Penn State University
Kevin Andreone
Mechanical Option
Advisor: Dr. Laura Miller

Renovation to Father O’Connell Hall — Building Overview — The Catholic University Of America

- **Introduction**
  - **Building Overview**
  - Existing Mechanical
- Combined Heat and Power Analysis
- Electrical Breath
- Recommendations
- Acknowledgments
- Questions

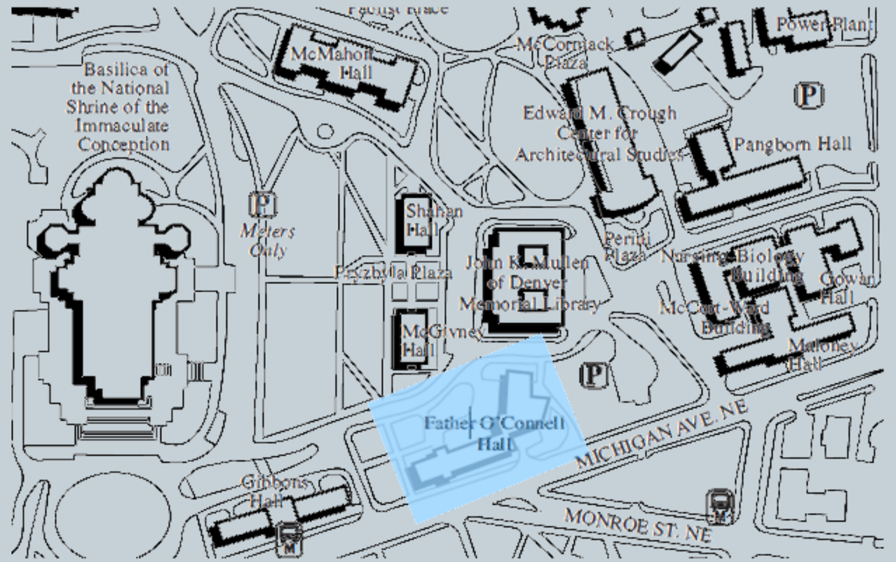
General Building Data

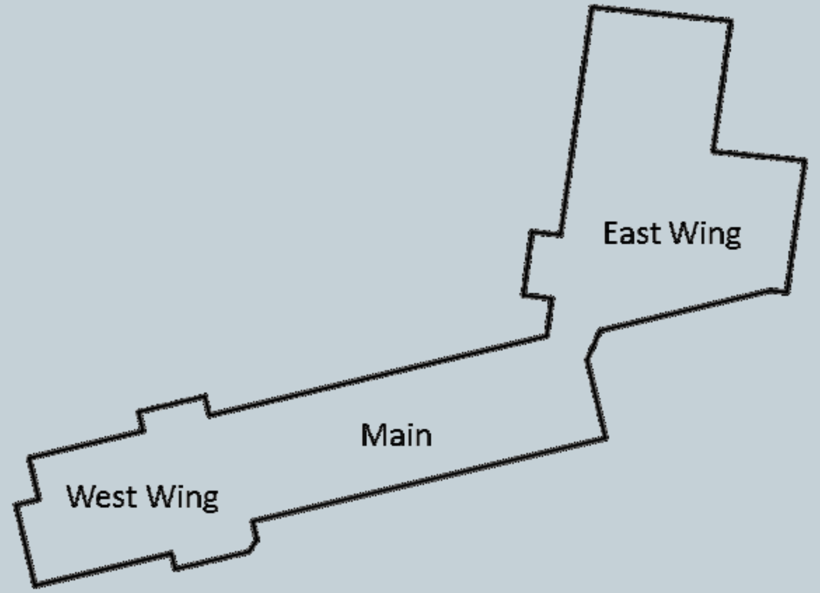
Location:	Washington, DC
Size:	54,000 GSF
Height:	4 Stories above grade, 1 below
Construction Dates:	July 2013-May 2014
Cost:	15 million
Occupancy	Administrative/Office

Project Team

Owner:	Catholic University of America
Architect:	SmithGroupJJR
MEP/FP Engineer:	SmithGroupJJR
Structural Engineer:	McMullan & Associates, Inc.
Civil Engineer:	ADTEK
Project Management:	Mark G Anderson Consultants, Inc.

Site Analysis





Renovation to Father O’Connell Hall

Existing Mechanical Systems

The Catholic University Of America

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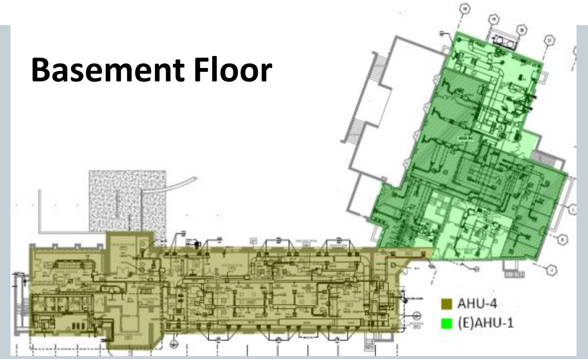

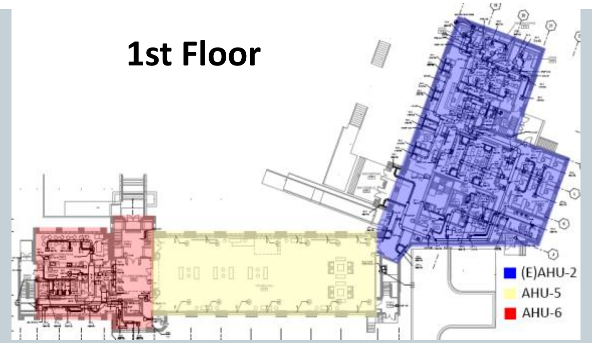

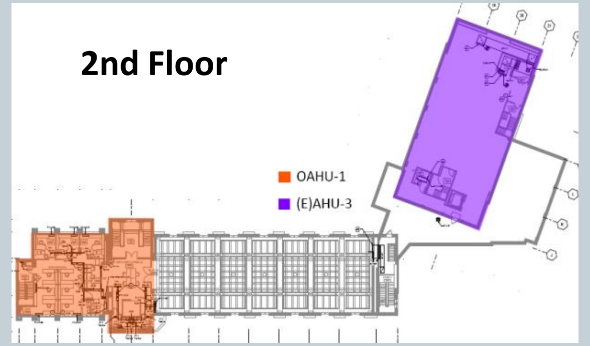

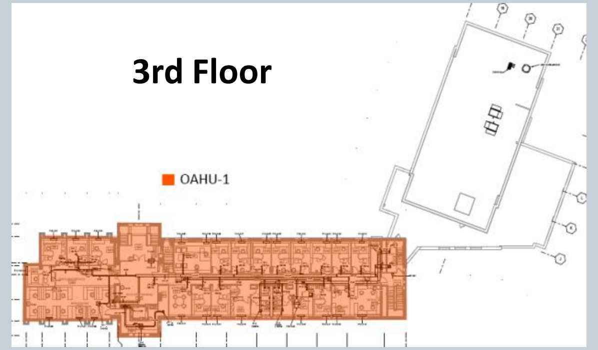

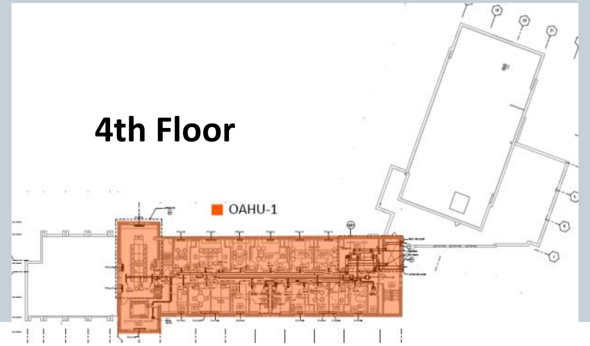

(E)AHU-1
(E)AHU-2
(E)AHU-3
AHU-4
AHU-5
AHU-6
OAHU-1
(E)-Existing

Air-Side

3 Existing AHU’s
- East wing not in scope

AHU-4 and AHU-6
- Use VAV and Fan powered boxes with hot water reheat in basement and first floors

AHU-5
- Displacement ventilation on first floor for two story banquet hall

OAHU-1
- Dedicated Outdoor AHU
- Ventilates floors 2-4 and uses 4 pipe Fan Coil Units

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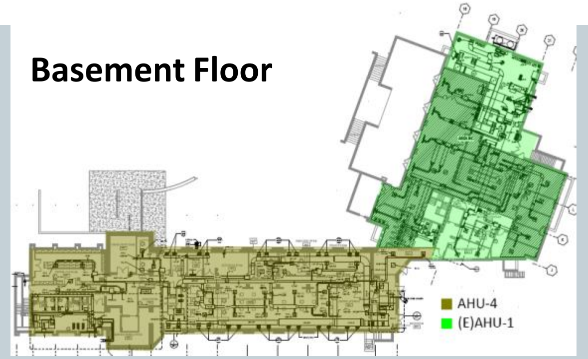
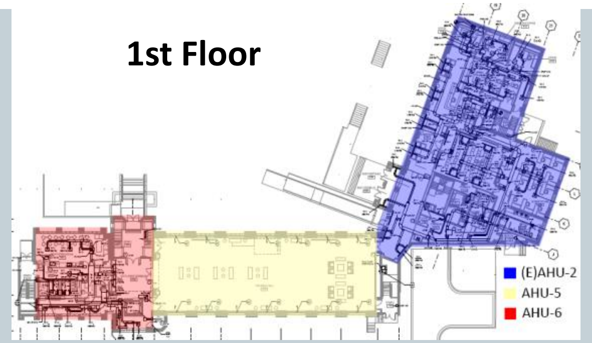
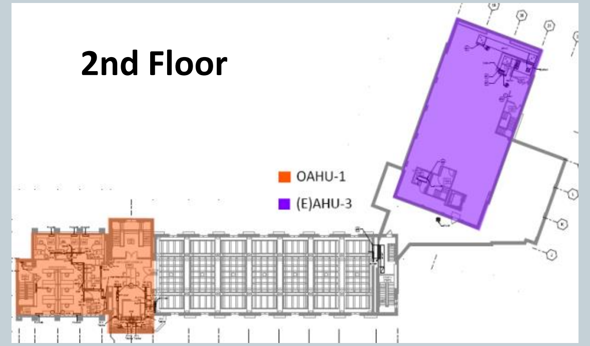
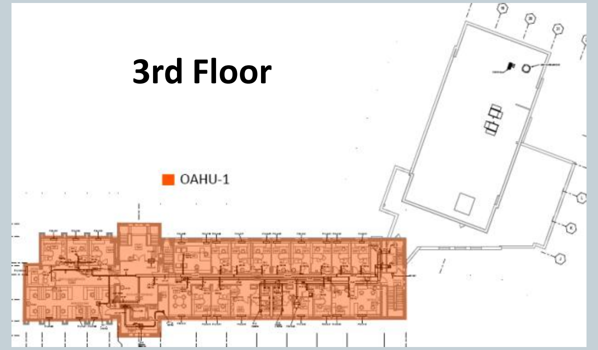
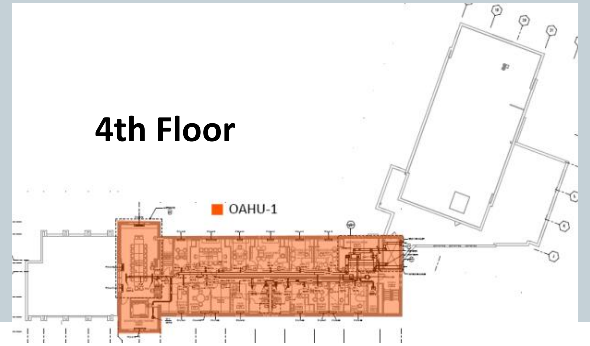










