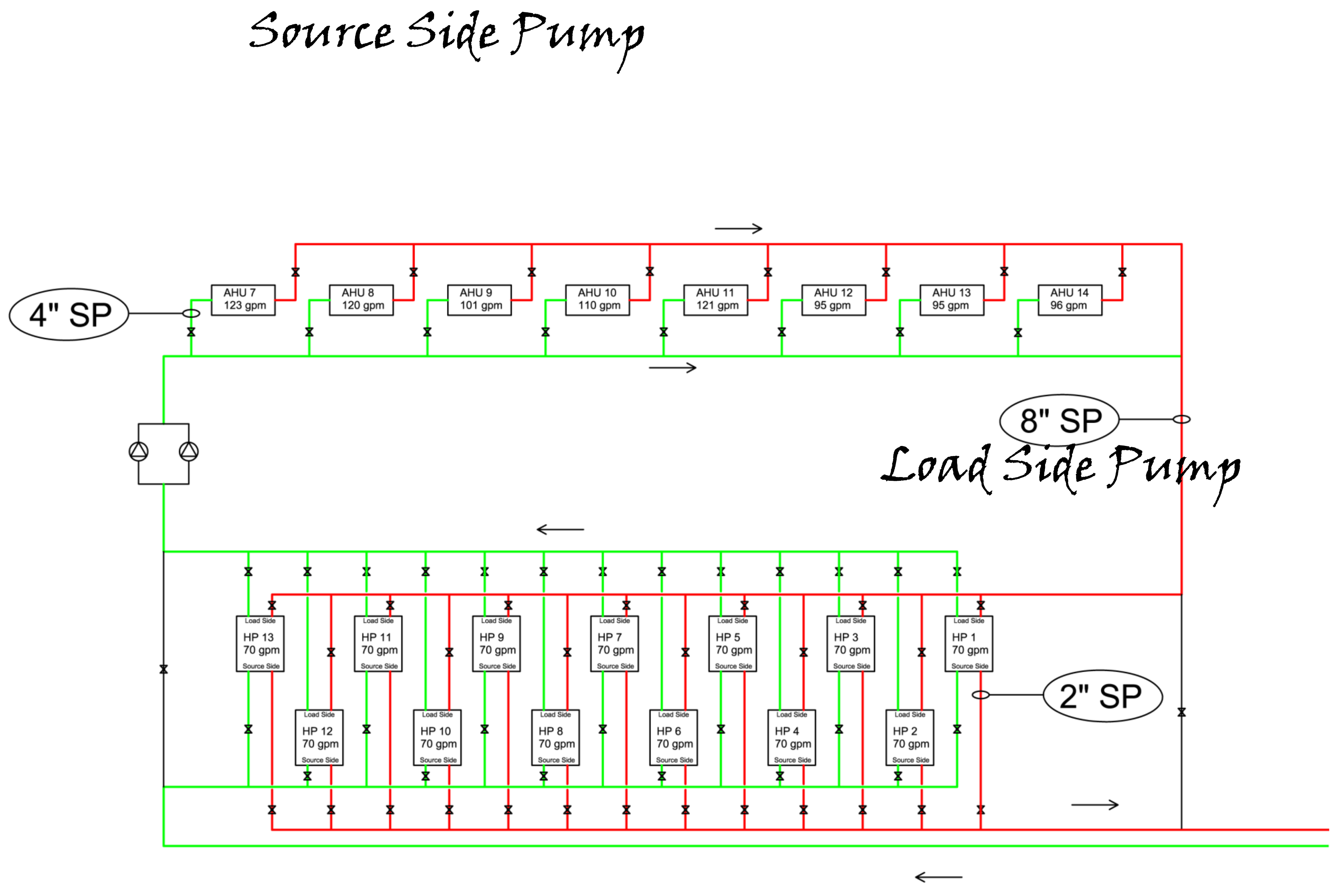

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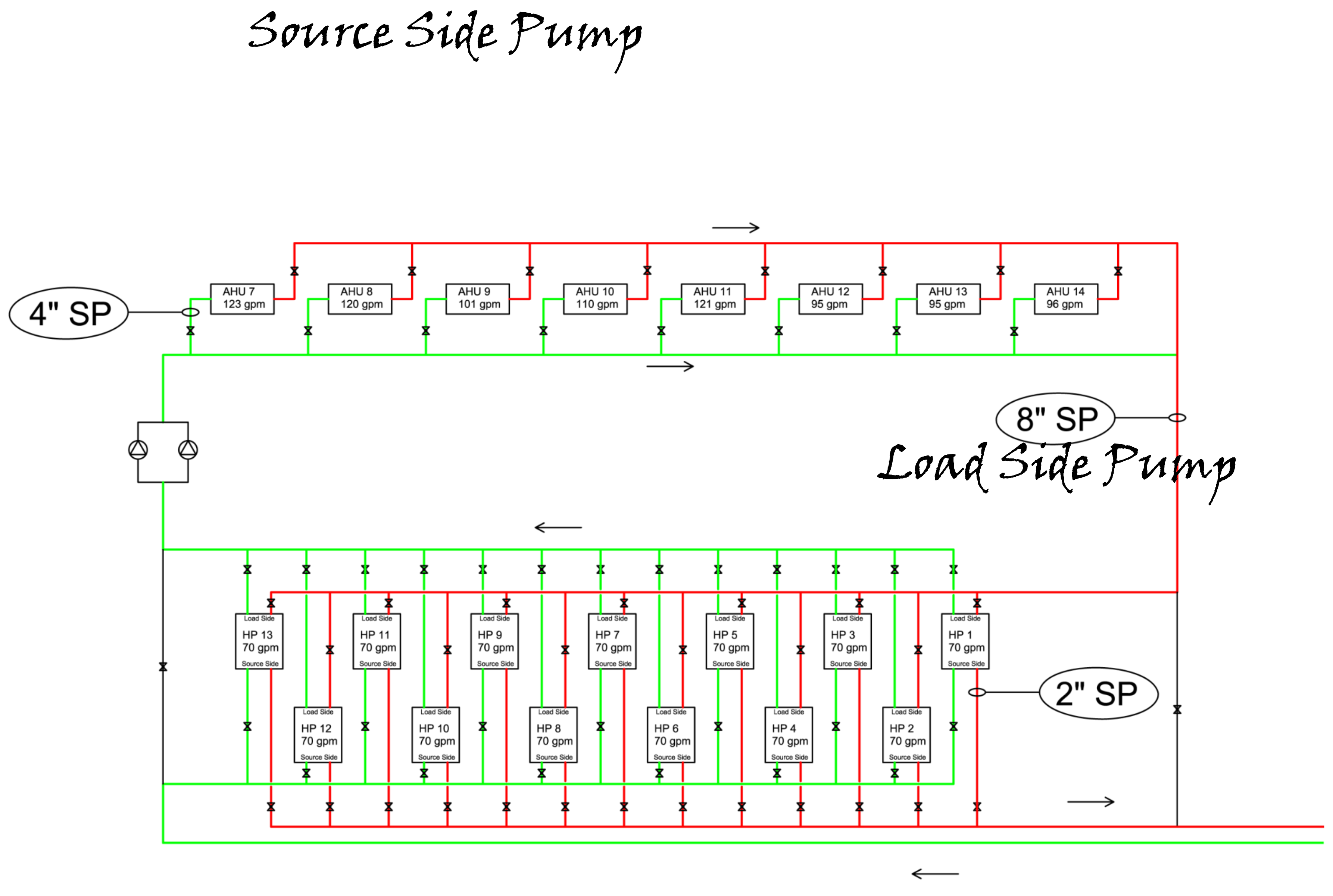

