The State Institute of Rehabilitation

New Jersey

Elizabeth C. Krauss
Mechanical Option

The State Institute of Rehabilitation

- Building Summary
- Objectives
- Mechanical Investigation
- Electrical Investigation
- Overall Evaluation
- Conclusion

- Building Summary
  - Location and Occupancy
  - Facility and Façade
  - Equipment
    - Existing Building
    - Building Addition
  - Electric Consumption
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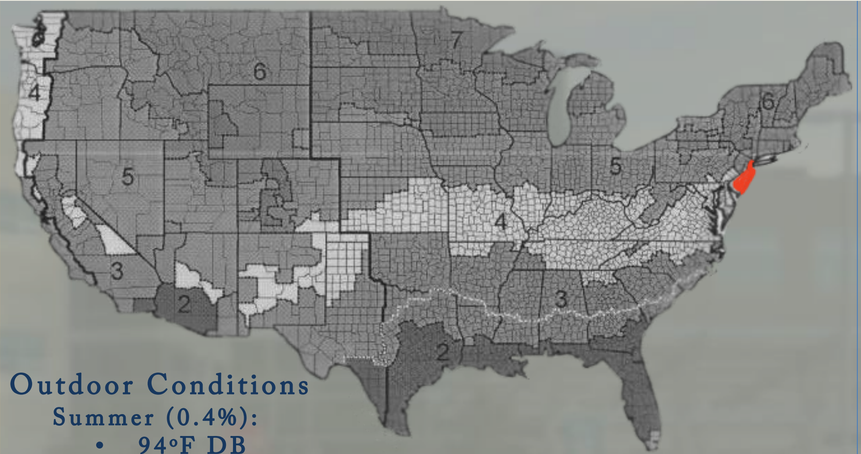
Location



Outdoor Conditions

Summer (0.4%):
- 94°F DB
- 74.9°F WB

Winter (99.6%):
- 11°F DB

Occupancy

Indoor Conditions

Summer:
- 75°F DB
- 50% RH

Winter:
- 72°F DB
- 50% RH

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Facility

Façade

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Heating

Boiler-1(1973):
Natural Gas
Output: 5021 MBH

Boiler-2(1973):
Natural Gas
Output: 5021 MBH

Cooling

Chiller-1(1973):
Electric Centrifugal
Output: 300 tons

Chiller-2(1973):
Air Cooled Liquid
Output: 15.2 tons

Chiller-2(1973):
Air Cooled Liquid
Output: 18.4 tons

Decommissioned Chiller (1973):
Steam Absorption
Output: 230 tons

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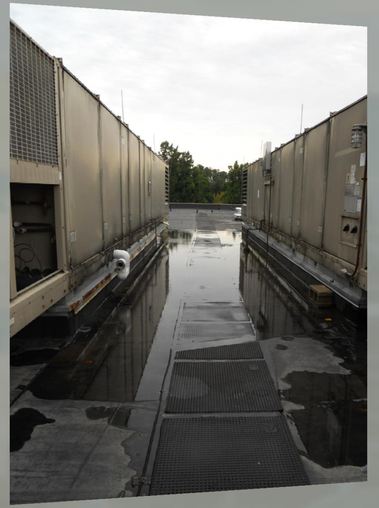
Rooftop Units



RTU-1
39 Tons cooling
470 MBH heating
11500 CFM

RTU-2
39 Tons cooling
470 MBH heating
11500 CFM

RTU-3
45 Tons cooling
470 MBH heating
12000 CFM

RTU-4
45 Tons cooling
470 MBH heating
12000 CFM

RTU-5
47 Tons cooling
570 MBH heating
14000 CFM

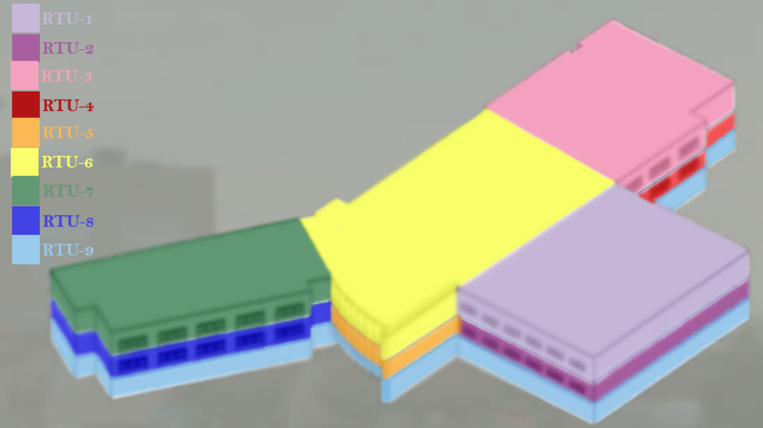
RTU-6
47 Tons cooling
570 MBH heating
14000 CFM