(E)AHU-1 | AHU-5
(E)AHU-2 | AHU-6
(E)AHU-3 | OAHU-1
AHU-4 | (E)-Existing

Water-Side

Cooling

One 97.7 ton electric air-cooled chiller

- Two chilled water pumps with VFD's

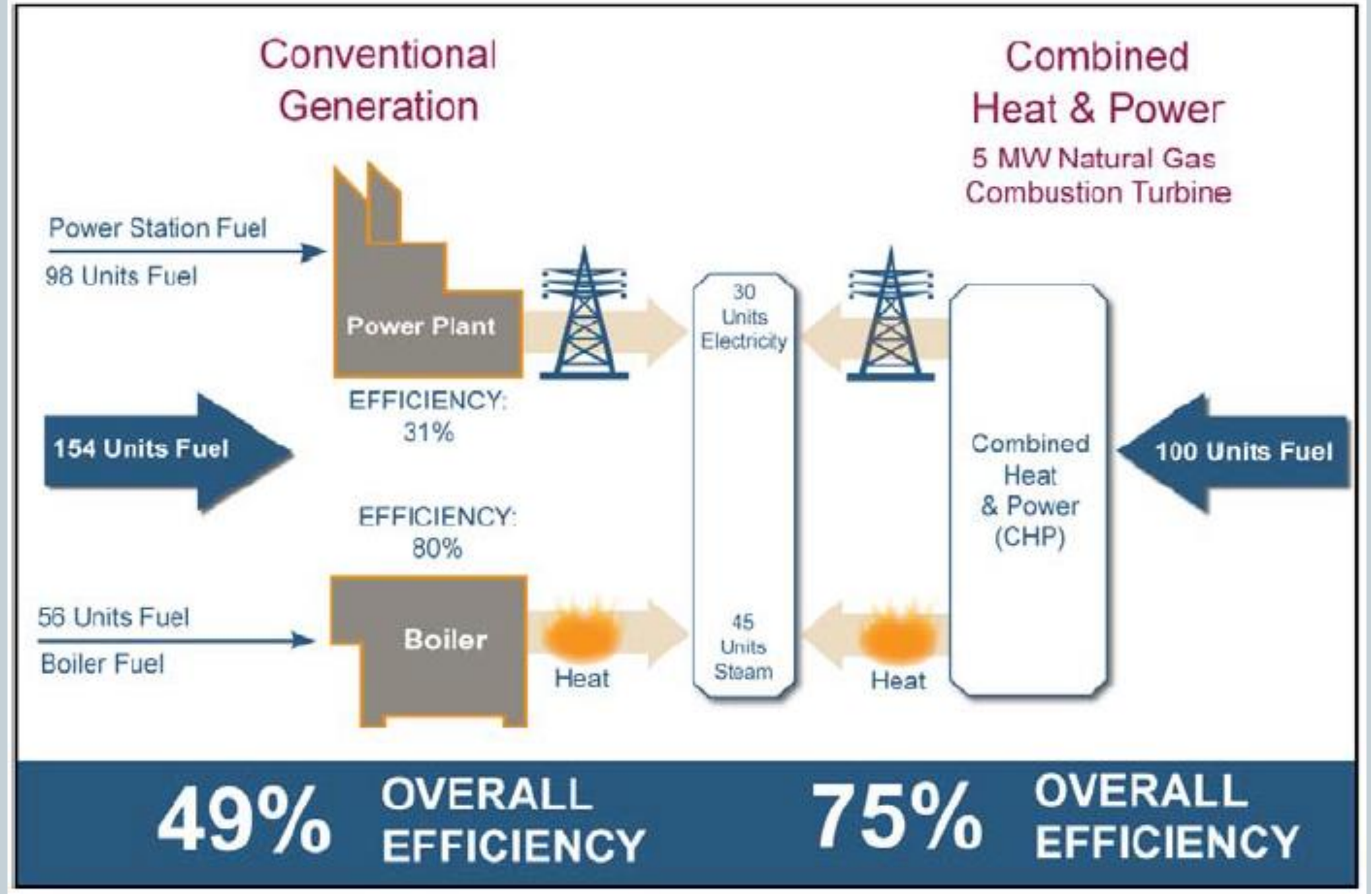
Heating

Two 500 MBH Condensing Boilers

- 84% Efficient
- Low Pressure (2psi) 2 inch gas pipe provided by Washington Gas Company
- Three hot water pumps with VFD's

CHP Introduction

Introduction



CHP Goals

- Simultaneous production of heat and power with on-site generation
- Reliable power during grid blackout or brownout
- Higher overall efficiencies
- Lower emissions

Absorption Cooling Goals

- Utilize waste heat in summer months
- Reduce existing chiller size
- Reduce power demand in summer months

Building Demand Profiles

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- **Combined Heat and Power Analysis**
  - CHP Introduction
  - **Building Demands Profiles**
  - CHP Demands
  - Primary Fuel Utilization Efficiency
  - Cost Analysis
  - Emissions
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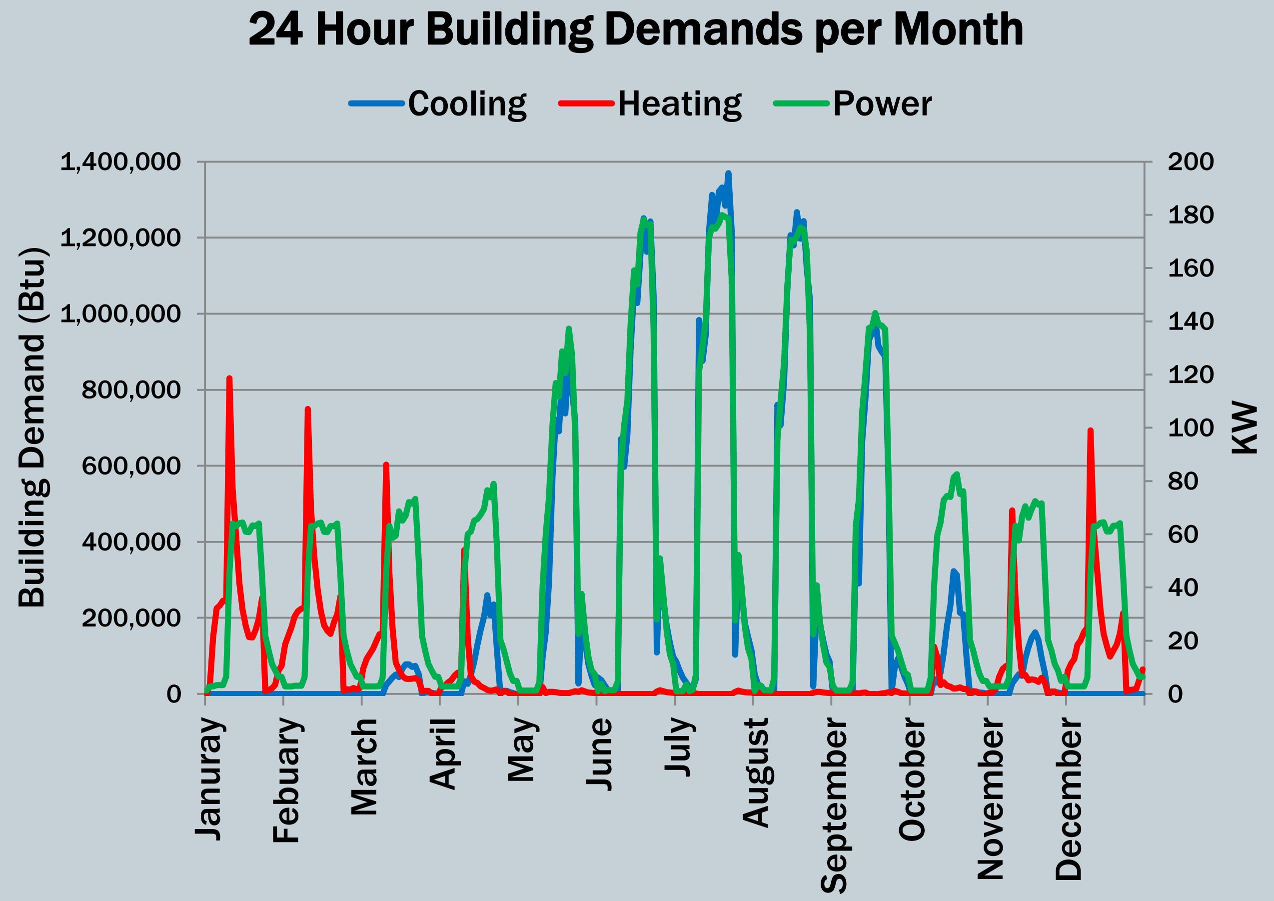

Spark Gap

- Difference between price of natural gas and electricity

	Price ($/MMBtu)	Spark Gap
Electricity	$ 38.00	$ 26.84
Natural Gas	$ 11.17	

Demands

- Thermal to power ratio

$$\lambda_D = \frac{Qq}{Qe}$$

- Driving factor

Demand	
Max Heating	830,403 Btu
Max Cooling	114 Ton
Max Power	179.95 KW
Average Heating	64,065 Btu
Average Cooling	17 Ton
Average Power	47.33 KW

Prime Movers

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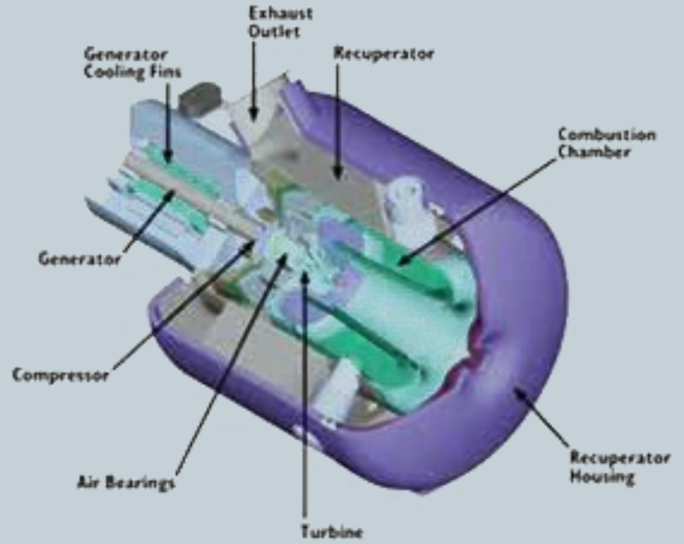
Table II: Summary of CHP Technologies

CHP system	Advantages	Disadvantages	Available sizes
Gas turbine	High reliability. Low emissions. High grade heat available. No cooling required.	Require high pressure gas or in-house gas compressor. Poor efficiency at low loading. Output falls as ambient temperature rises.	500 kW to 250 MW
Microturbine	Small number of moving parts. Compact size and light weight. Low emissions. No cooling required.	High costs. Relatively low mechanical efficiency. Limited to lower temperature cogeneration applications.	30 kW to 250 kW
Spark ignition (SI) reciprocating engine	High power efficiency with part-load operational flexibility. Fast start-up. Relatively low investment cost. Can be used in island mode and have good load following capability. Can be overhauled on site with normal operators. Operate on low-pressure gas.	High maintenance costs. Limited to lower temperature cogeneration applications. Relatively high air emissions. Must be cooled even if recovered heat is not used. High levels of low frequency noise.	< 5 MW in DG applications
Compression ignition (CI) reciprocating engine (dual fuel pilot ignition)			High speed (1,200 RPM) ≤4MW Low speed (102-514 RPM) 4-75 MW
Steam turbine	High overall efficiency. Any type of fuel may be used. Ability to meet more than one site heat grade requirement. Long working life and high reliability. Power to heat ratio can be varied.	Slow start up. Low power to heat ratio.	50 kW to 250 MW
Fuel Cells	Low emissions and low noise. High efficiency over load range. Modular design.	High costs. Low durability and power density. Fuels requiring processing unless pure hydrogen is used.	5 kW to 2 MW

Table from EPA

Microturbine

- Produce lowest power(15-250KW)
- Low electrical Efficiency
- Low Maintenance Cost
- Low emissions



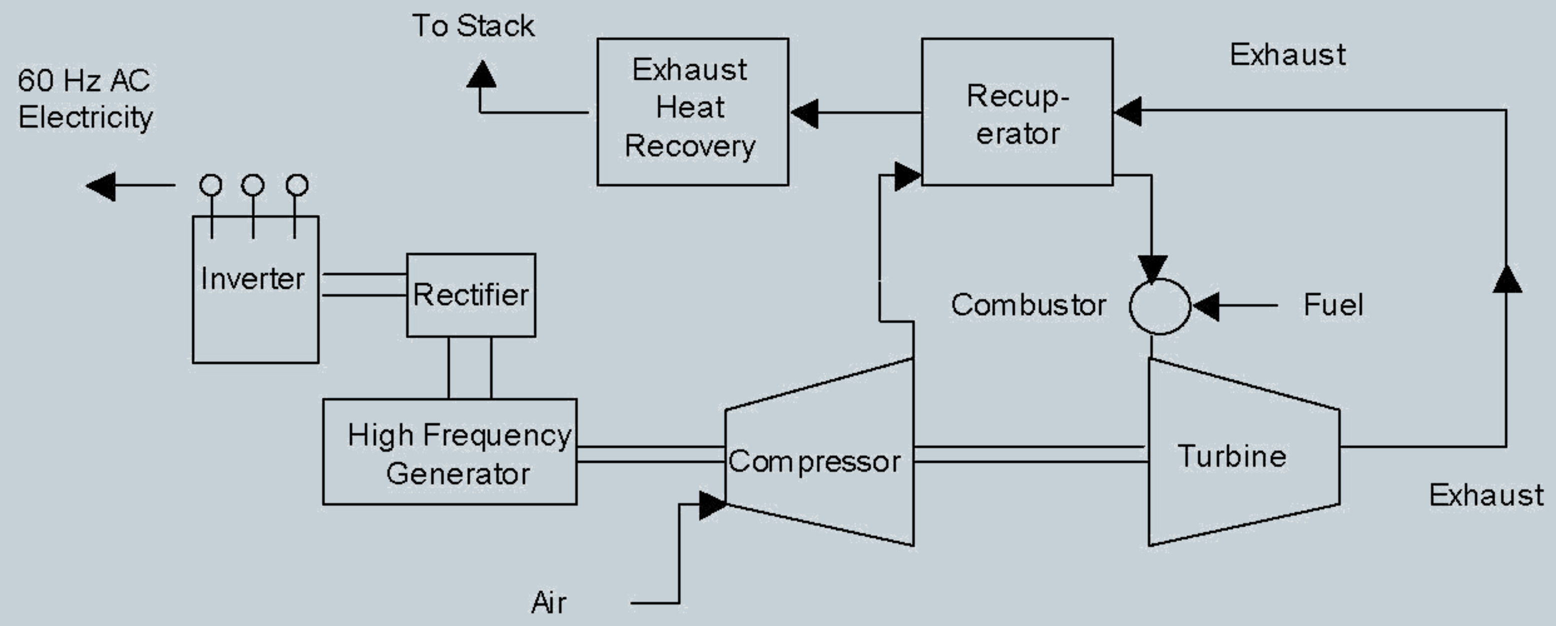
Capstone C30 Microturbine

Electrical Performance[2]	High Pressure
Electrical Power Output	30kW
Voltage	400–480 VAC
Electrical Service	3-Phase, 4 wire
Frequency	50/60 Hz, grid connect operation 10–60 Hz, stand alone operation
Maximum Output Current	46A, grid connect operation 46A, stand alone operation[3]
Electrical Efficiency LHV	26%