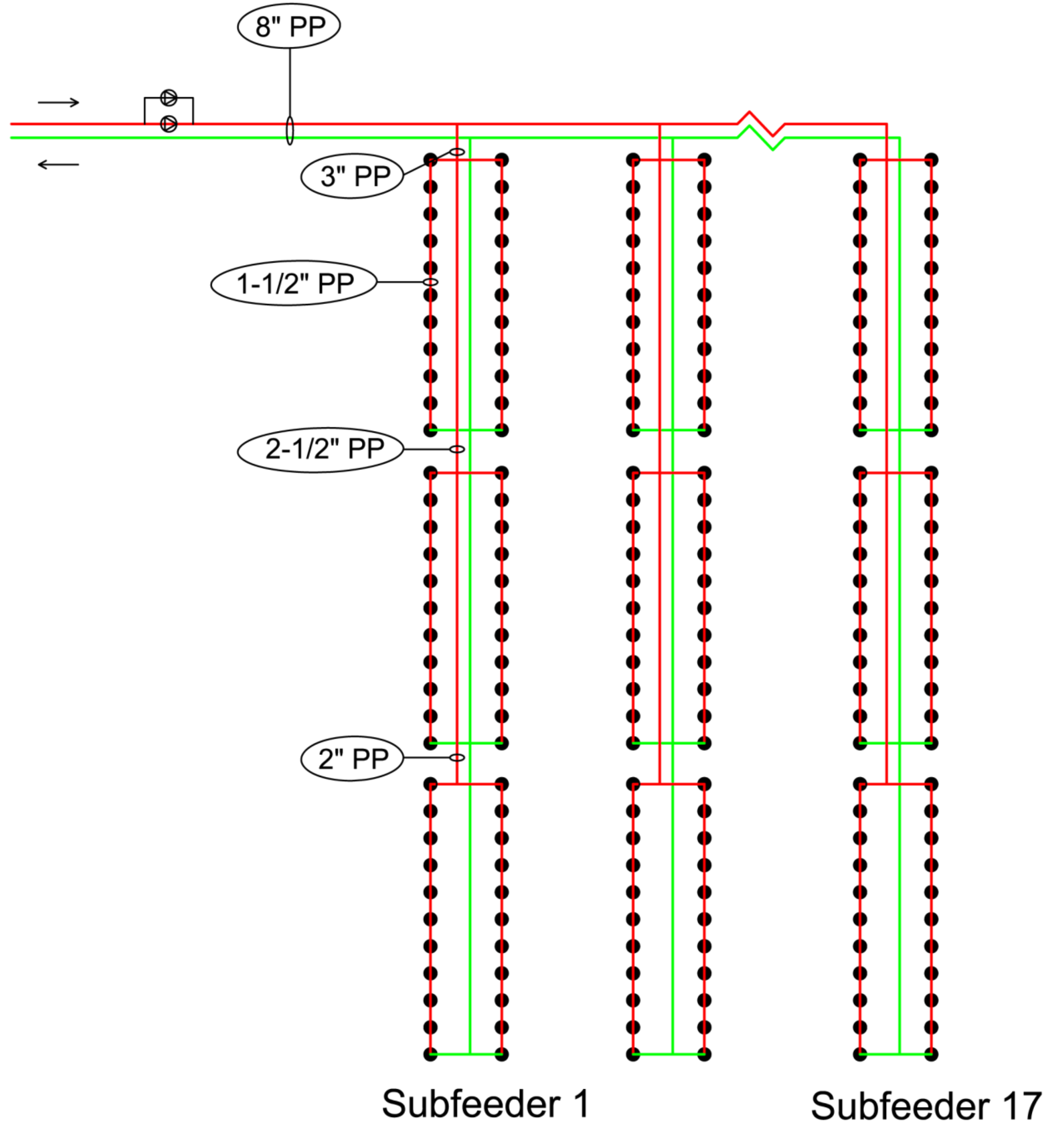

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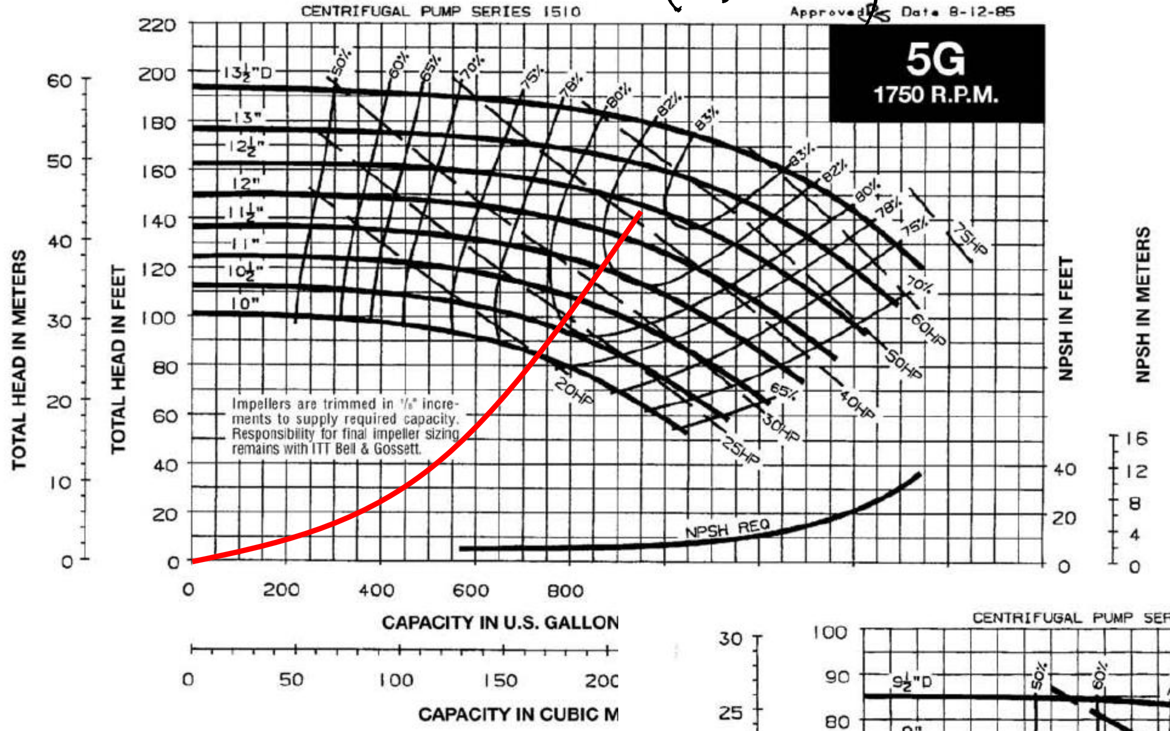
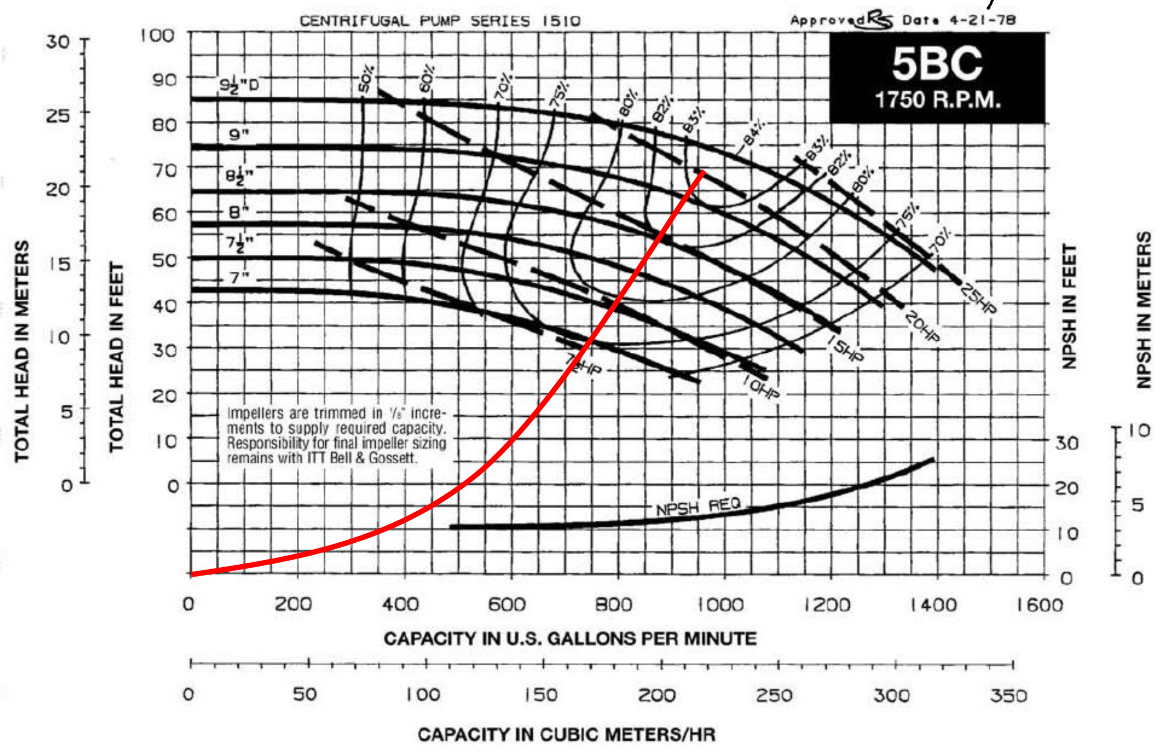
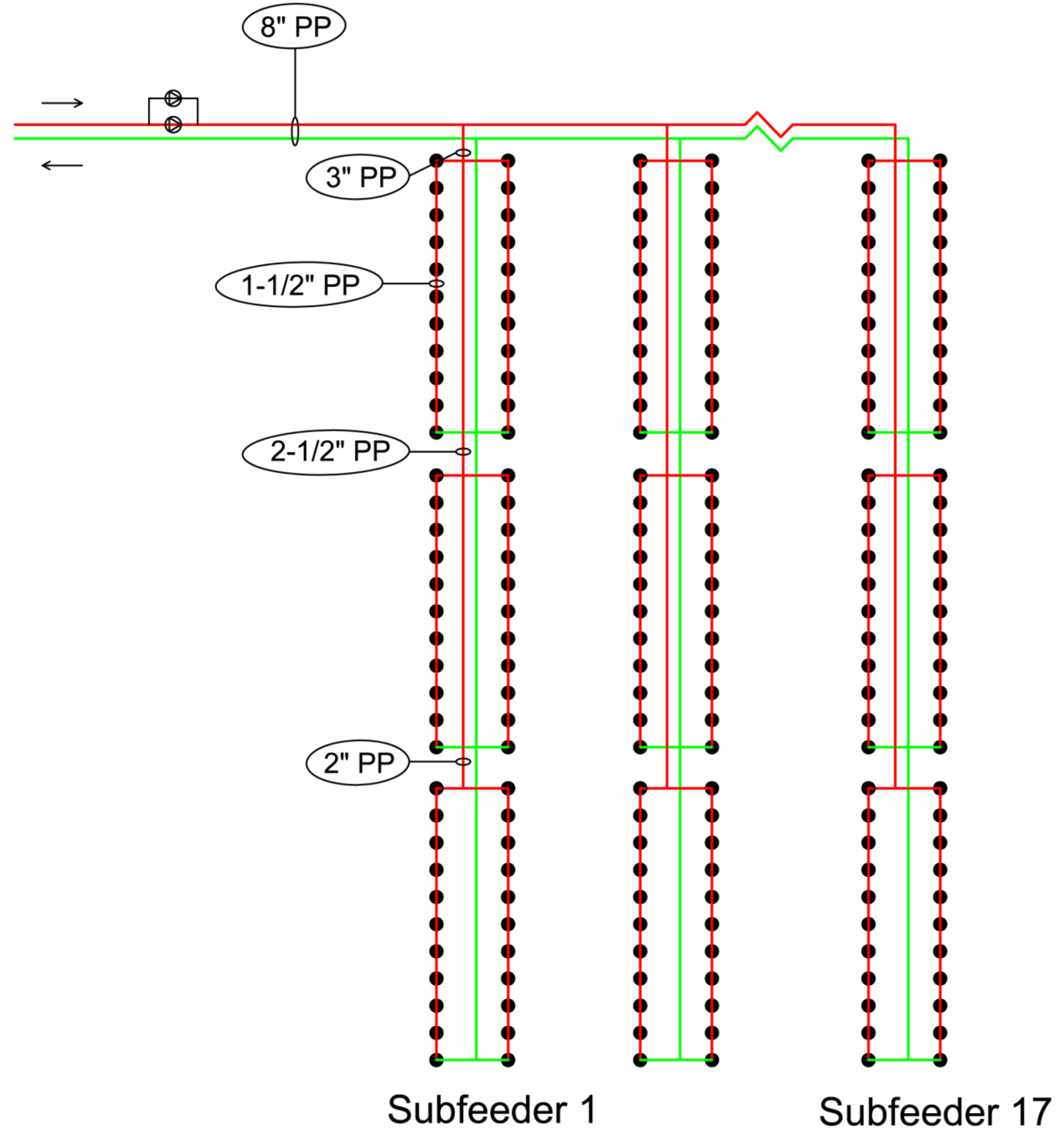
Source Side Pump