RTU-7
40 Tons cooling
510 MBH heating
12500 CFM

RTU-8
39 Tons cooling
510 MBH heating
12500 CFM

RTU-9
39 Tons cooling
476 MBH heating
12500 CFM

Capacities



Total:
381 Tons cooling | 4516 MBH | 112,500 CFM

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Heating

Boilers-1
Input: 2000 MBH
Output: 1600 MBH

Boilers-2
Input: 2000 MBH
Output: 1600 MBH

Boilers-3
Input: 2000 MBH
Output: 1600 MBH

Equipment

8 Cabinet Unit Heaters

8 Unit Heaters

137 Variable Air Volume Units, hot water reheat

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Building Addition, Electricity

Electricity Use					
Month	Elevator	Receptacles	System	Interior	Total
	MBtu	MBtu	MBtu	MBtu	MBtu
January	3.969	87.691	161.368	90.88	343.907
February	3.751	81.63	145.333	84.682	315.396
March	4.291	92.391	172.872	95.912	365.466
April	3.95	87.033	172.365	90.156	353.503
May	4.13	89.462	391.538	92.892	578.022
June	4.111	88.804	593.269	92.169	778.352
July	3.969	87.691	730.719	90.88	913.259
August	4.291	92.391	704.895	95.912	897.488
September	4.111	88.804	567.473	92.169	752.557
October	3.969	87.691	262.532	90.88	445.071
November	4.111	88.804	168.067	92.169	353.151
December	4.13	90.62	165.628	93.899	354.277
Annual	48.78	1063.01	4236.059	1102.598	6450.446

= 1890 MWh

Existing Building, Electricity

=(2)*1890 MWh

= 3780 MWh

Total: 5,671 MWh

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Operation Cost, Building Addition

Building Electricity				
Month	Btu	kWh	$/kWh	Cost
January	343,907,000.00	100789.2	$0.0688	$6,934.30
February	315,396,000.00	92433.4	$0.0688	$6,359.42
March	365,466,000.00	107107.5	$0.0688	$7,369.00
April	353,503,000.00	103601.5	$0.0688	$7,127.78
May	578,022,000.00	169401.5	$0.0688	$11,654.82
June	778,352,000.00	228112.5	$0.0737	$16,811.89
July	913,259,000.00	267649.8	$0.0737	$19,725.79
August	897,488,000.00	263027.8	$0.0737	$19,385.15
September	752,557,000.00	220552.7	$0.0737	$16,254.73
October	445,071,000.00	130437.4	$0.0688	$8,974.10
November	353,151,000.00	103498.3	$0.0688	$7,120.69
December	354,277,000.00	103828.3	$0.0688	$7,143.39
Annual	**6,450,449,000.00**	**1890440.0**	-	**$134,861.05**

(134,861) + (120,226) =$255,087

System Natural Gas				
Month	Btu	Therms	$/Therm	Cost
January	2,159,000,000.00	21595.2	$0.5780	$12,482.00
February	1,776,000,000.00	17764.2	$0.5740	$10,196.67
March	1,712,000,000.00	17124.1	$0.5860	$10,034.72
April	1,522,000,000.00	15223.6	$0.6280	$9,560.44
May	1,599,000,000.00	15993.8	$0.6470	$10,348.00
June	1,552,000,000.00	15523.7	$0.6470	$10,043.84
July	1,560,000,000.00	15603.7	$0.5980	$9,331.03
August	1,616,000,000.00	16163.9	$0.5590	$9,035.60
September	1,584,000,000.00	15843.8	$0.5710	$9,046.80
October	1,603,000,000.00	16033.8	$0.5630	$9,027.04
November	1,696,000,000.00	16964.0	$0.5570	$9,448.98
December	1,971,000,000.00	19714.7	$0.5920	$11,671.11
Annual	**20,350,000,000.00**	**203548.6**	-	**$120,226.22**

