FINAL REPORT

Mechanical Systems Re-Design and Breadth Topics

Northfield Mental Healthcare Center

Northfield, Ohio

Ji Won Park

Mechanical Option

Faculty Consultant: Dr. Stephen Treado

Date revised and submitted: April, 3rd, 2013

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NORTHFIELD MENTAL HEALTHCARE CENTER
NORTHFIELD, OHIO

JI WON PARK **MECHANICAL OPTION**

GENERAL INFORMATION:

Function: Mental Clinic

Size: ~300,000 SF

Overall Cost: ~62.5 Million

Delivery Method: Design-Bid-Build (Multiple Prime)

Construction Date: Approx. April, 2012 – January, 2013

ARCHITECTURE:

Additional 200,000 ft^2 to existing 100,000 ft^2

Quality of care for mental health patients and safety of patients and staff

Designed respect to surrounding facilities

Outdoor recreating areas and therapeutic spaces

Face brick for the exterior wall to match existing building

Smooth CMU, texted CMU, and curtain walls to highlight the new design

MECHANICAL:

2 custom AHU’s (65,000 CFM each)

1 Constant Volume AHU (3,700 CFM)

6 Variable Air Volume AHU’s (32,350 CFM)

2 Existing AHU’s

6 Gas Fired Boilers (113.5 HP each)

2 Centrifugal Chillers (450 Tons each)

Variable Frequency Drive for supply and return fan for each Air Handling Unit

Centrifugal Upblast Fans for Patient Room Exhaust and General Exhaust

Centrifugal In-Line Fans for Emergency Exhaust

Centrifugal Upblast Grease Fans for Kitchen Exhaust Hoods

PROJECT TEAM:

Owner: Ohio Department of Mental Health
Architects: Hasenstab Architects, Inc.
Landscape: Bedell-Tucci, LLC (N/A)
MEP and Fire Protection Engineers: Scheeser Buckley Mayfield, LLC
Structural Engineers: Thorson Baker & Associates

ELECTRICAL:

Two of 1500 / 2000KVA Dry Type Transformer (Primary: 12.47KVA, Secondary: 480/277V, 3 Phase) for the Energy Center

500 KVA Liquid Filled Pad-mount Transformer (Primary: 12.47KVA, Secondary: 480/277V, 3 Phase) for the North Patient Wing

500 KVA Liquid Filled Pad-mount Transformer (Primary: 12.47KVA, Secondary: 480/277V, 3 Phase) for the South Patient Wing

Two of 1500KW, 480/277V, 3Phase Emergency Generators

STRUCTURAL:

Floor System for Patient Wings: 4 1/2" Normal weight concrete slab on 3"x18GA

Roof System for Patient Wings: Wide rib deck welded to support on 3"x22GA

Typical Beam to Column Connections: Full capacity moment connections

EXECUTIVE SUMMARY

The first section of the report mainly explains the existing mechanical system design of the Northfield Mental Healthcare center. Based on the existing mechanical system, the TRACE model was created to evaluate a cooling load, heating load, and ventilation load to estimate the annual electrical and gas consumption. The procedures and assumptions used for the TRACE model are described in the first section of this report, as well.

The outputs of the energy model, including cooling load, heating load, ventilation load, Economical data, estimated energy consumption, and emission of pollutants, are compared with the ones provided by the engineer of the project. Comparison processes of some of these outputs, with design values, were omitted due to the lack of given information provided by the engineer.

The overall performance of the existing mechanical system was analyzed based on the outputs of the model. Better alternative mechanical systems were proposed after the analyses. Due to high demands on heating and cooling, even with the efficient ventilation equipment, annual electricity and gas consumptions are still high. Employing on-site energy generation systems is the main goal of this report.

The second section of the report evaluates the proposed systems: the cogeneration system and the tri-generation system. The overall performance of each designed system is evaluated, equipment for each system is selected, and the total savings and payback periods are calculated for each system.

The third section of the report evaluates the noise generation of the CHP module, which is selected in the previous section. The sound attenuation device, such as an exhaust air silencer, is studied, selected, and applied for the selected CHP module. The fourth section of the report evaluates whether the CHP generator can replace one of the existing emergency generators. The NEC code requirements for the emergency generator and the CHP generator are studied, and the load distribution systems of the existing generators are examined. The calculation on the size of the conductors, used to connect the CHP generator with the existing parallel switchgear, is also performed.

SECTION ONE. PROJECT BACKGROUND

1.1 PROJECT BACKGROUND

The Northfield Mental Healthcare center is located in Northfield, Ohio. The building is a five-story mental clinic building, and the project is a renovation and expansion of three existing buildings. Approximately 200,000 square feet would be added to the existing buildings, and the new portions of the buildings would be for patient wings, an administrative facility, a gym, and a clinic. The new buildings were designed to provide better quality for the structures, deliver to the safety of patients and staff, and to become an aesthetically pleasing environment.