Load Side Pump





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EES to calculate hourly energy savings

$\dot{V}_H = 123$ [gal/min] $\cdot \left| 0.1337 \cdot \frac{ft^3}{gal} \right|$ *Volumetric Flow rate of Water*

$p = 14.7$ [psi] *Atmospheric pressure in psi*

$T_{C,in} = 11$ [F] *Entering Air DB Temperature*

$\dot{V}_C = 46000$ [ft^3/min] *Volumetric Flow rate of Air*

$U = 681.5$ [BTU/hr·ft^2·F] *Heat Transfer coeficient*

$A = 105$ [ft^2] *Total face area*

$\rho_H = \rho$['Water' , $T = T_{H,in}$, $P = p$] *Water Density as defined by EES tables*

$\dot{m}_H = \rho_H \cdot \dot{V}_H \cdot \left| 60 \cdot \frac{min}{hr} \right|$ *Water mass flow rate*

$\rho_C = \rho$['Air' , $T = T_{C,in}$, $P = p$] *Air Density*

$\dot{m}_C = \rho_C \cdot \dot{V}_C \cdot \left| 60 \cdot \frac{min}{hr} \right|$ *Air mass flow rate*

//Must guess outlet temperatures to be able to calculate specific heat capacities. These values will be commented out once evaluated once

//Based on a precooling delta T estimate of 7 degrees F for water and 8 degrees F for air

c_H = **Cp** $\left[\text{'Water'}, T = \frac{T_{H,in} + T_{H,out}}{2}, P = p \right]$ *Specific Heat Capacity of Water*

c_C = **Cp** $\left[\text{'Air'}, T = \frac{T_{C,in} + T_{C,out}}{2} \right]$ *Specific heat capacity of Air*

$\dot{C}_H = \dot{m}_H \cdot c_H$

$\dot{C}_C = \dot{m}_C \cdot c_C$

$\dot{C}_{min}$ = **Min** [$\dot{C}_C$, $\dot{C}_H$] *min capacitance rate*

$\dot{C}_{max}$ = **Max** [$\dot{C}_C$, $\dot{C}_H$] *max capacitance rate*

$NTU = \frac{U \cdot A}{\dot{C}_{min}}$ *number of transfer units*

ε = **HX** ['crossflow$_{both,unmixed}$' , NTU , $\dot{C}_C$, $\dot{C}_H$, 'epsilon'] *Access effectiveness-NTU solution*

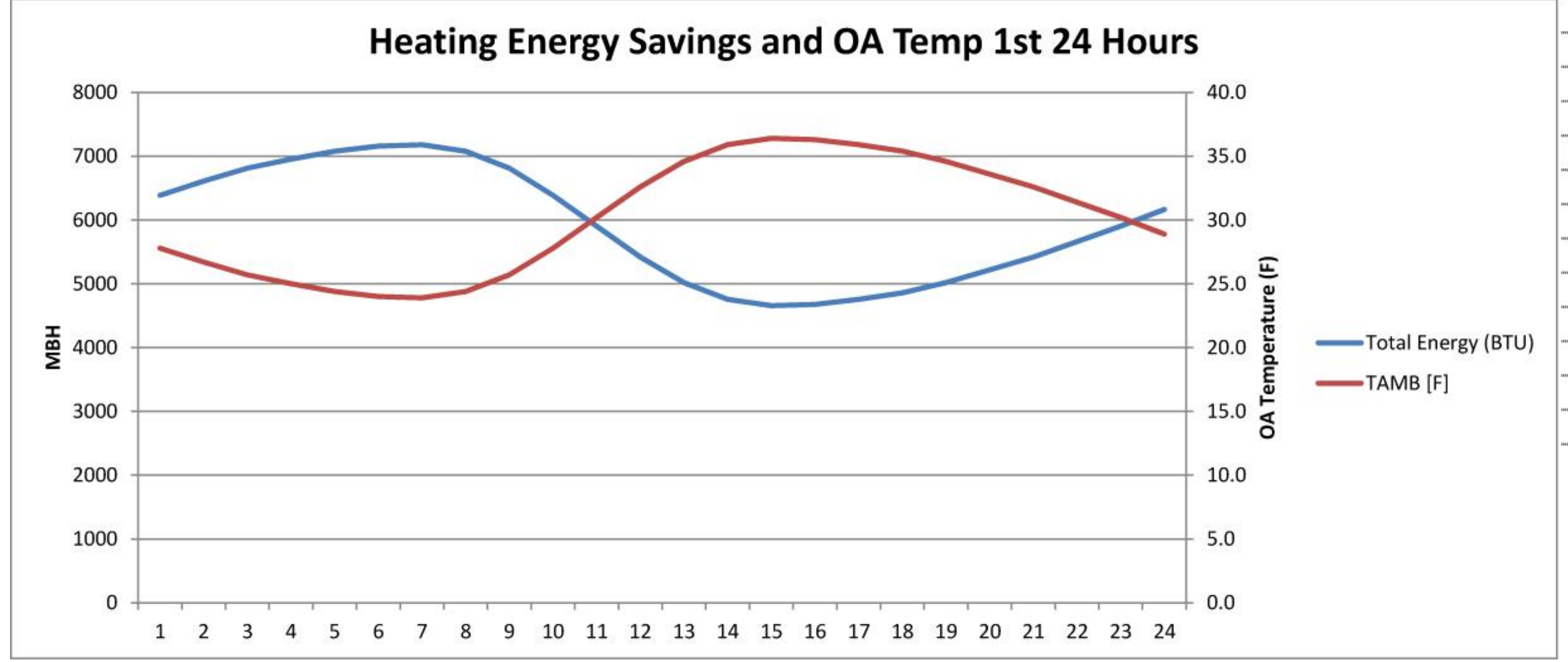
$\dot{q}_{max} = \dot{C}_{min} \cdot [T_{H,in} - T_{C,in}]$ *Max possible heat transfer rate*