Operation Cost, Existing Building

Building Electricity				
Month	Btu	kWh	$/kWh	Cost
January	687,814,000.00	201578.4	$0.0688	$13,868.59
February	630,792,000.00	184866.9	$0.0688	$12,718.84
March	730,932,000.00	214215.0	$0.0688	$14,737.99
April	707,006,000.00	207203.0	$0.0688	$14,255.57
May	1,156,044,000.00	338803.1	$0.0688	$23,309.65
June	1,556,704,000.00	456224.9	$0.0737	$33,623.78
July	1,826,518,000.00	535299.6	$0.0737	$39,451.58
August	1,794,976,000.00	526055.5	$0.0737	$38,770.29
September	1,505,114,000.00	441105.4	$0.0737	$32,509.47
October	890,142,000.00	260874.9	$0.0688	$17,948.19
November	706,302,000.00	206996.7	$0.0688	$14,241.37
December	708,554,000.00	207656.7	$0.0688	$14,286.78
Annual	**12,900,898,000.00**	**3780880.0**	-	**$269,722.10**

(269,772) + (240,452) =$510,174

System Natural Gas				
Month	Btu	Therms	$/Therm	Cost
January	4,318,000,000.00	43190.3	$0.5780	$24,964.00
February	3,552,000,000.00	35528.5	$0.5740	$20,393.35
March	3,424,000,000.00	34248.2	$0.5860	$20,069.43
April	3,044,000,000.00	30447.3	$0.6280	$19,120.88
May	3,198,000,000.00	31987.6	$0.6470	$20,696.00
June	3,104,000,000.00	31047.4	$0.6470	$20,087.68
July	3,120,000,000.00	31207.4	$0.5980	$18,662.05
August	3,232,000,000.00	32327.7	$0.5590	$18,071.19
September	3,168,000,000.00	31687.6	$0.5710	$18,093.60
October	3,206,000,000.00	32067.7	$0.5630	$18,054.09
November	3,392,000,000.00	33928.1	$0.5570	$18,897.95
December	3,942,000,000.00	39429.4	$0.5920	$23,342.21
Annual	**40,700,000,000.00**	**407097.2**	-	**$240,452.44**

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Objectives

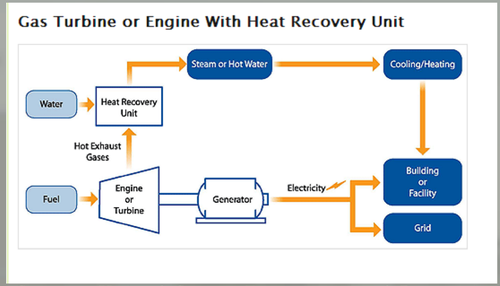
Upgrade

Increase

Decrease

Plan

Combined Heat, Cooling, and Power



Source: United States Environmental Protection Agency (EPA)

- Building Summary
- Objectives
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    - Boilers
      - Combustion Turbine
      - Chiller
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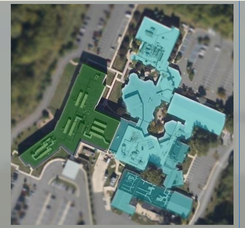
Heating



Peak Demand Loads

Existing Building
2 * (5021 MBH)
= 10042 MBH

Building Addition
4080 MBH

Total:

10042 MBH
+ 4080 MBH
14,122 MBH Demand

14,122 MBH ÷ (3 boilers) = 4703.3 MBH/boiler

Boilers

(3) 6400 MBH Output
(3) 8000 MBH Input
6,598 lbs./hr. steam ea.

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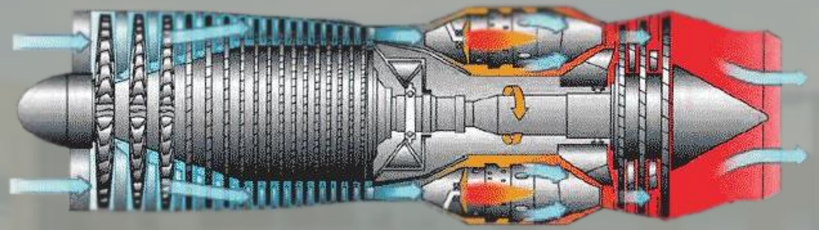
Waste Heat