Fuel/Engine Characteristics[2]	High Pressure
Natural Gas HHV	30.7–47.5 MJ/m^3 (825–1,275 BTU/scf)
Inlet Pressure	379–414 kPa gauge (55–60 psig)
Fuel Flow HHV	457 MJ/hr (433,000 BTU/hr)
Net Heat Rate LHV	13.8 MJ/kWh (13,100 BTU/kWh)

Exhaust Characteristics[2]	High Pressure
NOx Emissions @ 15% O_2[4]	< 9 ppmvd (18 mg/m^3)
NOx / Electrical Output[4]	0.22 g/bhp-hr (0.64 lb/MWhe)
Exhaust Gas Flow	0.31 kg/s (0.68 lbm/s)
Exhaust Gas Temperature	275°C (530°F)

Prime Movers



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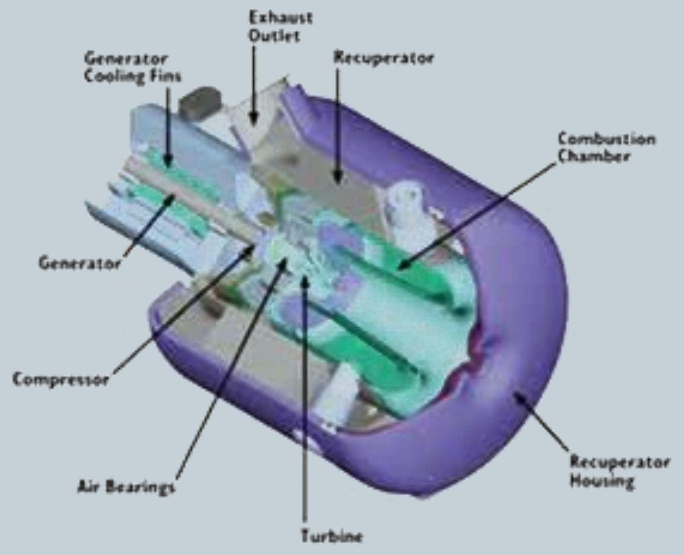

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Net Heat Rate

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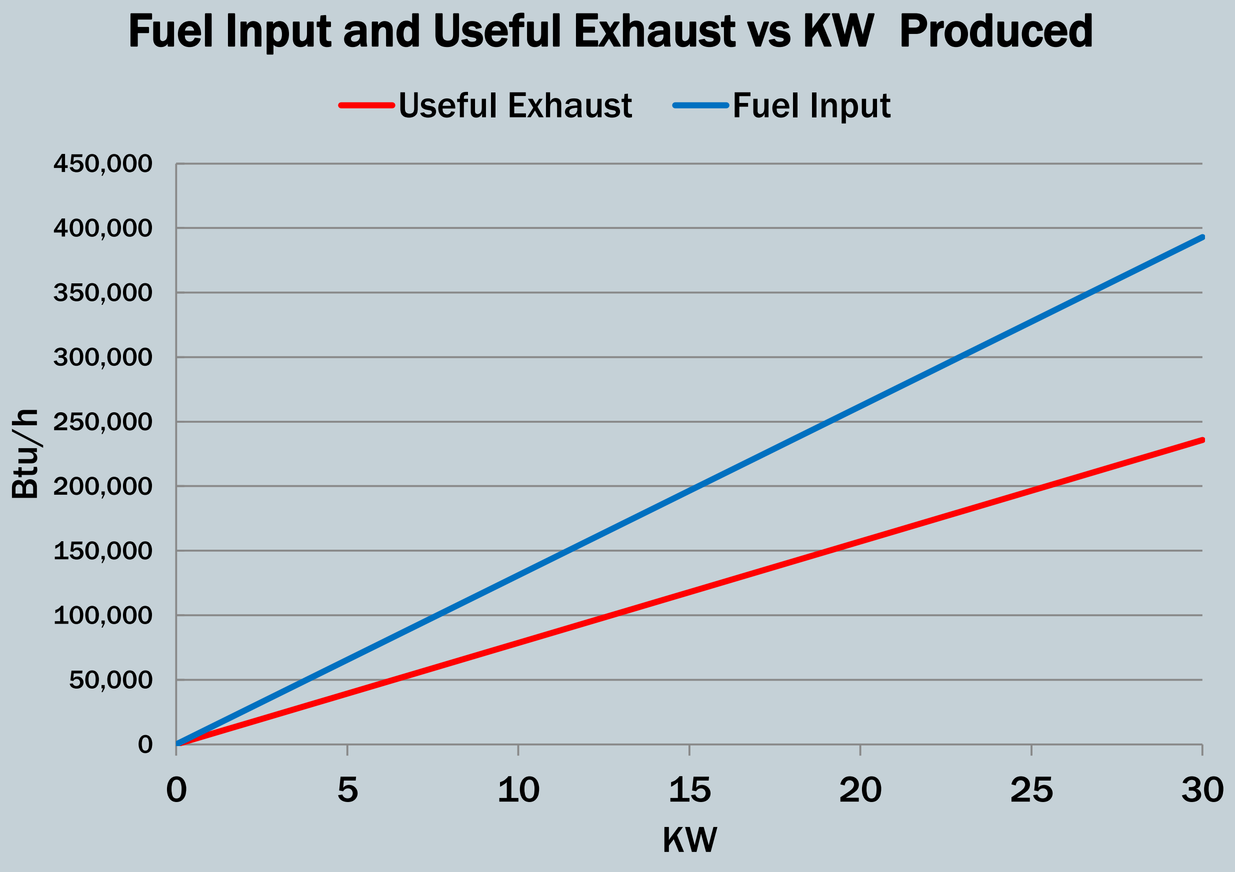

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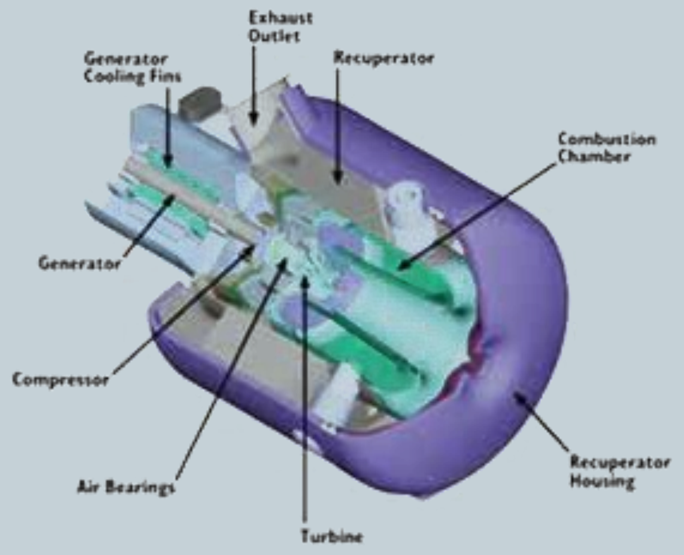

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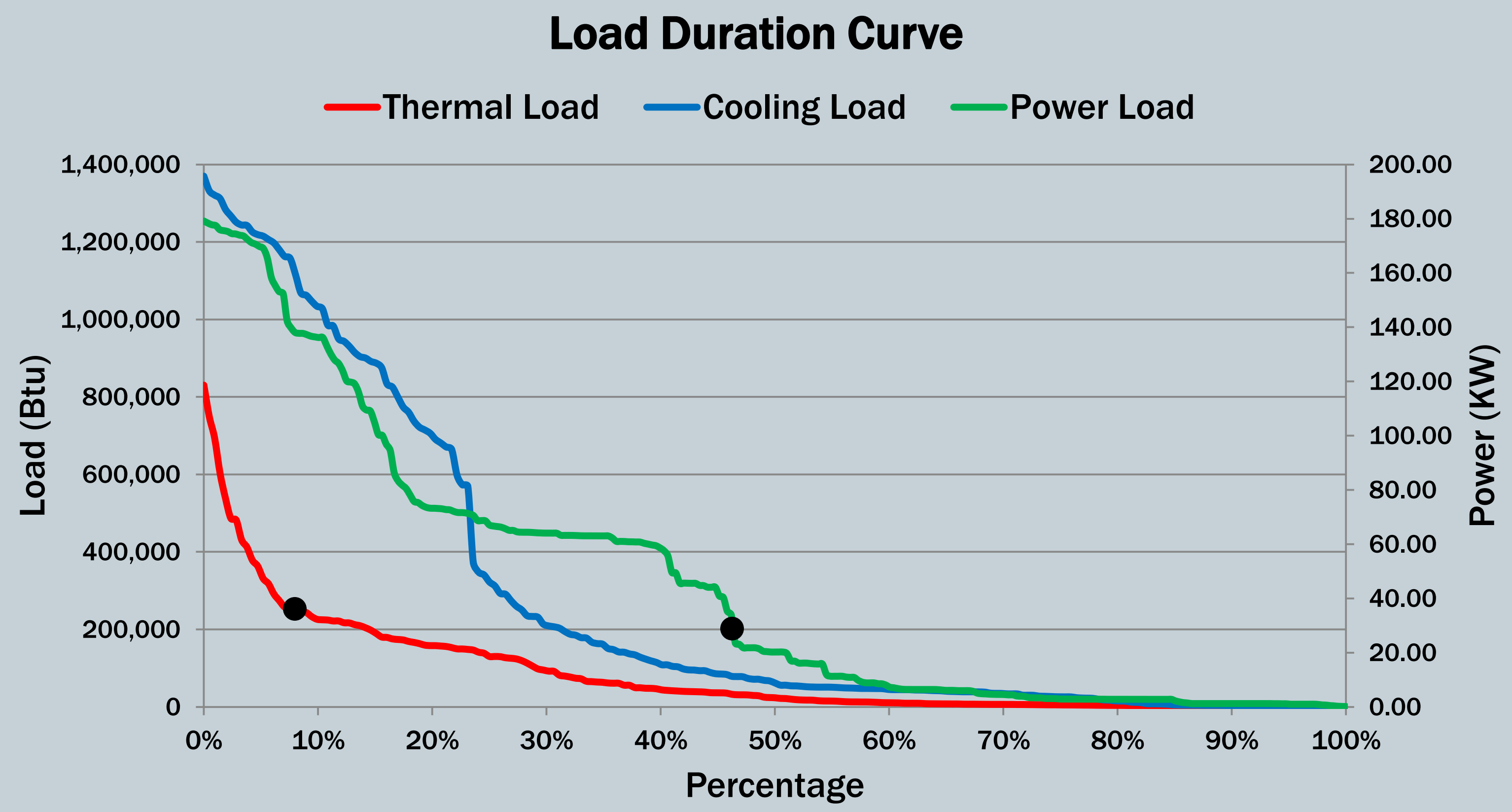

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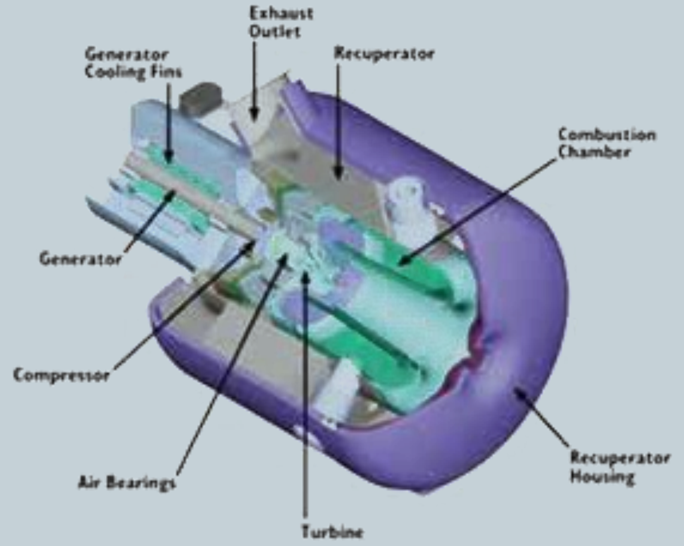