$\dot{q} = \dot{q}_{max} \cdot \varepsilon$ *Actual Heat Transfer rate*

$T_{C,out} = T_{C,in} + \frac{\dot{q}}{\dot{C}_C}$ *Air exit temp*

$T_{H,out} = T_{H,in} - \frac{\dot{q}}{\dot{C}_H}$ *Water exit temp*

Hour of Year	TAMB [F]	AHU - 7	AHU - 8	AHU - 9	AHU - 10	AHU - 11	AHU - 12	AHU - 13	AHU - 14		Total Energy (BTU)
1	27.8	959412	1.01E+06	744807	839189	1.01E+06	663101	663101	502921		6386531
2	26.7	992850	1.04E+06	770787	868389	1.04E+06	686267	686267	520596		6609156
3	25.7	1.02E+06	1.08E+06	794437	894965	1.07E+06	707357	707357	536693		6811809
4	25.0	1.04E+06	1.10E+06	811010	913586	1.10E+06	722136	722136	547978		6953846
5	24.4	1.06E+06	1.12E+06	825226	929557	1.12E+06	734815	734815	557661		7077074
6	24.0	1.08E+06	1.13E+06	834711	940211	1.13E+06	743274	743274	564122		7157592
7	23.9	1.08E+06	1.13E+06	837083	942875	1.13E+06	745389	745389	565738		7178474
8	24.4	1.06E+06	1.12E+06	825227	929558	1.12E+06	734815	734815	557661		7077076
9	25.7	1.02E+06	1.08E+06	794437	894965	1.07E+06	707356	707356	536693		6811807
10	27.8	959412	1.01E+06	744807	839189	1.01E+06	663101	663101	502921		6386531
11	30.2	886613	932020	688246	775605	929921	612678	612678	464472		5902233



Simple Payback for Heat Pump System to Base System

Energy Savings of GSHP and GHX and hours of Operation						
Peak Heating Capacity Peak (MBTU)	Annual Heating Savings (MBH)	Operating Hours		Peak Cooling Capacity (Tons)	Annual Cooling Savings (Tons)	Operating Hours
7,178.50	18,693,690	5,243		219	101,830	983

Alternative Heating Savings				Alternative Cooling Savings		
Annual Heating Savings (MBH)	Natural Gas Savings (Therms)	**NG Savings**		Annual Cooling Savings (Tons)	Natural Gas Savings (Therms)	**NG Savings**
18,693,690	333,816	**$65,428**		1,221,956	101,830	**$19,959**

Simple Payback for GSHP and GHX Alternative						
Total NG Savings	Operating Cost	**Total Cost Savings**		Additional Capital Investment		**Simple Payback (years)**
$85,387	$29,939	**$55,448**		$6,359,695		**115**

Compared to 23 for Glycol Runaround

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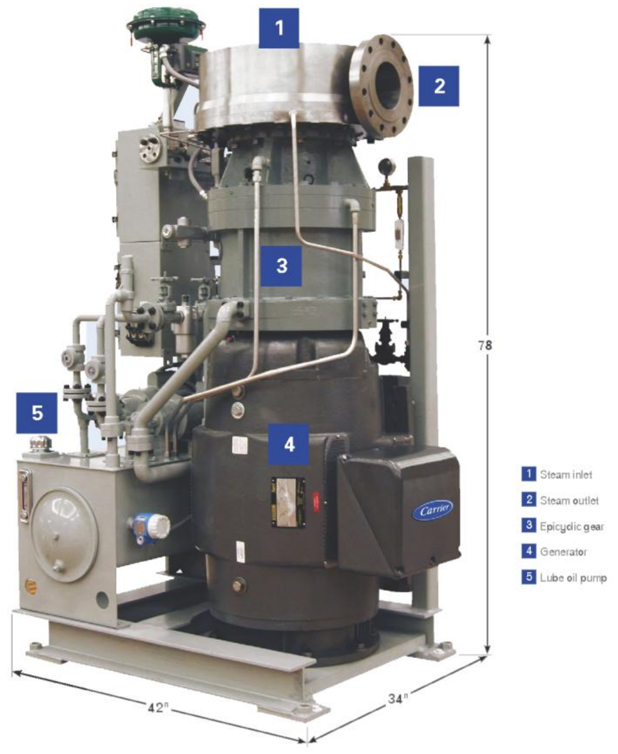

Carrier.com

Micro Steam Turbine

- Location of PRV
- Flow Rate
- Energy Output

- What to power?
- Paralleling Switchgear
- Transfer Switch

Annual Peak Savings
461 kW

Microsteam Turbine Design Criteria			
Inlet Pressure (psi)	Outlet Pressure (psi)	**Steam Flow Rate (lb/hr)**	Steam Temperature (°F)
150	15	**41,400**	365.87

Microsteam Turbine Performanc Data				
Inlet Pressure (psi)	Outlet Pressure (psi)	**Steam Flow Rate (lb/hr)**	Steam Temperature (°F)	**Electrical Output (kW)**
150	15	**11,150**	366	**275**

AHU Electrical Load Requirements						
Unit	HP	kVA	FLA	Volt	Phase	kW
AHU 1	12x10 = 120	130	156	480	3	**191**
AHU 2	9x7.5 = 67.5	80	96	480	3	**118**
AHU 3	12x7.5 = 90	103	124	480	3	**152**