Combustion Turbine Operation					
Inputs					
Exhaust Flow (lb./hr)	51890				
Exhaust Temperature (^{o}F)	940				
c_p(BTU/lb.-^{o}F)	0.26				
T_{ex}, boiler (^{o}F)	440				
Electric Generation (MW)	1.2				
Result					
$Qu = m_{ex} \times cp_{ex} \times (T_{ex}\text{engine} - T_{ex}\text{boiler})$	=	6745700	=	6745.7	MBTU

Combustion Turbine

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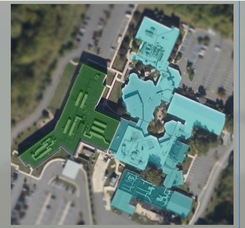
Cooling Loads



Peak Demand Loads

Existing Building
300 tons
+ 18.4 tons
+ 15.2 tons
= 333.6 tons

Building Addition
448 tons

Total:

333.6 tons
+448.0 tons
781.6 ton Demand

Double Effect Absorption Chiller

802 ton capacity
6873 lbs. steam/hr. consumption

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Air Distribution, Addition

Cooling:
DX to Chilled Water

Heating:
Gas Burner to Steam

Air Distribution, Existing

Cooling:
Chilled Water

Heating:
Steam

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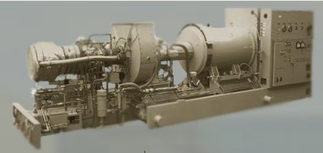
Operation, Winter



1.2 MW electricity

6745 MBH
Waste Heat

1255 MBH
Nat. Gas

6400 MBH,
6598 lbs. steam

8000 MBH
Nat. Gas

6400 MBH,
6598 lbs. steam

8000 MBH
Nat. Gas

6400 MBH,
6598 lbs. steam

Operation, Summer

1.2 MW electricity

6745 MBH
Waste Heat

1255 MBH
Nat. Gas

6598 lbs./hr.
steam

802 tons
cooling

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Building Addition, Demand

Month	Heating Load	Heating Load (BTU)	Percentage of Maximum Demand
January	1786	1786000000	100.00%
February	1464	1464000000	81.97%
March	1398	1398000000	78.28%
April	1231	1231000000	68.92%
May	1297	1297000000	72.62%
June	1259	1259000000	70.49%
July	1262	1262000000	70.66%
August	1312	1312000000	73.46%
September	1288	1288000000	72.12%
October	1301	1301000000	72.84%
November	1384	1384000000	77.49%
December	1623	1623000000	90.87%
Maximum	**1786**	**1786000000**	100.00%

Month	Cooling	Cooling Load (BTU)	Percentage of Maximum Demand
January	57	57000000	2.30%
February	56	56000000	2.26%
March	103	103000000	4.15%
April	136	136000000	5.48%
May	964	964000000	38.84%
June	1931	1931000000	77.80%
July	2482	2482000000	100.00%
August	2408	2408000000	97.02%
September	1817	1817000000	73.21%
October	455	455000000	18.33%
November	141	141000000	5.68%
December	100	100000000	4.03%
Maximum	**2482**	**2482000000**	100.00%

Existing Building, Demand

Month	Percentage of Maximum Demand	Heating Load (BTU)
January	100.00%	7471248000.00
February	81.97%	6124248080.63
March	78.28%	5848154929.45
April	68.92%	5149555592.39
May	72.62%	5425648743.56
June	70.49%	5266686020.16
July	70.66%	5279235708.85
August	73.46%	5488397187.01
September	72.12%	5387999677.49
October	72.84%	5442381661.81
November	77.49%	5789589715.57
December	90.87%	6789381581.19
Maximum	**100.00%**	**7471248000.00**

Maximum Heating Load: 7,471,248,000 BTU, Jan.

Maximum Cooling Load: 2,978,380,800 BTU, July

Month	Percentage of Maximum Demand	Cooling Load (BTU)
January	2.30%	68399559.07
February	2.26%	67199566.80
March	4.15%	123599203.22
April	5.48%	163198947.95
May	38.84%	1156792542.79
June	77.80%	2317185062.37
July	100.00%	2978380800.00
August	97.02%	2889581372.44
September	73.21%	2180385944.24
October	18.33%	545996480.26
November	5.68%	169198909.27
December	4.03%	119999226.43
Maximum	**100.00%**	**2482000000.00**