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Heating Demands

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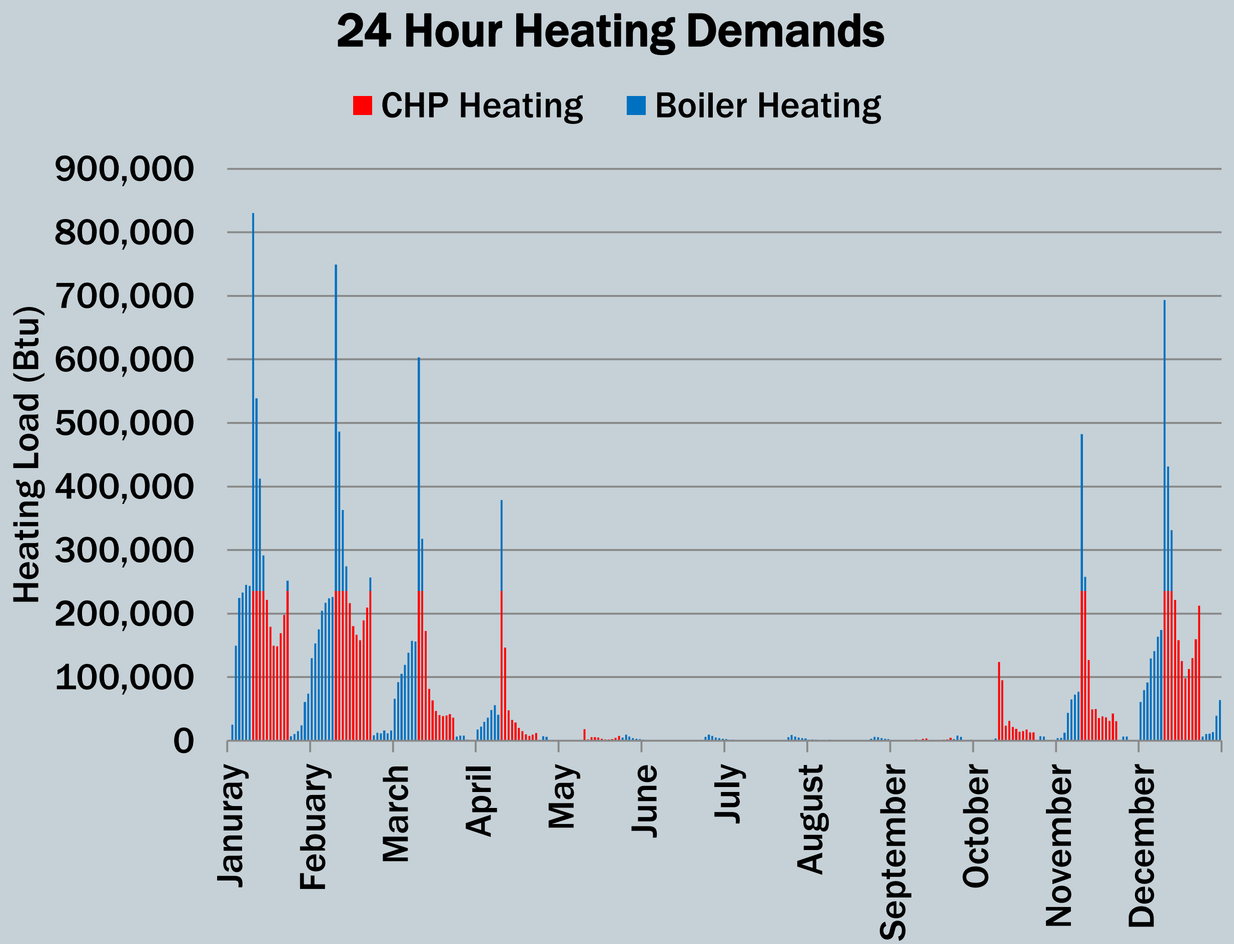

January Sample Calculations

CHP INPUT	
η_{CHP}	0.26
Turbine KW Produced	30 kw
Net Heat Rate	13100 btu/kw
η_{HRU}	0.6
η_{B}	0.84
η_{GTD}	0.33
Absorption Chiller COP	0.7

Month	Hour	Electric Demand (KW)	Monlthy Electric Consumption (KWh)	Heating (Btu)	Cooling (Tons)	Heat to Power Ratio (λ_D)	(λ_D) inclduing absorption cooling	Useful Exhaust (Btu)	$Q_{qD, CHP}$ (Btu)	$Q_{qD, Boiler}$ (Btu)	$e_{D, CHP}$ (KW)	$e_{D, GTD}$ (KW)	Absorption Cooling (Tons)	Electric Cooling (Tons)	Wasted Exhaust (Btu)	$f_{eD,CHP}$	$f_{eD, GTD}$	$f_{qD, CHP}$	$f_{qD, Boiler}$	Monlthy Electric Consumption From grid (KWh)	Sell back to Grid (KW)	Monlthy Electric Sell back To Grid (KWh)	Boiler Fuel Consumption (Therms/h)
January	1	1.22	26.93	0	0	0.00	0	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	26.93	0	0.00	0.000
	2	2.79	61.58	25,045	0	2.63	2.63	0	0	25045	0	3	0	0	0	0.000	1.000	0.000	1.000	61.58	0	0.00	0.250
	3	2.89	63.79	149,776	0	15.19	15.19	0	0	149776	0	3	0	0	0	0.000	1.000	0.000	1.000	63.79	0	0.00	1.498
	4	3.32	73.28	224,807	0	19.84	19.84	0	0	224807	0	3	0	0	0	0.000	1.000	0.000	1.000	73.28	0	0.00	2.248
	5	3.32	73.28	233,113	0	20.58	20.58	0	0	233113	0	3	0	0	0	0.000	1.000	0.000	1.000	73.28	0	0.00	2.331
	6	3.37	74.39	245,193	0	21.32	21.32	0	0	245193	0	3	0	0	0	0.000	1.000	0.000	1.000	74.39	0	0.00	2.452
	7	6.53	144.14	243,605	0	10.93	10.93	0	0	243605	0	7	0	0	0	0.000	1.000	0.000	1.000	144.14	0	0.00	2.436
	8	45.55	1005.42	830,403	0	5.34	5.34	235,800	235800	594603	30	16	0	0	0	0.888	0.112	0.284	0.716	105.42	0	0.00	5.946
	9	64.03	1413.33	538,896	0	2.47	2.47	235,800	235800	303096	30	34	0	0	0	0.632	0.368	0.438	0.562	513.33	0	0.00	3.031
	10	63.07	1392.14	412,184	0	1.92	1.92	235,800	235800	176384	30	33	0	0	0	0.642	0.358	0.572	0.428	492.14	0	0.00	1.764
	11	64.19	1416.86	291,334	0	1.33	1.33	235,800	235800	55534	30	34	0	0	0	0.630	0.370	0.809	0.191	516.86	0	0.00	0.555
	12	64.38	1421.05	221,791	0	1.01	1.01	235,800	221791	0	30	34	0	0	14,009	0.591	0.409	1.000	0.000	521.05	0	0.00	0.000
	13	60.89	1344.02	179,292	0	0.86	0.86	235,800	179292	0	30	31	0	0	56,508	0.505	0.495	1.000	0.000	444.02	0	0.00	0.000
	14	60.81	1342.25	149,512	0	0.72	0.72	235,800	149512	0	30	31	0	0	86,288	0.422	0.578	1.000	0.000	442.25	0	0.00	0.000
	15	63.28	1396.77	148,331	0	0.69	0.69	235,800	148331	0	30	33	0	0	87,469	0.402	0.598	1.000	0.000	496.77	0	0.00	0.000
	16	63.11	1393.02	168,958	0	0.78	0.78	235,800	168958	0	30	33	0	0	66,842	0.459	0.541	1.000	0.000	493.02	0	0.00	0.000
	17	64.08	1414.43	197,948	0	0.91	0.91	235,800	197948	0	30	34	0	0	37,852	0.530	0.470	1.000	0.000	514.43	0	0.00	0.000
	18	44.08	972.97	251,764	0	1.67	1.67	235,800	235800	15964	30	14	0	0	0	0.918	0.082	0.937	0.063	72.97	0	0.00	0.160
	19	21.79	480.97	6,995	0	0.09	0.09	0	0	6995	0	22	0	0	0	0.000	1.000	0.000	1.000	480.97	0	0.00	0.070
	20	16.15	356.48	10,771	0	0.20	0.20	0	0	10771	0	16	0	0	0	0.000	1.000	0.000	1.000	356.48	0	0.00	0.108
	21	11.29	249.20	15,158	0	0.39	0.39	0	0	15158	0	11	0	0	0	0.000	1.000	0.000	1.000	249.20	0	0.00	0.152
	22	8.86	195.57	24,148	0	0.80	0.80	0	0	24148	0	9	0	0	0	0.000	1.000	0.000	1.000	195.57	0	0.00	0.241
	23	6.42	141.71	60,965	0	2.78	2.78	0	0	60965	0	6	0	0	0	0.000	1.000	0.000	1.000	141.71	0	0.00	0.610
	24	6.43	141.93	73,999	0	3.37	3.37	0	0	73999.38	0	6.43	0	0	0	0.000	1.000	0	1	141.93	0	0.00	0.7399938

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Cooling Demands

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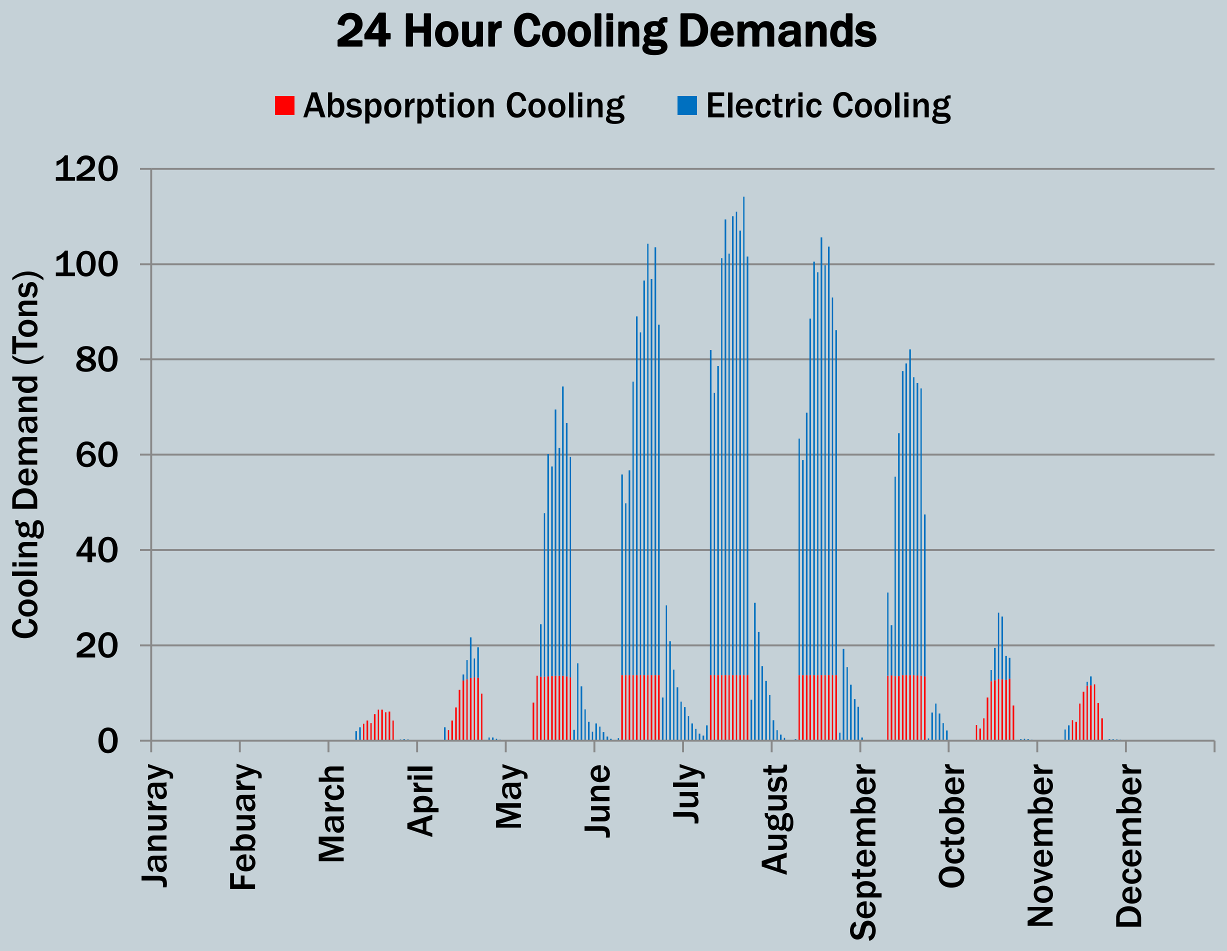

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January	1	1.22	26.93	0	0	0.00	0	0	0	0	0	1
	2	2.79	61.58	25,045	0	2.63	2.63	0	0	25045	0	3
	3	2.89	63.79	149,776	0	15.19	15.19	0	0	149776	0	3
	4	3.32	73.28	224,807	0	19.84	19.84	0	0	224807	0	3
	5	3.32	73.28	233,113	0	20.58	20.58	0	0	233113	0	3
	6	3.37	74.39	245,193	0	21.32	21.32	0	0	245193	0	3
	7	6.53	144.14	243,605	0	10.93	10.93	0	0	243605	0	7
	8	45.55	1005.42	830,403	0	5.34	5.34	235,800	235800	594603	30	16
	9	64.03	1413.33	538,896	0	2.47	2.47	235,800	235800	303096	30	34
	10	63.07	1392.14	412,184	0	1.92	1.92	235,800	235800	176384	30	33
	11	64.19	1416.86	291,334	0	1.33	1.33	235,800	235800	55534	30	34
	12	64.38	1421.05	221,791	0	1.01	1.01	235,800	221791	0	30	34
	13	60.89	1344.02	179,292	0	0.86	0.86	235,800	179292	0	30	31
	14	60.81	1342.25	149,512	0	0.72	0.72	235,800	149512	0	30	31
	15	63.28	1396.77	148,331	0	0.69	0.69	235,800	148331	0	30	33
	16	63.11	1393.02	168,958	0	0.78	0.78	235,800	168958	0	30	33
	17	64.08	1414.43	197,948	0	0.91	0.91	235,800	197948	0	30	34
	18	44.08	972.97	251,764	0	1.67	1.67	235,800	235800	15964	30	14
	19	21.79	480.97	6,995	0	0.09	0.09	0	0	6995	0	22
	20	16.15	356.48	10,771	0	0.20	0.20	0	0	10771	0	16
	21	11.29	249.20	15,158	0	0.39	0.39	0	0	15158	0	11
	22	8.86	195.57	24,148	0	0.80	0.80	0	0	24148	0	9
	23	6.42	141.71	60,965	0	2.78	2.78	0	0	60965	0	6
	24	6.43	141.93	73,999	0	3.37	3.37	0	0	73999.38	0	6.43