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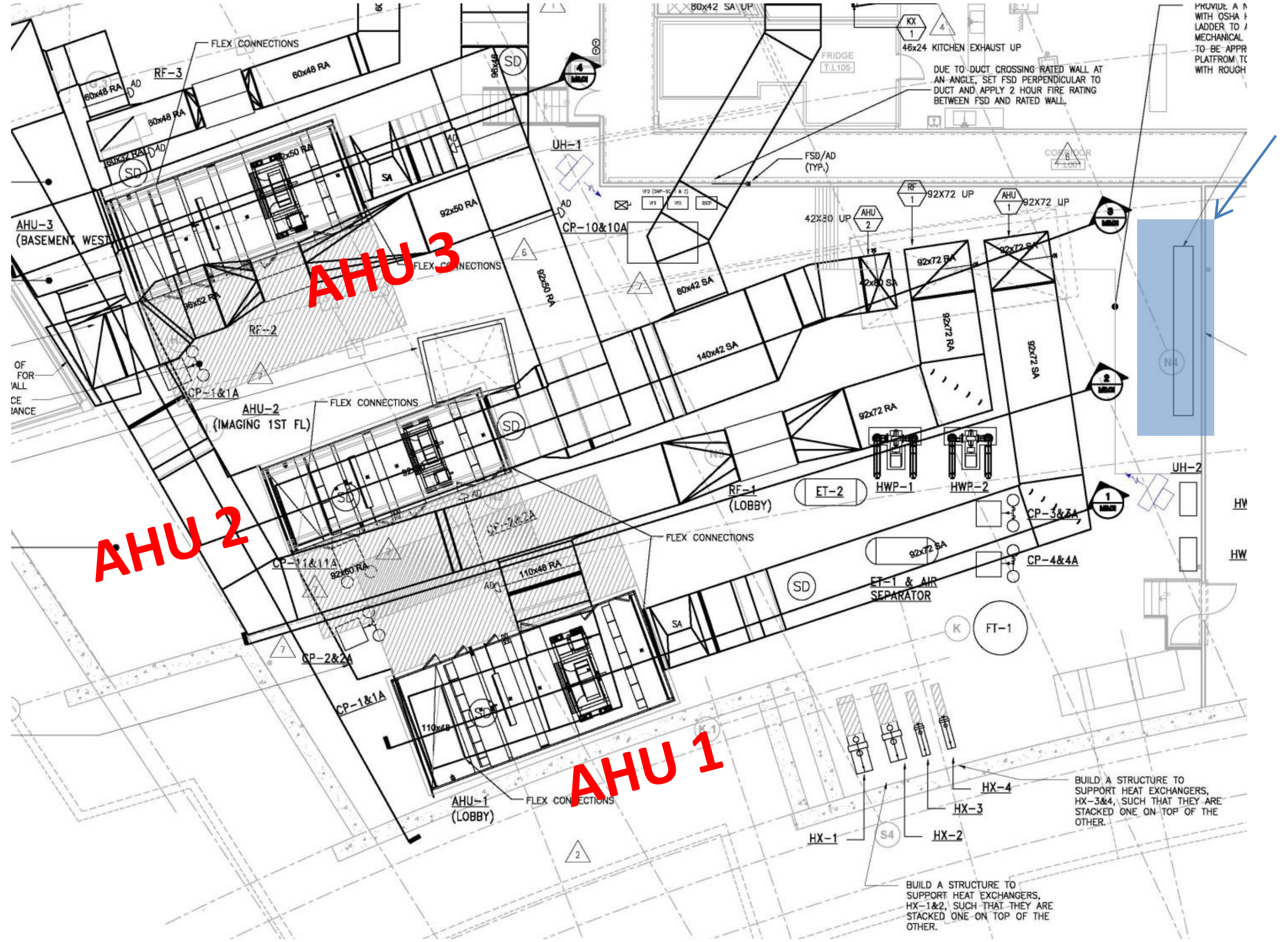
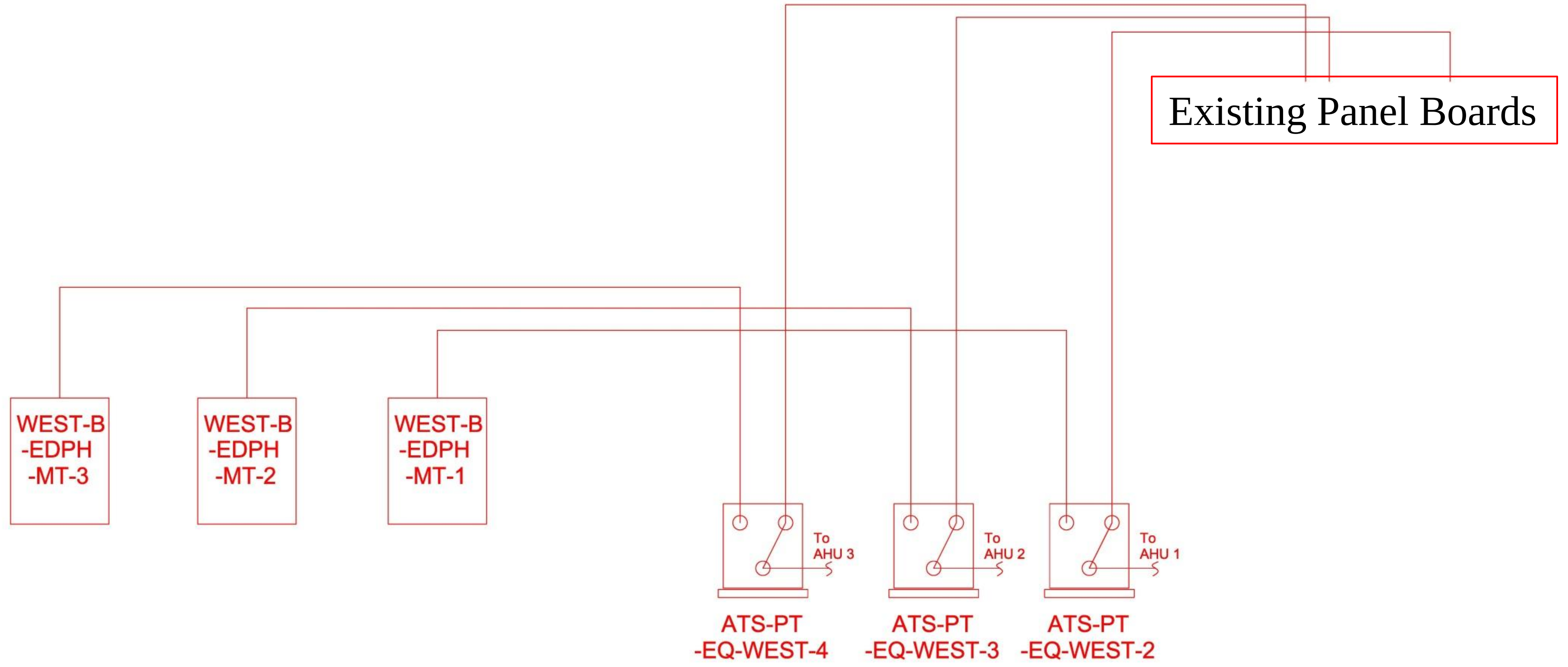
Lower Level Mechanical Room Layout