The main goal of the Northfield Mental Healthcare center project is to provide a comfortable and safe environment for both patients and staff members. The main purpose of this project is to establish more spaces for additional patients transferred from the Cleveland healthcare campus, which is going to be closed after the completion of this project. The building is not yet constructed, as it is still in the bidding process. The total estimated project cost is approximately $62.5 million, including $10.3 million for HVAC and fire protection equipment costs.

1.2 EXISTING MECHANICAL SYSTEM SUMMARY

From this section, the existing mechanical system is referred to a newly designed mechanical system for The Northfield Mental Healthcare center expansion and renovation project.

10 different air-handling units are equipped in the Northfield Mental Healthcare Center, including two already existing air handlers. Two 65,000 CFM rooftop air handlers serve the two patient wings. Clinic and administration areas are served by a 7,950 CFM rooftop air handler. A 3,700 CFM indoor air handler and an 8,400 CFM indoor air handler serve the gym area and dietary areas, respectively. The boiler plant, chiller plant, and electrical room

are served by the other three indoor air handlers, which have a maximum capacity of 5,000 CFM, 5,000 CFM, and 6,000 CFM, respectively. The existing air handlers serve partially renovated areas and existing administration areas.

Customized air handler 1 and 2 for the two patient wings are equipped with DDC-VAV terminals, which will reset the ventilation rate based on occupancy. The DDC-VAV terminals continuously measure the amount of supply air and ventilation fraction for each space. A building automation system controls the DDC-VAV terminals and outdoor airflow by changing the position of the outdoor air dampers. The control system of a DDC-VAV terminal is described in the Figure 1.

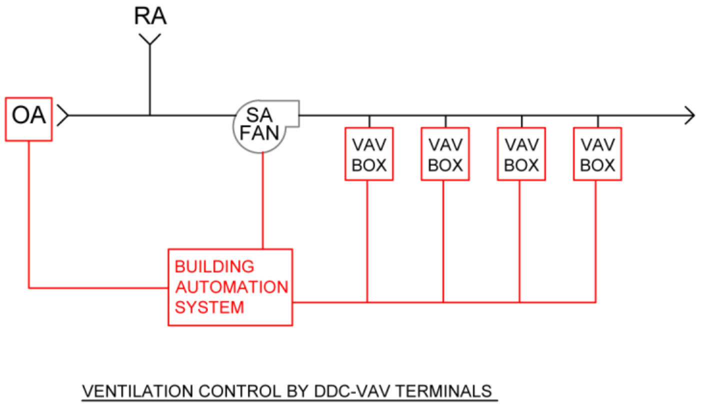


Figure 1: Ventilation Control by DDC-VAV Terminals

Air handler 3, which serves the gym area, is a dedicated outdoor air unit equipped with a sensible wheel. A total energy enthalpy wheel preconditions the outdoor air transferred to the unit. The total enthalpy wheel cools the outdoor air to 80.53 ˚F DB during the cooling season and heats the outdoor air to 51.55 ˚F DB during heating season, before delivering the conditioned outdoor air to the cooling coil and heating coil. Appendix A contains simplified control diagrams of air handlers.

The building use programmable temperature control sensors and occupancy sensors, which reduce equipment load by a significant amount. Since most of the openings in the building are not operative, the amount of the outside air for each air handler is oversized in order to achieve the better indoor air quality. In order to maintain the comfortable temperature, even with the great amount of outside air entering the building, cabinet unit heaters and horizontal unit heaters are additionally placed to efficiently meet the space heating load.

Two 450-ton centrifugal chillers are located in the chiller plant and connected to a 2-cell-cooling tower, which is located outside of the energy center. Each chiller consists of two chilled water pumps: a primary chilled water pump and a secondary chilled water pump. The primary and secondary pumping arrangements help to increase system controllability, while decreasing total power input. It is recommended to use primary and secondary pumping systems for large complexes, all for energy efficiency. The primary chilled water pumps serve chilled water to chillers, while secondary chilled water pumps send chilled water to a cooling coil for each air handling equipment to serve the cooling load of the building.

Six 113.5-horsepower condensing boilers are located in the boiler plant and serve hot water. A primary pump equipped with each boiler sends heated water to the main hot water loop. Two secondary pumps, along with the main hot water loop, send hot water to a heating coil for each air handling equipment to serve the heating load of the building. Makeup water is heated by two domestic water heaters and served to the building. Variable frequency drive devices are used for most of the HVAC equipment, including heating water pumps, chilled water pumps, chillers, and cooling towers. Figure 2 shows the existing heating and cooling system.