Hour	Absorption Cooling (Tons)	Electric Cooling (Tons)	Wasted Exhaust (Btu)	$f_{eD,CHP}$	$f_{eD, Grid}$	$f_{qD, CHP}$	$f_{qD, Boiler}$	Monlthy Electric Consumption From grid (KWh)	Sell back to Grid (KW)	Monlthy Electric Sell back To Grid (KWh)	Boiler Fuel Consumption (Therms/h)
1	0	0	0	0.000	1.000	0.000	0.000	26.93	0	0.00	0.000
2	0	0	0	0.000	1.000	0.000	1.000	61.58	0	0.00	0.250
3	0	0	0	0.000	1.000	0.000	1.000	63.79	0	0.00	1.498
4	0	0	0	0.000	1.000	0.000	1.000	73.28	0	0.00	2.248
5	0	0	0	0.000	1.000	0.000	1.000	73.28	0	0.00	2.331
6	0	0	0	0.000	1.000	0.000	1.000	74.39	0	0.00	2.452
7	0	0	0	0.000	1.000	0.000	1.000	144.14	0	0.00	2.436
8	0	0	0	0.888	0.112	0.284	0.716	105.42	0	0.00	5.946
9	0	0	0	0.632	0.368	0.438	0.562	513.33	0	0.00	3.031
10	0	0	0	0.642	0.358	0.572	0.428	492.14	0	0.00	1.764
11	0	0	0	0.630	0.370	0.809	0.191	516.86	0	0.00	0.555
12	0	0	14,009	0.591	0.409	1.000	0.000	521.05	0	0.00	0.000
13	0	0	56,508	0.505	0.495	1.000	0.000	444.02	0	0.00	0.000
14	0	0	86,288	0.422	0.578	1.000	0.000	442.25	0	0.00	0.000
15	0	0	87,469	0.402	0.598	1.000	0.000	496.77	0	0.00	0.000
16	0	0	66,842	0.459	0.541	1.000	0.000	493.02	0	0.00	0.000
17	0	0	37,852	0.530	0.470	1.000	0.000	514.43	0	0.00	0.000
18	0	0	0	0.918	0.082	0.937	0.063	72.97	0	0.00	0.160
19	0	0	0	0.000	1.000	0.000	1.000	480.97	0	0.00	0.070
20	0	0	0	0.000	1.000	0.000	1.000	356.48	0	0.00	0.108
21	0	0	0	0.000	1.000	0.000	1.000	249.20	0	0.00	0.152
22	0	0	0	0.000	1.000	0.000	1.000	195.57	0	0.00	0.241
23	0	0	0	0.000	1.000	0.000	1.000	141.71	0	0.00	0.610
24	0	0	0	0.000	1.000	0	1	141.93	0	0.00	0.7399938

Renovation to Father O'Connell Hall

Power Demands

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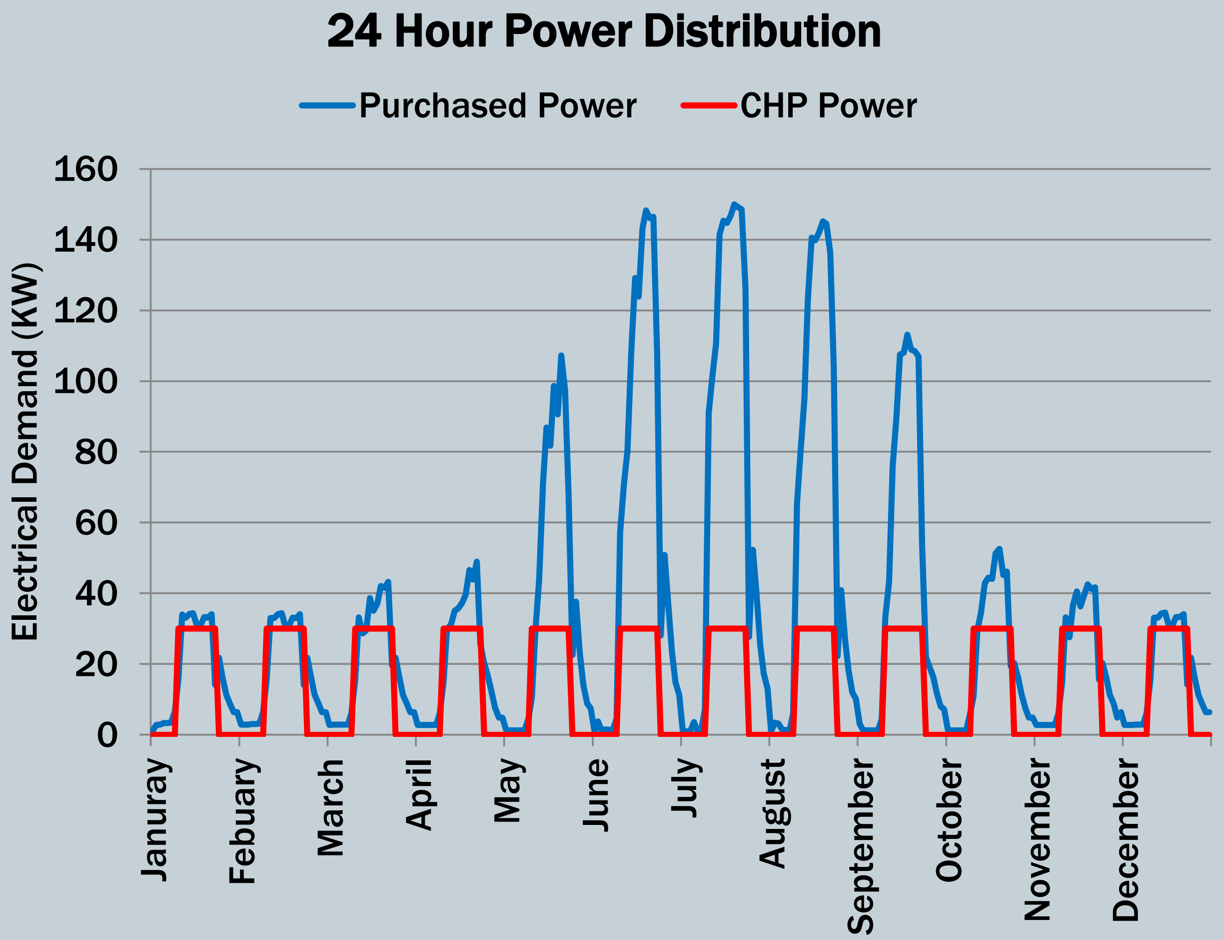

January Sample Calculations

CHP INPUT	
η_{CHP}	0.26
Turbine KW Produced	30 kw
Net Heat Rate	13100 btu/kw
η_{HRU}	0.6
η_{B}	0.84
η_{GTD}	0.33
Absorption Chiller COP	0.7

Month	Hour	Electric Demand (KW)	Monlthy Electric Consumption (KWh)	Heating (Btu)	Cooling (Tons)	Heat to Power Ratio (λ_0)	(λ_0) inclduing absorption cooling	Useful Exhaust (Btu)	$Q_{q0, CHP}$ (Btu)	$Q_{q0, Boiler}$ (Btu)	$e_{0, CHP}$ (KW)	$e_{0, Grid}$ (KW)	Absorption Cooling (Tons)	Electric Cooling (Tons)	Wasted Exhaust (Btu)	$f_{e0,CHP}$	$f_{e0, Grid}$	$f_{q0, CHP}$	$f_{q0, Boiler}$	Monlthy Electric Consumption From grid (KWh)	Sell back to Grid (KW)	Monlthy Electric Sell back To Grid (KWh)	Boiler Fuel Consumption (Therms/h)
January	1	1.22	26.93	0	0	0.00	0	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	26.93	0	0.00	0.000
	2	2.79	61.58	25,045	0	2.63	2.63	0	0	25045	0	3	0	0	0	0.000	1.000	0.000	1.000	61.58	0	0.00	0.250
	3	2.89	63.79	149,776	0	15.19	15.19	0	0	149776	0	3	0	0	0	0.000	1.000	0.000	1.000	63.79	0	0.00	1.498
	4	3.32	73.28	224,807	0	19.84	19.84	0	0	224807	0	3	0	0	0	0.000	1.000	0.000	1.000	73.28	0	0.00	2.248
	5	3.32	73.28	233,113	0	20.58	20.58	0	0	233113	0	3	0	0	0	0.000	1.000	0.000	1.000	73.28	0	0.00	2.331
	6	3.37	74.39	245,193	0	21.32	21.32	0	0	245193	0	3	0	0	0	0.000	1.000	0.000	1.000	74.39	0	0.00	2.452
	7	6.53	144.14	243,605	0	10.93	10.93	0	0	243605	0	7	0	0	0	0.000	1.000	0.000	1.000	144.14	0	0.00	2.436
	8	45.55	1005.42	830,403	0	5.34	5.34	235,800	235800	594603	30	16	0	0	0	0.888	0.112	0.284	0.716	105.42	0	0.00	5.946
	9	64.03	1413.33	538,896	0	2.47	2.47	235,800	235800	303096	30	34	0	0	0	0.632	0.368	0.438	0.562	513.33	0	0.00	3.031
	10	63.07	1392.14	412,184	0	1.92	1.92	235,800	235800	176384	30	33	0	0	0	0.642	0.358	0.572	0.428	492.14	0	0.00	1.764
	11	64.19	1416.86	291,334	0	1.33	1.33	235,800	235800	55534	30	34	0	0	0	0.630	0.370	0.809	0.191	516.86	0	0.00	0.555
	12	64.38	1421.05	221,791	0	1.01	1.01	235,800	221791	0	30	34	0	0	14,009	0.591	0.409	1.000	0.000	521.05	0	0.00	0.000
	13	60.89	1344.02	179,292	0	0.86	0.86	235,800	179292	0	30	31	0	0	56,508	0.505	0.495	1.000	0.000	444.02	0	0.00	0.000
	14	60.81	1342.25	149,512	0	0.72	0.72	235,800	149512	0	30	31	0	0	86,288	0.422	0.578	1.000	0.000	442.25	0	0.00	0.000
	15	63.28	1396.77	148,331	0	0.69	0.69	235,800	148331	0	30	33	0	0	87,469	0.402	0.598	1.000	0.000	496.77	0	0.00	0.000
	16	63.11	1393.02	168,958	0	0.78	0.78	235,800	168958	0	30	33	0	0	66,842	0.459	0.541	1.000	0.000	493.02	0	0.00	0.000
	17	64.08	1414.43	197,948	0	0.91	0.91	235,800	197948	0	30	34	0	0	37,852	0.530	0.470	1.000	0.000	514.43	0	0.00	0.000
	18	44.08	972.97	251,764	0	1.67	1.67	235,800	235800	15964	30	14	0	0	0	0.918	0.082	0.937	0.063	72.97	0	0.00	0.160
	19	21.79	480.97	6,995	0	0.09	0.09	0	0	6995	0	22	0	0	0	0.000	1.000	0.000	1.000	480.97	0	0.00	0.070
	20	16.15	356.48	10,771	0	0.20	0.20	0	0	10771	0	16	0	0	0	0.000	1.000	0.000	1.000	356.48	0	0.00	0.108
	21	11.29	249.20	15,158	0	0.39	0.39	0	0	15158	0	11	0	0	0	0.000	1.000	0.000	1.000	249.20	0	0.00	0.152
	22	8.86	195.57	24,148	0	0.80	0.80	0	0	24148	0	9	0	0	0	0.000	1.000	0.000	1.000	195.57	0	0.00	0.241
	23	6.42	141.71	60,965	0	2.78	2.78	0	0	60965	0	6	0	0	0	0.000	1.000	0.000	1.000	141.71	0	0.00	0.610
	24	6.43	141.93	73,999	0	3.37	3.37	0	0	73999.38	0	6.43	0	0	0	0.000	1.000	0	1	141.93	0	0.00	0.7399938