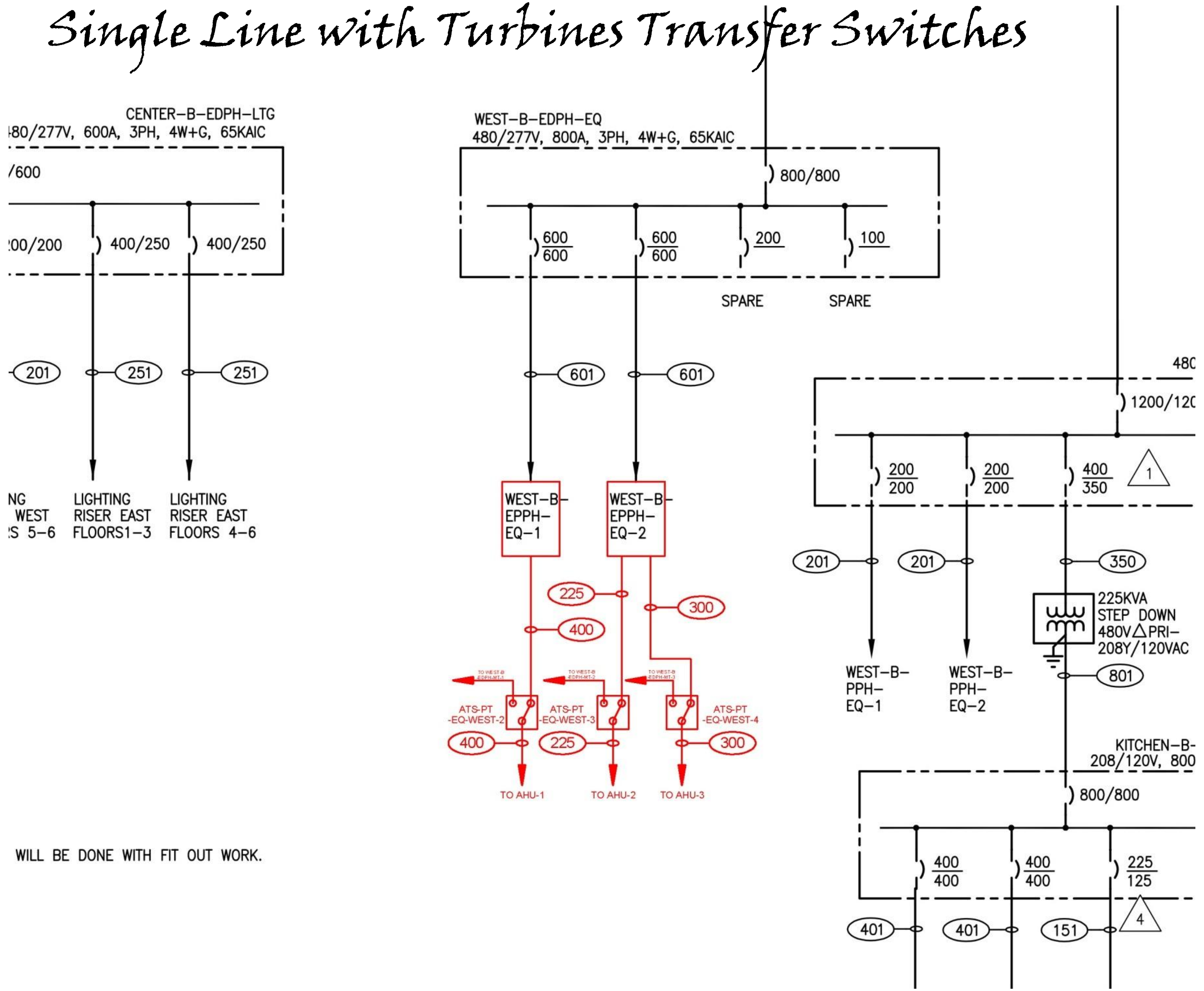


Pressure Reducing Valve Station 1

Riser Diagram with Turbines and Transfer Switches



Single Line with Turbines Transfer Switches



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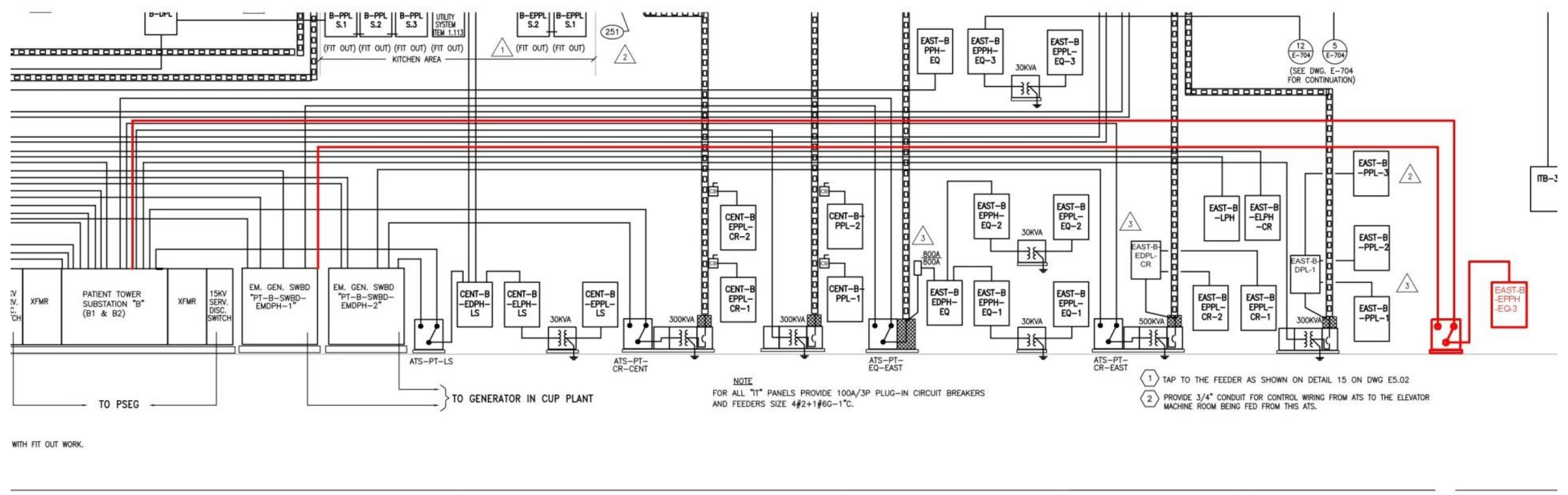
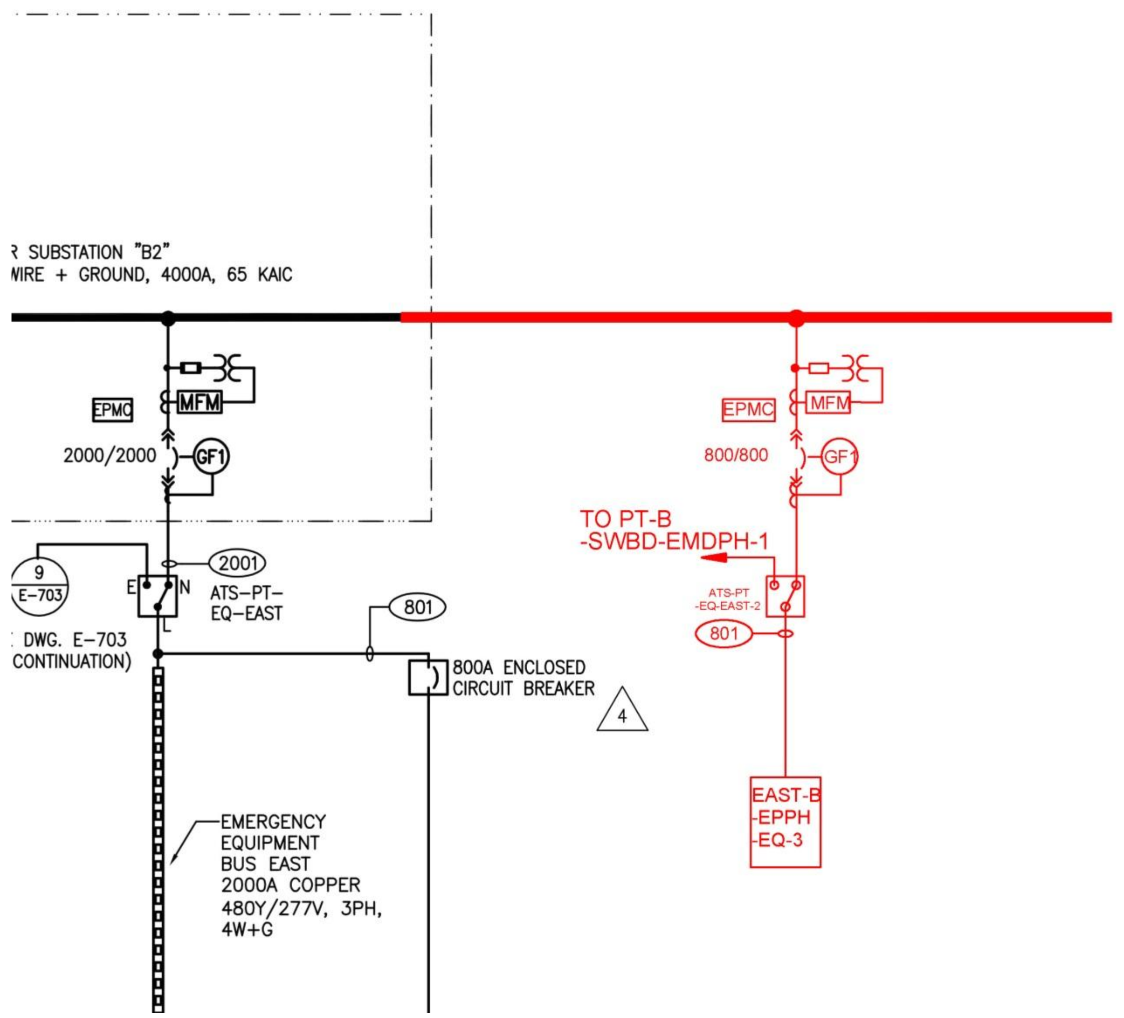
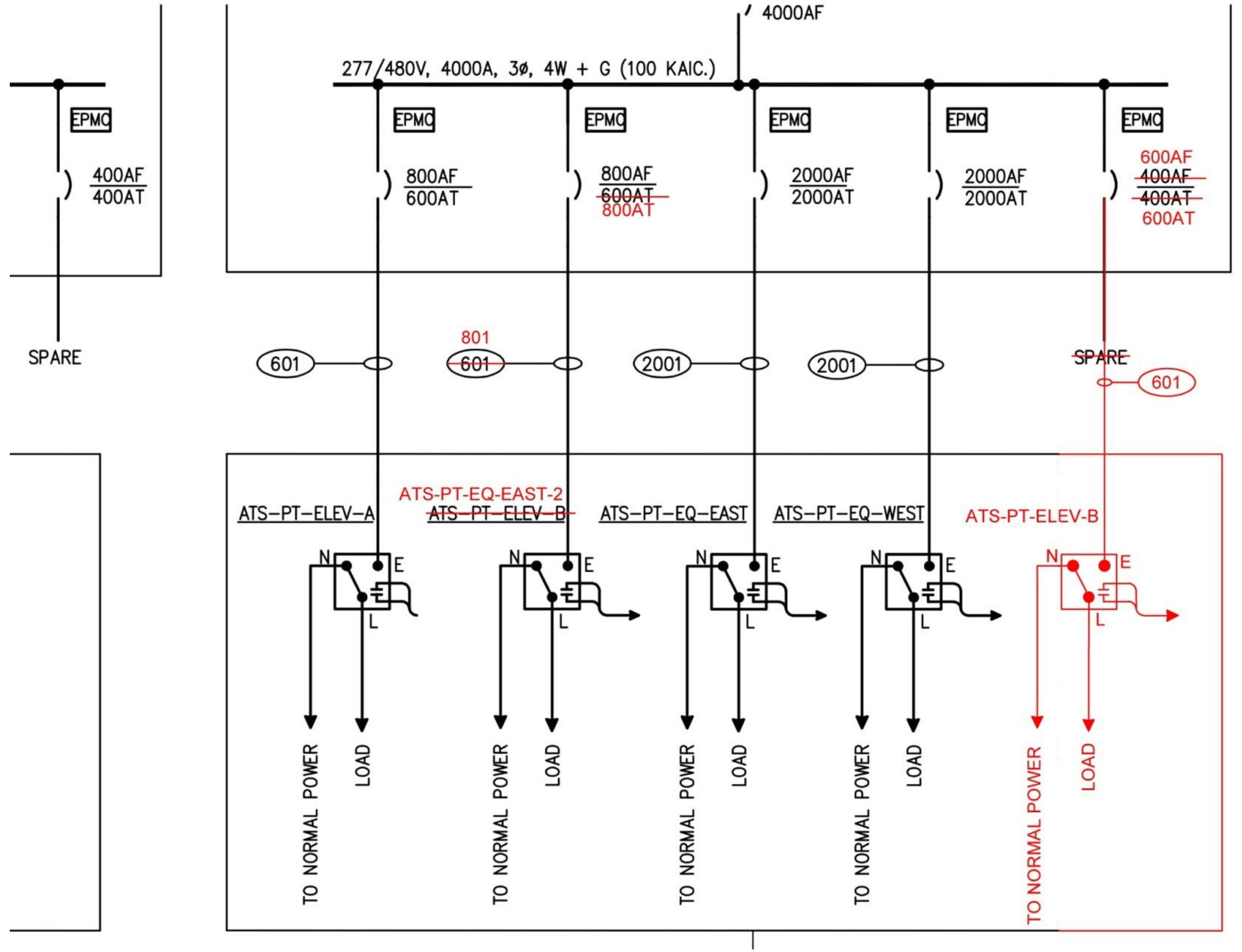
Riser Drawing with HP Transfer Switch and Panel Board