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Annual Operating Cost

Heating Plant								
Month	Heating Load	Modeled (BTU)	Existing (BTU)	Sum (BTU)	Sum, load (Therms)	Input (Therms)	$/Therm	Cost
January	1786	1786000000	7471248000.00	9257248000.00	92594.58	115743.23	$0.5780	$66,899.59
February	1464	1464000000	6124248080.63	7588248080.63	75900.60	94875.75	$0.5740	$54,458.68
March	1398	1398000000	5848154929.45	7246154929.45	72478.85	90598.56	$0.5860	$53,090.76
April	1231	1231000000	5149555592.39	6380555592.39	63820.79	79775.99	$0.6280	$50,099.32
May	1297	1297000000	5425648743.56	6722648743.56	67242.54	84053.17	$0.6470	$54,382.40
June	1259	1259000000	5266686020.16	6525686020.16	65272.44	81590.55	$0.6470	$52,789.09
July	1262	1262000000	5279235708.85	6541235708.85	65427.98	81784.97	$0.5980	$48,907.41
August	1312	1312000000	5488397187.01	6800397187.01	68020.21	85025.26	$0.5590	$47,529.12
September	1288	1288000000	5387999677.49	6675999677.49	66775.94	83469.92	$0.5710	$47,661.32
October	1301	1301000000	5442381661.81	6743381661.81	67449.92	84312.40	$0.5630	$47,467.88
November	1384	1384000000	5789589715.57	7173589715.57	71753.03	89691.28	$0.5570	$49,958.04
December	1623	1623000000	6789381581.19	8412381581.19	84143.90	105179.88	$0.5920	$62,266.49
Total	**1786**	**16605000000**	**69462526898**	**86067526898**	**860880.77**	**1076100.963**	-	$635,510.1037

Annual Operating Cost, Cooling

Cooling				
Month	Modeled (BTU)	Sum (BTU)	Sum(Therms)	% Heating System
January	57000000	125399559	1254.30	0.00001%
February	56000000	123199567	1232.29	0.00001%
March	103000000	226599203	2266.53	0.00002%
April	136000000	299198948	2992.70	0.00003%
May	964000000	2120792543	21212.99	0.00023%
June	1931000000	4248185062	42491.99	0.00046%
July	2482000000	5460380800	54616.85	0.00059%
August	2408000000	5297581372	52988.46	0.00057%
September	1817000000	3997385944	39983.40	0.00043%
October	455000000	1000996480	10012.35	0.00011%
November	141000000	310198909	3102.73	0.00003%
December	100000000	219999226	2200.52	0.00002%

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Emissions, Before

Electricity

At Power Plant Combustion Byproducts by Fuel Source for Specified Electric Consumption (MWh): 5671				
Fuel Type	Distribution by Fuel Source, MWh	lbs CO_2	lbs SO_2	lbs NO_x
Natural Gas	2325.04	2,638,920.48	232.50	3,952.57
Coal	146.84	330,253.59	1,908.98	881.07
Nuclear	3059.26	-	-	-
Renewables	139.85	-	-	-

On Site Combustion Byproducts by Fuel Source for Specified Electric Consumption (MWh): 5671				
Fuel Type	Distribution by Fuel Source, MWh	lbs CO_2	lbs SO_2	lbs NO_x
Natural Gas	2325.04	7,916,761.45	697.51	11,857.70
Coal	146.84	990,760.76	5,726.94	2,643.20
Nuclear	3059.26	-	-	-
Renewables	5671.00	-	-	-
	Total	8907522.213	6424.453	14500.90783

Natural Gas

Emissions (lbs/MWh)			
Combustion Byproduct	Emissions (lbs/MWh)	MWh	Emissions, lbs
Carbon Dioxide	1135	17889	20,304,015
Sulfur Dioxide	0.1	17889	1,789
Nitrous Oxides	1.7	17889	30,411

Total

29,211,537 lbs. CO_2 | 8,213 lbs. SO_2 | 44,912 lbs. NO

Emissions, After

Electricity

0

Natural Gas

Emissions (lbs/MWh)			
Combustion Byproduct	Emissions (lbs/MWh)	MWh	Emissions, lbs
Carbon Dioxide	1135	41120	46,671,200
Sulfur Dioxide	0.1	41120	4,112
Nitrous Oxides	1.7	41120	69,904