Renovation to Father O'Connell Hall

Useful Waste Heat

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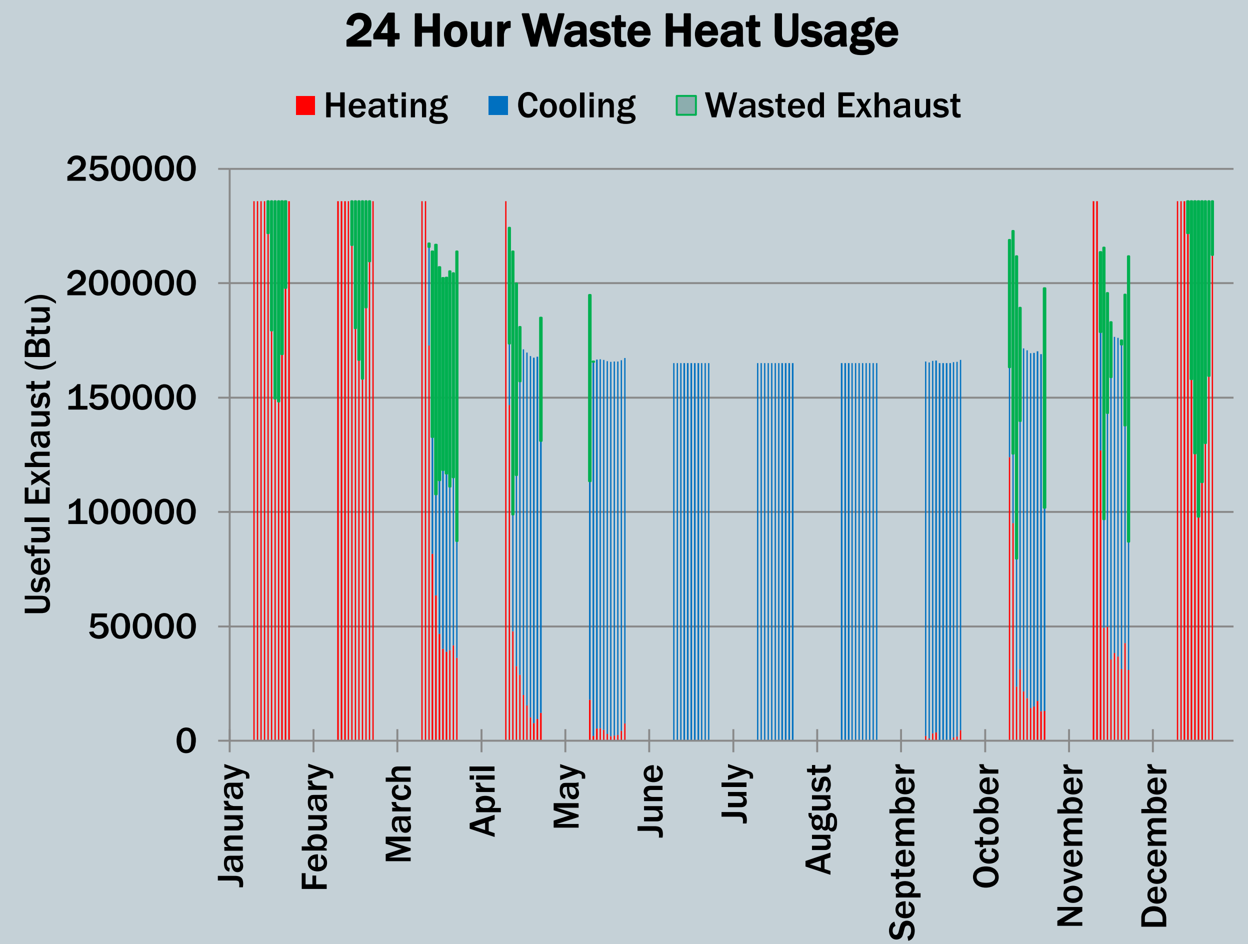

January Sample Calculations

CHP INPUT	
$\acute{\eta}_{CHP}$	0.26
Turbine KW Produced	30 kw
Net Heat Rate	13100 btu/kw
$\acute{\eta}_{HRU}$	0.6
$\acute{\eta}_{B}$	0.84
$\acute{\eta}_{GTD}$	0.33
Absorption Chiller COP	0.7

Month	Hour	Electric Demand (KW)	Monlthy Electric Consumption (KWh)	Heating (Btu)	Cooling (Tons)	Heat to Power Ratio (λ_D)	(λ_D) incilduing absorption cooling	Useful Exhaust (Btu)	$Q_{qD,CHP}$ (Btu)	$Q_{qD,Boiler}$ (Btu)	$e_{D,CHP}$ (KW)	$e_{D,GTD}$ (KW)	Absorption Cooling (Tons)	Electric Cooling (Tons)	Wasted Exhaust (Btu)	$f_{eD,CHP}$	$f_{eD,GTD}$	$f_{qD,CHP}$	$f_{qD,Boiler}$	Monlthy Electric Consumption From grid (KWh)	Sell back to Grid (KW)	Monlthy Electric Sell back To Grid (KWh)	Boiler Fuel Consumption (Therms/h)
January	1	1.22	26.93	0	0	0.00	0	0	0	0	0	1	0	0	0	0.000	1.000	0.000	0.000	26.93	0	0.00	0.000
	2	2.79	61.58	25,045	0	2.63	2.63	0	0	25045	0	3	0	0	0	0.000	1.000	0.000	1.000	61.58	0	0.00	0.250
	3	2.89	63.79	149,776	0	15.19	15.19	0	0	149776	0	3	0	0	0	0.000	1.000	0.000	1.000	63.79	0	0.00	1.498
	4	3.32	73.28	224,807	0	19.84	19.84	0	0	224807	0	3	0	0	0	0.000	1.000	0.000	1.000	73.28	0	0.00	2.248
	5	3.32	73.28	233,113	0	20.58	20.58	0	0	233113	0	3	0	0	0	0.000	1.000	0.000	1.000	73.28	0	0.00	2.331
	6	3.37	74.39	245,193	0	21.32	21.32	0	0	245193	0	3	0	0	0	0.000	1.000	0.000	1.000	74.39	0	0.00	2.452
	7	6.53	144.14	243,605	0	10.93	10.93	0	0	243605	0	7	0	0	0	0.000	1.000	0.000	1.000	144.14	0	0.00	2.436
	8	45.55	1005.42	830,403	0	5.34	5.34	235,800	235800	594603	30	16	0	0	0	0.888	0.112	0.284	0.716	105.42	0	0.00	5.946
	9	64.03	1413.33	538,896	0	2.47	2.47	235,800	235800	303096	30	34	0	0	0	0.632	0.368	0.438	0.562	513.33	0	0.00	3.031
	10	63.07	1392.14	412,184	0	1.92	1.92	235,800	235800	176384	30	33	0	0	0	0.642	0.358	0.572	0.428	492.14	0	0.00	1.764
	11	64.19	1416.86	291,334	0	1.33	1.33	235,800	235800	55534	30	34	0	0	0	0.630	0.370	0.809	0.191	516.86	0	0.00	0.555
	12	64.38	1421.05	221,791	0	1.01	1.01	235,800	221791	0	30	34	0	0	14,009	0.591	0.409	1.000	0.000	521.05	0	0.00	0.000
	13	60.89	1344.02	179,292	0	0.86	0.86	235,800	179292	0	30	31	0	0	56,508	0.505	0.495	1.000	0.000	444.02	0	0.00	0.000
	14	60.81	1342.25	149,512	0	0.72	0.72	235,800	149512	0	30	31	0	0	86,288	0.422	0.578	1.000	0.000	442.25	0	0.00	0.000
	15	63.28	1396.77	148,331	0	0.69	0.69	235,800	148331	0	30	33	0	0	87,469	0.402	0.598	1.000	0.000	496.77	0	0.00	0.000
	16	63.11	1393.02	168,958	0	0.78	0.78	235,800	168958	0	30	33	0	0	66,842	0.459	0.541	1.000	0.000	493.02	0	0.00	0.000
	17	64.08	1414.43	197,948	0	0.91	0.91	235,800	197948	0	30	34	0	0	37,852	0.530	0.470	1.000	0.000	514.43	0	0.00	0.000
	18	44.08	972.97	251,764	0	1.67	1.67	235,800	235800	15964	30	14	0	0	0	0.918	0.082	0.937	0.063	72.97	0	0.00	0.160
	19	21.79	480.97	6,995	0	0.09	0.09	0	0	6995	0	22	0	0	0	0.000	1.000	0.000	1.000	480.97	0	0.00	0.070
	20	16.15	356.48	10,771	0	0.20	0.20	0	0	10771	0	16	0	0	0	0.000	1.000	0.000	1.000	356.48	0	0.00	0.108
	21	11.29	249.20	15,158	0	0.39	0.39	0	0	15158	0	11	0	0	0	0.000	1.000	0.000	1.000	249.20	0	0.00	0.152
	22	8.86	195.57	24,148	0	0.80	0.80	0	0	24148	0	9	0	0	0	0.000	1.000	0.000	1.000	195.57	0	0.00	0.241
	23	6.42	141.71	60,965	0	2.78	2.78	0	0	60965	0	6	0	0	0	0.000	1.000	0.000	1.000	141.71	0	0.00	0.610
	24	6.43	141.93	73,999	0	3.37	3.37	0	0	73999.38	0	6.43	0	0	0	0.000	1.000	0	1	141.93	0	0.00	0.7399938

Renovation to Father O'Connell Hall   Primary Fuel Utilization Efficiency   The Catholic University Of America

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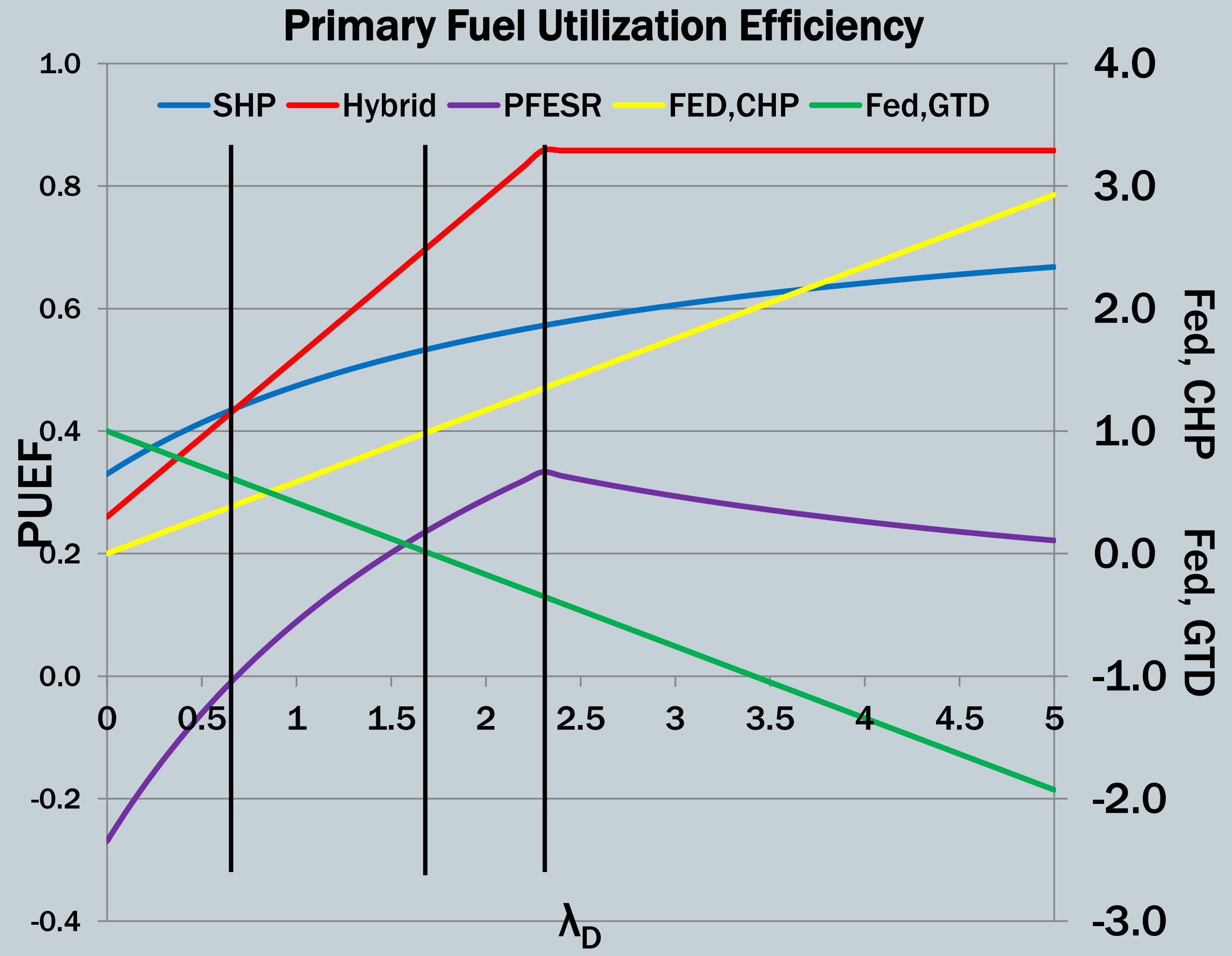

CHP vs SHP

$$PEUF_{SHP} = \frac{\eta_{GTD}\eta_B(1+\lambda_D)}{\eta_B + \eta_{GTD}\lambda_D}$$

$$PEUF_{CHP} = \eta_{eCHP}(1+\lambda_D)$$

$$PEUF_{Hybrid} = \frac{\eta_{CHP}\eta_{GTD}\eta_B\ (1+\lambda_D)}{(\eta_{CHP}\eta_B f_{eD,GTD} + \eta_{GTD}\eta_B f_{eD,CHP} + \eta_{GTD}\eta_{CHP}\lambda_{QD,B}}$$

CHP INPUT	
$ή_{CHP}$	0.26
KW Produced	30kw
Net Heat Rate	13100btu/kw
$ή_{HRU}$	0.6
$ή_B$	0.84
$ή_{GTD}$	0.33
Absorption Chiller COP	0.7

Renovation to Father O'Connell Hall **Primary Fuel Utilization Efficiency** The Catholic University Of America