Single Line with HP Transfer Switch and Panel Board



Emergency Single Line with HP Transfer Switch



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Acoustical Breadth

- Introduction
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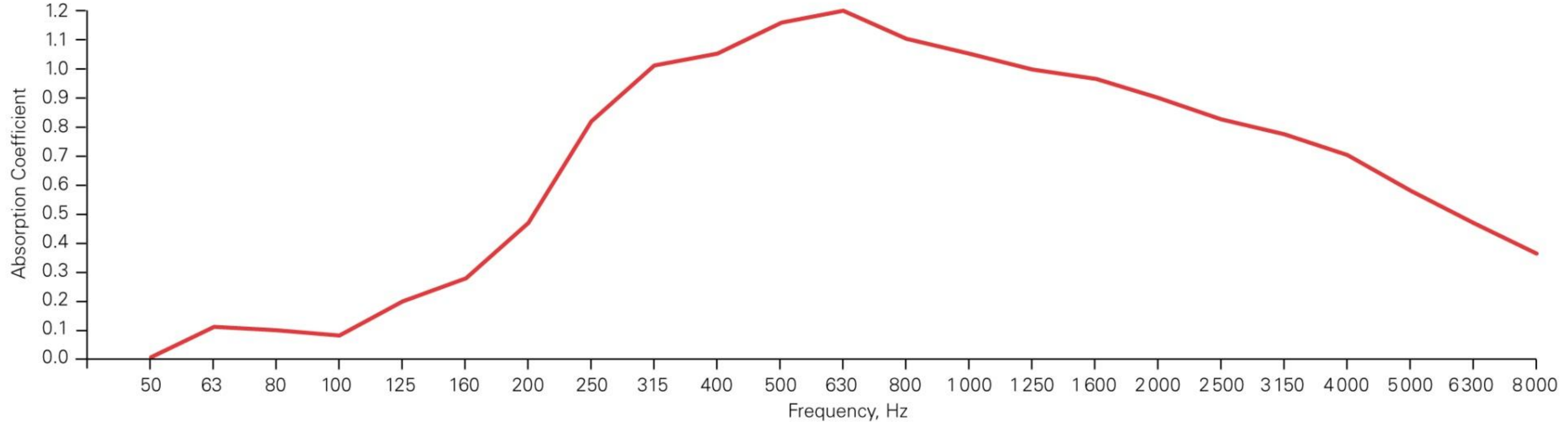
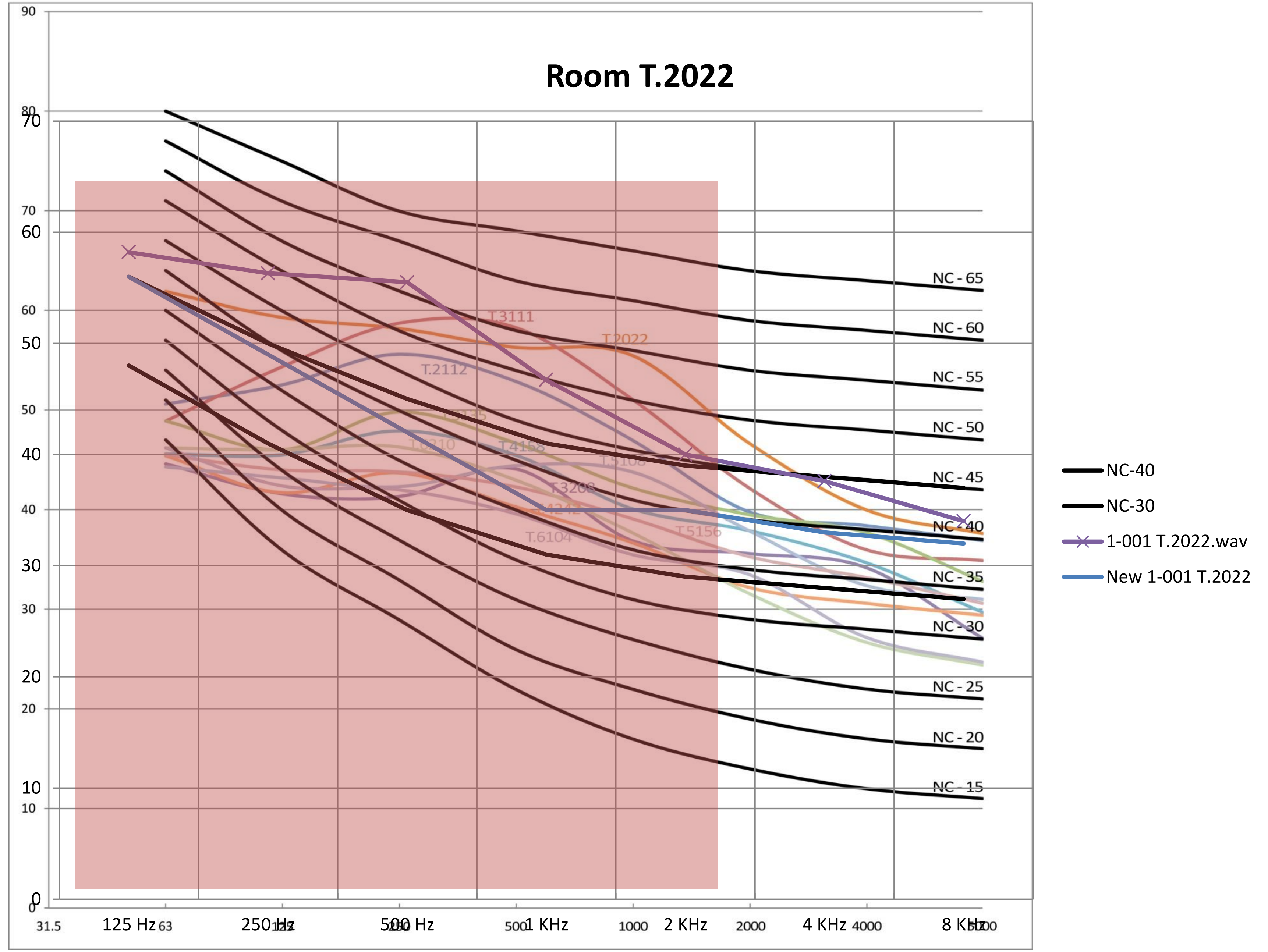


- Acoustical Comfort Improves Healing Process
- AIA / AHA dBA and NC standards
- DuPont Audio Comfort Panels with Tyvek Cover

AudioComfort Panel Area Summary						
File Name	Room Type	Compliant based on dBA	NC	Compliant based in NC	DuPont Panel Area Required to meet NC compliance	Area of Dupont panel to meet dBA
1-001 T.2022.wav	Staff Work	NO	55	NO	245	**400**
2-001 T.2112.wav	Hold Recovery Room	NO	48	NO	**310**	310
2-002 T.3111.wav	Family Respite	NO	56	NO	**483**	250
2-003 T.3135.wav	Critical Patient Room	NO	43	Yes	--	**100**
2-004 T.3208.wav	Intermediate Patient Room	Yes	39	Yes	--	--
2-005 T.4158.wav	Patient Room	Yes	41	Yes	--	--
2-006 T.4212.wav	Patient Room	Yes	36	Yes	--	--
2-007 T.5108.wav	Patient Room	Yes	43	Yes	--	--
2-008 T.5156.wav	Patient Room	Yes	38	Yes	--	--
2-009 T.6210.wav	Nursery Patient Room	Yes	38	Yes	--	--
2-010 T.6104.wav	Patient Room	Yes	35	Yes	--	--