Total

46,671,200 lbs. CO_2 | 4,112 lbs. SO_2 | 69,904 lbs. NO

37% increase CO_2 | 50% decrease lbs. SO_2 | 35% increase NO

- Building Summary
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- Mechanical Investigation
- Electrical Investigation
  - First Cost & Offset
  - Cost of Operation & Grid Resale
- Overall Evaluation
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First Cost, System

Electricity

Capital Cost								
Equipment			$/sf	$/KW	$/kWh	$/ton	$/MMBH	Total Cost
Name	Capacity	Unit						
Boiler 1	6400	MBH	-	-	-	-	$5,100.00	$32,640.00
Boiler 2	6400	MBH	-	-	-	-	$5,100.00	$32,640.00
Boiler 3	6400	MBH	-	-	-	-	$5,100.00	$32,640.00
SAM-1	802	Tons	-	-	-	$430.00	-	$344,860.00
CT-1	1.2	MW	-	$1,200.00	-	-	-	$1,440,000.00
							Total	$1,882,780.00

Incentives

Incentive		
Incentive Quanities	**1 MW**	**>1 MW**
Electricity Produced, MW	1.2 MW	
Electricity Produced, W	1000000	200000
Incentive Price ($/W)	0.55	0.35
Financial Incentive, $	$550,000.00	$70,000.00
Total Incentive, $	$620,000.00	

$1,882,780.00-$620,000.000 = $1,262,780

32.9% savings

- Building Summary
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  - First Cost & Offset
  - Cost of Operation & Grid Resale
- Overall Evaluation
- Conclusion

Costs of Operation

Before Retrofit

(255,087, Addition)+(510,174, Existing) = $765,261

After Retrofit

(458,418, boilers)+(371,945,CT) = $830,364

Grid Resale

Electricity Consumption vs. Production			
	Produced (MWh)	Used (MWh)	Residual (MWh)
Addition	10512	1890	4841.2
Existing		3780.8	

=$340,981 *earned*

$830,364-$340,981 = *$489,383*

36% decrease in operational costs

- Building Summary
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Equipment

Installed Equipment

- (1) Gas-fired generator Combustion Turbine (1.2 MW)
- (1) 6400 MBh waste-heat fueled, forced draft steam boiler
- (2) 6400 natural-gas fired, forced draft steam boilers
- (1) 802 ton steam absorption chiller

Altered Equipment

Rooftop Air Handling Units
- DX to Chilled Water
- Gas Burner to Steam

Performance

37% increase CO_2 | 50% decrease lbs. SO_2 | 35% increase NO

32.9% first-cost savings

36% decrease in operational costs

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Also to:

Family
Friends
Fellow AE students

Questions

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  - Domestic Water Reheat
  - Electricity Production, Plant vs. Site

Mechanical Space, Before

Mechanical Room											
Equipment	Machine		Access Requirements								
			Front		Back		Side		Side		Area
	Width	Length	Width	Length	Width	Length	Width	Length	Width	Length	Total
Water Softener	5	3	-	-	-	-	-	-	-	-	15
Hot Water Boiler, 1	3	9.167	3	3	3	3	3	9.167	3	9.167	100.503
Hot Water Boiler, 2	3	9.167	3	3	3	3	3	9.167	3	9.167	100.503
Hot Water Boiler, 3	3	9.167	3	3	3	3	3	9.167	3	9.167	100.503
Hot Water Pump,1	2	4.5	3	3	3	3	3	4.5	3	4.5	54
Hot Water Pump,2	2	4.5	3	3	3	3	3	4.5	3	4.5	54
Hot Water Pump, 3	2	4.5	3	3	3	3	3	4.5	3	4.5	54
										Total	**478.509**

Mechanical Space, After

Mechanical Room											
Equipment	Machine		Access Requirements								
			Front		Back		Side		Side		Area
	Width	Length	Width	Length	Width	Length	Width	Length	Width	Length	Total
Combustion Turbine	8	21.91	3	3	3	3	3	3	3	3	202.28
Steam Absorption Chiller	9.51	25.85	3	3	3	3	3	9.167	3	9.167	318.8355
Hot Water Boiler, 1	4.5	14	3	3	3	3	3	9.167	3	9.167	136.002
Hot Water Boiler, 2	4.5	14	3	3	3	3	3	9.167	3	9.167	136.002
Hot Water Boiler, 3	4.5	14	3	3	3	3	3	9.167	3	9.167	136.002
										Total	**929.122**