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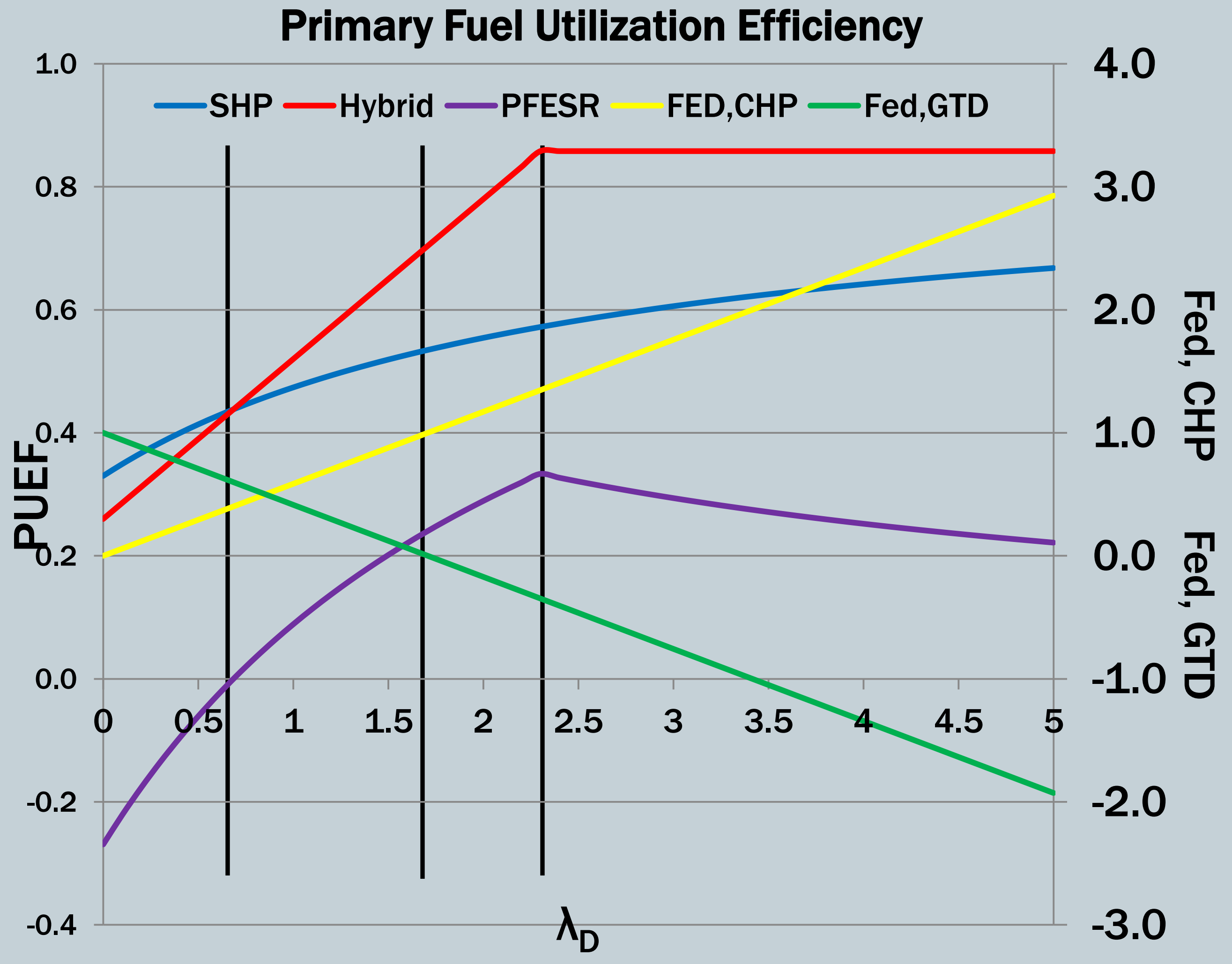

Primary Fuel Utilization Efficiency (PUEF)

λ_D < 0.7 SHP has a higher PUEF
λ_D > 0.7 CHP has a higher PUEF
λ_D > 1.7 start over producing electricity and start to lose money
λ_D = 2.3 maximum PUEF and percent fuel savings ratio
λ_D < 2.3 start supplemental boiler and PFESR starts to decline but still positive

CHP INPUT	
$ή_{CHP}$	0.26
KW Produced	30kw
Net Heat Rate	13100btu/kw
$ή_{HRU}$	0.6
$ή_{B}$	0.84
$ή_{GTD}$	0.33
Absorption Chiller COP	0.7

Renovation to Father O'Connell Hall   Primary Fuel Utilization Efficiency   The Catholic University Of America

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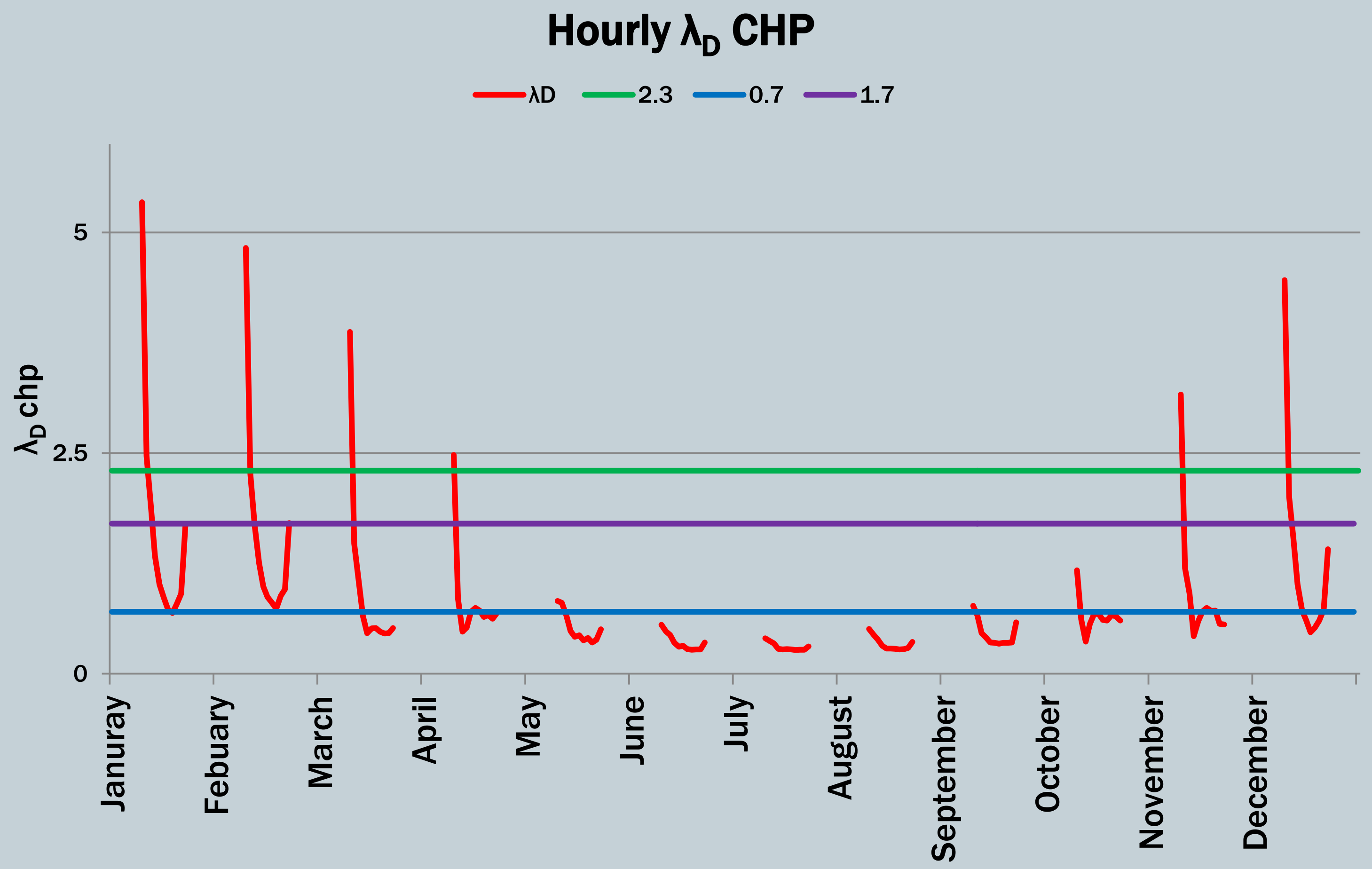

Primary Fuel Utilization Efficiency (PUEF)

λ_D < 0.7 SHP has a higher PUEF
λ_D > 0.7 CHP has a higher PUEF
λ_D > 1.7 start over producing electricity and start to lose money
λ_D = 2.3 maximum PUEF and percent fuel savings ratio
λ_D < 2.3 start supplemental boiler and PFESR starts to decline but still positive

CHP INPUT	
$ή_{CHP}$	0.26
KW Produced	30kw
Net Heat Rate	13100btu/kw
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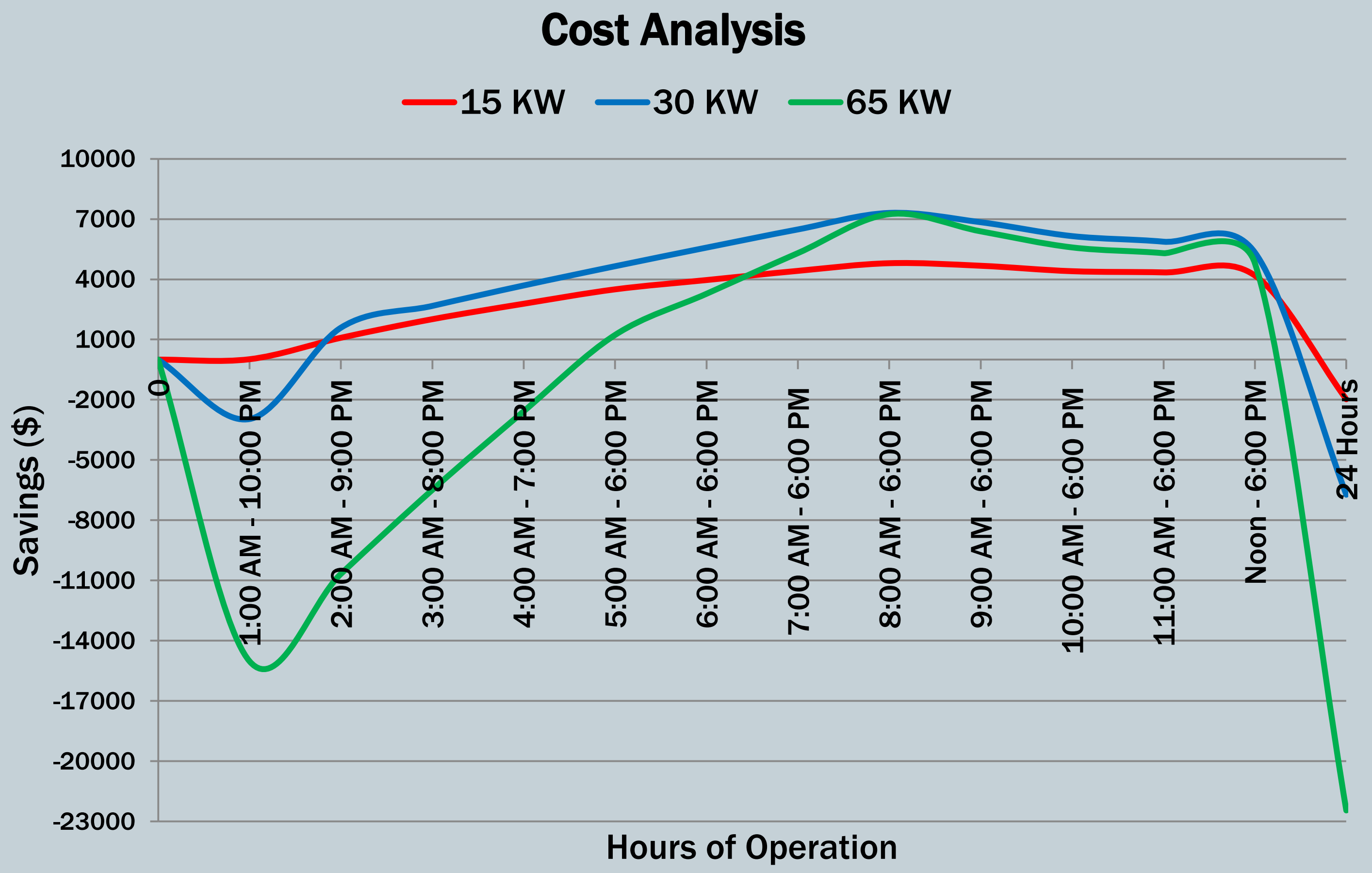
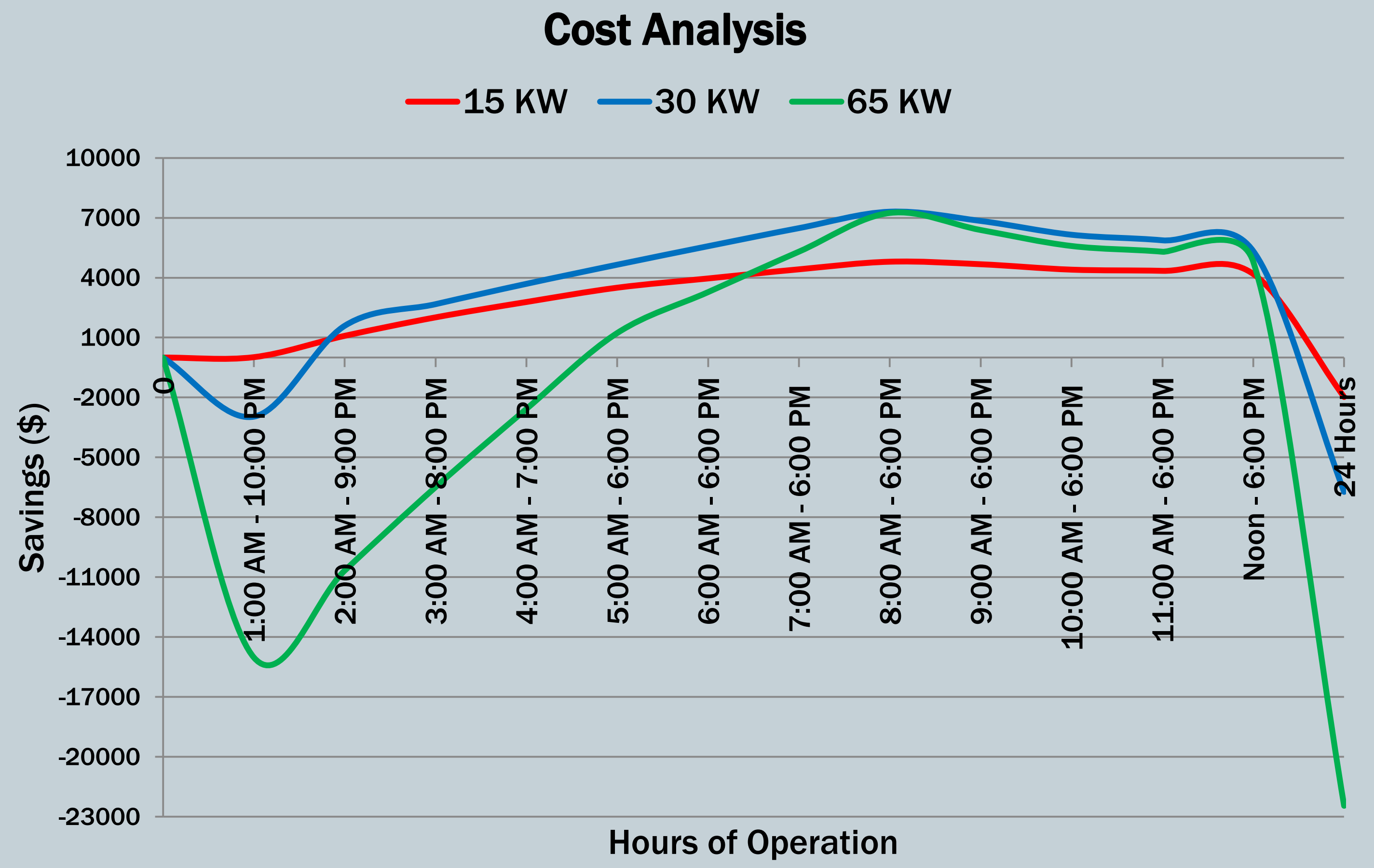