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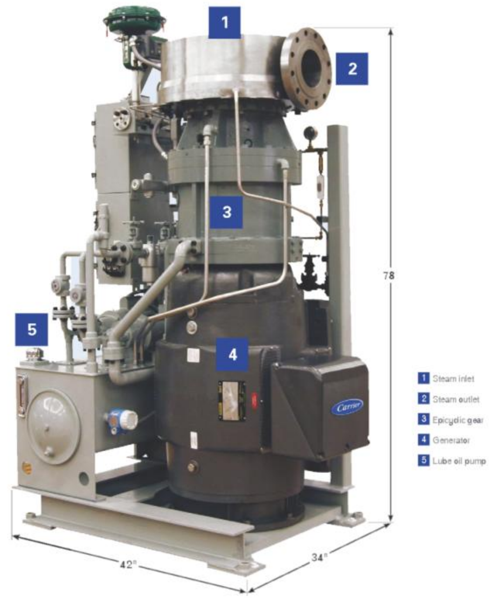
- Evaluated HR System
  - 23 Year Payback
- Designed GSHP / GHX
  - 115 Year Payback
- Final Remarks

- Implemented Microsteam Turbines
  - Peak savings 461 kW
- Evaluated Room Acoustics
  - DuPont AudioComfort Panels

Simple Payback of Runaround Glycol Heat Recovery System												
Heating Base Cost	Heating Cost with HR	**Savings**		Cooling Base Cost	Cooling Cost with HR	**Savings**		Total Cost Savings		Additional Capital Investment		**Simple Payback (years)**
$134,946	$91,512	**$43,434**		$476,779	$466,914	**$9,865**		$53,299		$1,233,000		**23**

Simple Payback for GSHP and GHX Alternative						
Total NG Savings	Operating Cost	**Total Cost Savings**		Additional Capital Investment		**Simple Payback (years)**
$85,387	$29,939	**$55,448**		$6,359,695		**115**



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- I would like to take this opportunity to thank all those who played a vital role in this project.
- Turner Construction, for granting access to the drawings and information on this wonderful building.
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- The rest of the AE faculty and staff and students.

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Thank You




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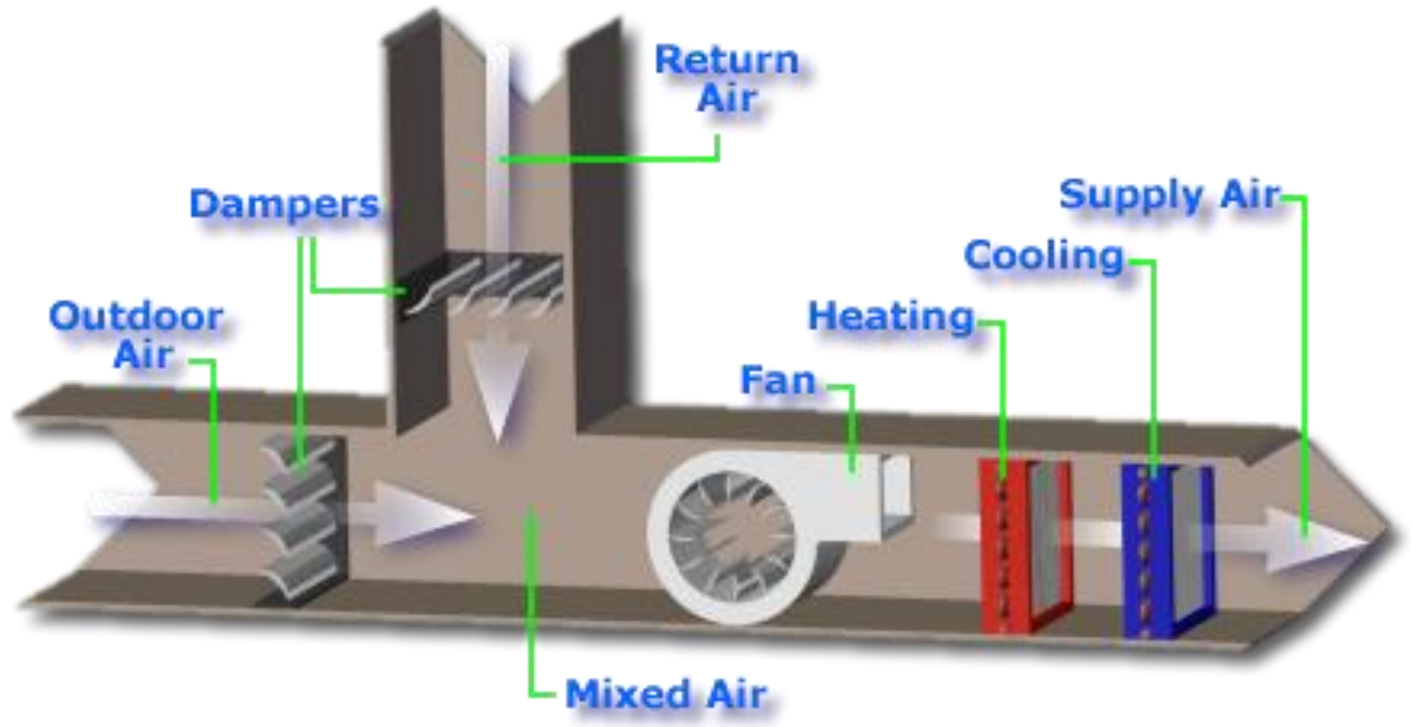
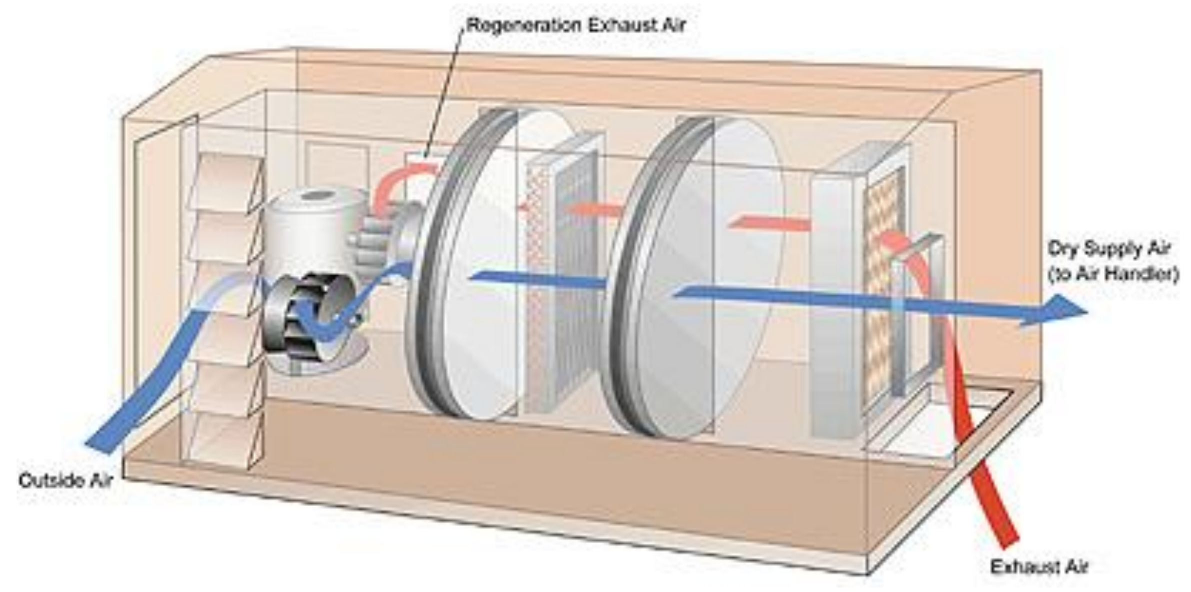
Economizer



Advantages
- Reduction in outdoor air
- Reduction in Energy Consumption

Disadvantages
- Cross Contamination
- More Control Logic and Sensors

Energy Recovery Wheel



Advantages
- Reduction in Energy Consumption
- Enthalpy Recovered

Disadvantages
- Cross Contamination
- Large Duct Work on Roof

Hybrid Systems

Fewer Heat Pumps in series provide large delta T mix into rest of flow

Decrease water flow on load side by percent of current

Preheat water going into heat pump in winter to decrease delta T