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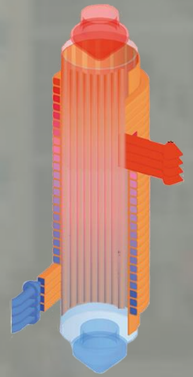
Domestic Water Reheat

Logarithmic Mean Area

For use in Heat Transfer Equations

$$A_m = \frac{2\pi(L)(r_e - r_i)}{\ln(r_o/r_i)} = \frac{0.0150}{0.0870} = 0.1727$$



Heat Transfer Through Schedule 40 Steel

Through a Pipe of Singular Composition (one material)

$$Q = \frac{(k_{pipe})(A_m)(T_i - T_o)}{(r_o - r_i)} = \frac{269.457}{0.023} = 11715.53 \text{ BTU/hr}$$

Heat Transfer Through Steel "Insulation"

Through Insulation Only

$$*Q = \frac{(k_{insulation})(A_m)(T_e - T_i)}{(r_e - r_o)} = \frac{269.457}{0.011} = 24496.1$$

*Assumes that thermal resistance of pipe is negligible compared to thermal resistance of insulation, and that little accuracy will be lost if the pipe wall thickness term is omitted from the denominator

Heat Transfer

Through an Insulated Pipe

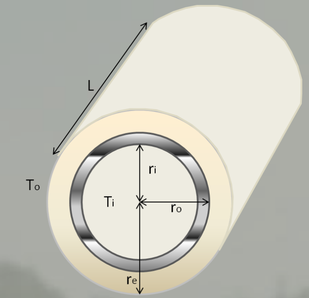
$$Q = \frac{(2\pi)(L)(T_i - T_o)}{[\{\ln(r_o/r_i)/k_{pipe}\} + \{\ln(r_e/r_o)/k_{insulation}\}]} = \frac{39.226}{0.005} = 8088.385$$

Inputs

Input Data

Equation Variables

L =	0.104	Pipe Length (ft)
r_o =	0.276	Radius, outer (ft)
r_i =	0.253	Radius, inner (ft)
r_e =	0.287	Radius, insulation exterior (ft)
T_o =	40	Temperature, outside (°F)
T_i =	100	Temperature, inside (°F)
k_{pipe} =	26	Thermal conductivity (Btu-ft/(hr-ft^2-°F)), pipe
$k_{insulation}$ =	26	Thermal conductivity (Btu-ft/(hr-ft2-oF)), insulation



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Results

8.088 MBh heat recovered

358.87 MBh required

2.3% savings

Suggestions
- Change condensate pipe to copper
- Increase length of apparatus
- Duplicate apparatus for existing building sanitary line

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1.2 MW Electricity, Plant

Electricity, Consumed

At Power Plant

Combustion Byproducts by Fuel Source for Specified Electric Consumption (MWh): 10512

Fuel Type	Distribution by Fuel Source, MWh	lbs CO_2	lbs SO_2	lbs NO_2
Natural Gas	4309.79	4,891,612.08	430.98	7,326.64
Coal	272.20	612,171.70	3,538.56	1,633.18
Nuclear	5670.78	-	-	-
Renewables	259.24	-	-	-

On Site

Combustion Byproducts by Fuel Source for Specified Electric Consumption (MWh): 10512

Fuel Type	Distribution by Fuel Source, MWh	lbs CO_2	lbs SO_2	lbs NO_2
Natural Gas	4309.79	14,674,836.25	1,292.94	21,979.93
Coal	272.20	1,836,515.10	10,615.69	4,899.55
Nuclear	5670.78	-	-	-
Renewables	10512.00	-	-	-
	Total	16511351.35	11908.63	26879.48212

Total

16,511,351 lbs. CO_2 | 11,909 lbs. SO_2 | 26,879 lbs. NO

1.2 MW Electricity, Site

Electricity, Produced

Emissions (lbs/MWh)

Combustion Byproduct	Emissions (lbs/MWh)	MWh	Emissions, lbs
Carbon Dioxide	1135	18419	20,905,565
Sulfur Dioxide	0.1	18419	1,842
Nitrous Oxides	1.7	18419	31,312

Total

20,905,565 lbs. CO_2 | 1,842 lbs. SO_2 | 31,312 lbs. NO

21% increase CO_2 | 84% decrease lbs. SO_2 | 14% decrease NO