Cost Analysis

Total System Savings							
Turbine	CHP Cost			SHP Cost			Savings
	Electricity	Natural Gas	Total	Electricity	Natural Gas	Total	
30KW	$23,403.95	$18,784.19	$42,188.14	$40,402.75	$9,090.30	$49,493.05	$7,304.90

Cost Analysis

- Introduction
- **Combined Heat and Power Analysis**
  - CHP Introduction
  - Building Demands Profiles
  - CHP Demands
  - Primary Fuel Utilization Efficiency
  - **Cost Analysis**
  - Emissions
- Electrical Breath
- Conclusion
- Acknowledgments
- Questions



Payback Period

Equipment	Installed Cost		
	Cost	CHP	SHP
500 MBH Condensing Boiler	$ 11,206.00	$0.00	$22,412.00
600 MBH Condensing Boiler	$ 14,483.00	$14,483.00	$0.00
20 Ton Absorption Chiller	1250 $/Ton	$25,000.00	$0.00
30 KW Microturbine	2790 $/KW	$83,700.00	$0.00
	Total	$123,183.00	$22,412.00
	Savings	$ 7,304.90	
	Payback Period	13.8	Years

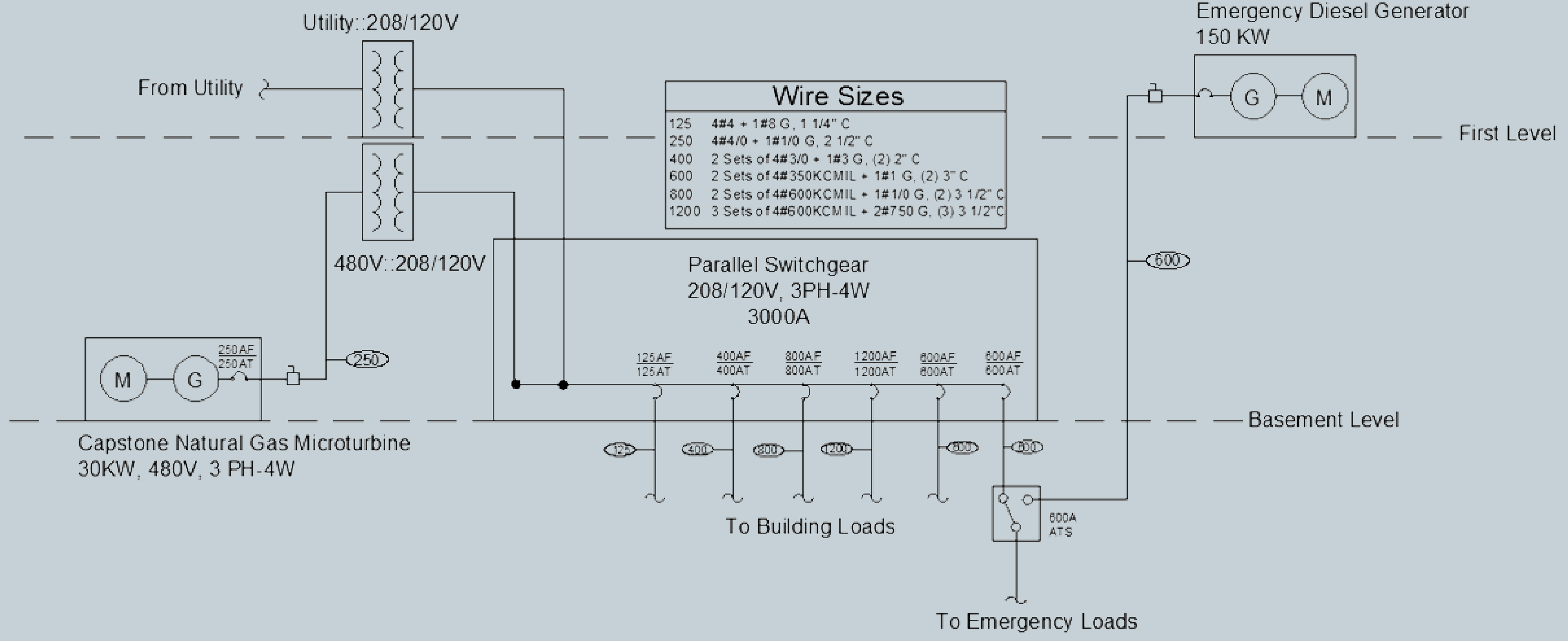
Annual Emissions Analysis

	CHP System	Displaced Electricity Production	Displaced Thermal Production	Emissions/Fuel Reduction	Percent Reduction
NO_x (tons/year)	0.03	0.29	0.00	0.26	89%
SO_2 (tons/year)	0.00	1.19	0.00	1.19	100%
CO_2 (tons/year)	84	159	0	75	47%
CH_4 (tons/year)	0.00	0.007	0.00	0.005	77%
N_2O (tons/year)	0.00	0.001	0.00	0.001	88%
Total GHGs (CO_2e tons/year)	84	160	0	76	47%
Carbon (metric tons/year)	21	39	0	19	47%
Fuel Consumption (MMBtu/year)	1,437	1,961	1	525	27%
Number of Equivalent Cars Removed				12	
Number of Equivalent Homes Removed				4	

Emissions Spreadsheet from EPA

Emissions

- Introduction
- Combined Heat and Power Analysis
- **Electrical Breath**
- Recommendations
- Acknowledgments
- Questions



Power Connection

- Replace Switchgear with Parallel Switchgear
  - 208/120V, 3PH-4W 3000A
  - Syncs power from two sources
- Add 480V:208/120V transformer
- Size wires and breakers

Emergency Power

- 150 KW emergency generator
- Duel fuel microturbine to replace emergency generator
- Reduce payback period

Recommendations

- Introduction
- Combined Heat and Power Analysis
- Electrical Breath
- **Recommendations**
- Acknowledgments
- Questions

Recommendations

- Economically
  - Do not recommend CHP System
  - 14 year payback period
  - Not enough heat load
- Environmentally
  - Recommend CHP system
  - Save 27% Fuel Consumption
  - Reduce Carbon footprint by 47%

Acknowledgments

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SmithGroupJJR

Dr. James Freihaut – Help with CHP systems

AE Faculty and Students

Friends and Family

- Introduction
- Combined Heat and Power Analysis
- Electrical Breath
- Recommendations
- Acknowledgments
- **Questions**

<u>Questions?</u>

Cost Analysis

Separate Heat and Power Gas Costs			
Month	Natural Gas (Therms)	Cost ($/Therm)	Total Cost Per Month
Jan	2,112	$ 1.089	$2,299.58
Feb	1,824	$ 1.112	$2,028.69
Mar	983	$ 1.098	$1,079.59
Apr	343	$ 1.198	$410.35
May	29	$ 1.206	$34.74
Jun	27	$ 1.201	$32.64
Jul	15	$ 1.143	$17.65
Aug	13	$ 1.011	$13.38
Sep	18	$ 1.054	$18.86
Oct	430	$ 1.080	$463.94
Nov	736	$ 1.106	$814.44
Dec	1,704	$ 1.101	$1,876.46
			$9,090.30

Combined Heat and Power Gas Costs					
Month	Microturbine Therms	Boiler Therms	Total Therms	Cost ($/Therm)	Total Cost Per Month
Jan	1179.0	737.7	1916.7	1.089	$2,087.34
Feb	1179.0	707.5	1886.5	1.112	$2,097.78
Mar	1179.0	392.4	1571.4	1.098	$1,725.44
Apr	1179.0	122.1	1301.1	1.198	$1,558.69
May	1179.0	9.2	1188.2	1.206	$1,433.02
Jun	1179.0	11.4	1190.4	1.201	$1,429.63
Jul	1179.0	12.6	1191.6	1.143	$1,361.98
Aug	1179.0	8.9	1187.9	1.011	$1,200.92
Sep	1179.0	6.3	1185.3	1.054	$1,249.26
Oct	1179.0	5.2	1184.2	1.080	$1,278.93
Nov	1179.0	168.5	1347.5	1.106	$1,490.32
Dec	1179.0	520.3	1699.3	1.101	$1,870.89
					$18,784.19

Combined Heat and Power Electricity Costs									
Month	KW From Grid	KWh	KW Demand Charge 3.5$/KW	DC electric Cost ($/KWh)	Consumption Cost	Sell Back to Grid (Kwh)	Price to sell back ($/KWh)	Total Cost Sell Back	Total Cost Per Month
Jan	34.4	6,696	$120.33	$0.120	$803.462	0.00	0.03	$0.00	$923.79
Feb	34.4	5,118	$120.44	$0.122	$624.428	19.03	0.03	$0.57	$744.29
Mar	43.3	8,004	$151.45	$0.125	$1,000.516	0.00	0.03	$0.00	$1,151.97
Apr	48.9	5,910	$171.32	$0.124	$732.809	24.33	0.03	$0.73	$903.40
May	107.2	15,725	$375.28	$0.121	$1,902.712	69.70	0.03	$2.09	$2,275.90
Jun	148.3	23,064	$518.91	$0.132	$3,044.505	0.00	0.03	$0.00	$3,563.42
Jul	150.0	27,617	$524.83	$0.136	$3,755.936	0.00	0.03	$0.00	$4,280.77
Aug	145.2	25,620	$508.17	$0.139	$3,561.148	0.00	0.03	$0.00	$4,069.32
Sep	113.1	13,922	$395.89	$0.140	$1,949.014	0.00	0.03	$0.00	$2,344.90
Oct	52.6	7,651	$184.04	$0.135	$1,032.852	37.10	0.03	$1.11	$1,215.78
Nov	42.5	6,682	$148.67	$0.131	$875.321	0.00	0.03	$0.00	$1,023.99
Dec	34.5	5,997	$120.86	$0.131	$785.565	0.00	0.03	$0.00	$906.42
			$3,340.184		$20,068.269			$4.505	$23,403.95

Separate Heat and Power Electricty Costs						
Month	KW From Grid	KWh	KW Demand Charge 3.5$/KW	DC electric Cost ($/KWh)	Consumption Cost	Total Cost Per Month
Jan	64.87	16,596	$227.05	$0.120	$1,991.46	$2,218.51
Feb	64.92	14,999	$227.22	$0.122	$1,829.91	$2,057.13
Mar	66.01	17,904	$231.04	$0.125	$2,238.02	$2,469.05
Apr	87.94	15,785	$307.79	$0.124	$1,957.39	$2,265.18
May	153.89	25,555	$538.62	$0.121	$3,092.18	$3,630.79
Jun	195.19	32,964	$683.17	$0.132	$4,351.30	$5,034.47
Jul	196.88	37,517	$689.08	$0.136	$5,102.34	$5,791.42
Aug	192.11	35,520	$672.39	$0.139	$4,937.25	$5,609.63
Sep	160.28	23,822	$560.98	$0.140	$3,335.01	$3,895.99
Oct	92.01	17,514	$322.04	$0.135	$2,364.34	$2,686.38
Nov	74.63	16,582	$261.21	$0.131	$2,172.22	$2,433.43
Dec	65.23	15,897	$228.31	$0.131	$2,082.47	$2,310.77
			$4,948.860		$35,453.888	$40,402.75