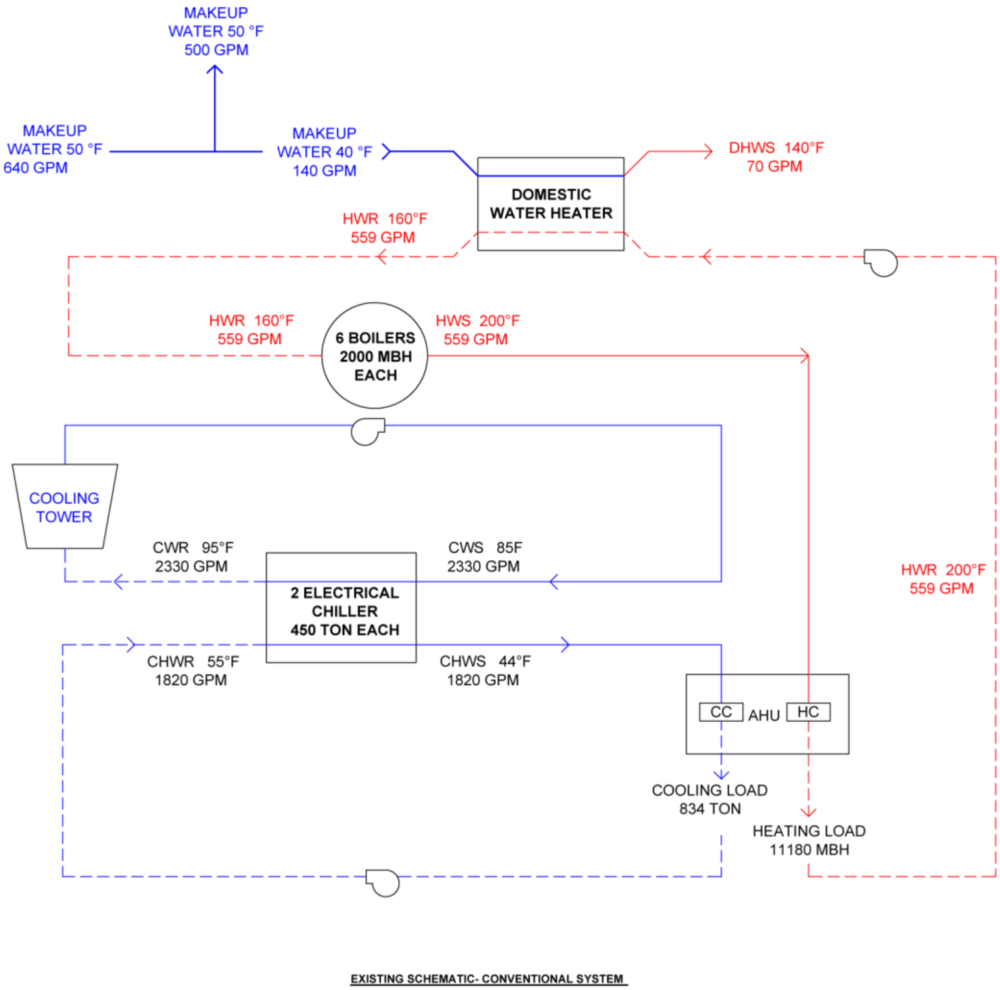


Figure 2: Existing Heating and Cooling System

1.3 ENERGY MODELING - INPUT

The building load and energy simulation program, Trane Air Conditioning Economics 700 (TRACE), was used to evaluate the ventilation loads, heating and cooling load, and to estimate annual energy consumption and operation costs of the Northfield Mental Healthcare Center. The ventilation load, heating load, and cooling load, calculated by the TRACE 700 program, will be used for system design comparisons. Design conditions and assumptions, used for the energy model, are described in the following sections.

1.3.1 DESIGN CONDITION

The Northfield Mental Healthcare Center is located in Northfield, OH. Since the Northfield area is not listed in the ASHRAE Fundamental 2009, Cleveland, the closest big city, was used for the analysis. Table 1 shows the weather data inputs that were used for the analysis.

Cleveland, OH	
Latitude	41.4N
Longitude	81.85W
Elevation	804 FT
Heating DB (99.6%)	2.5 ˚F
Cooling DB (0.4%)	89.4˚F

Table 1: Design Condition

1.3.2 MODEL DESIGN

Each of the 1130 rooms was input into the TRACE model. Each room was designated with different internal loads and airflow assumptions, depending upon the primary space use and occupancy. Restrooms and small storages were neglected. All the exterior walls, windows, as well as doors with their orientations, were input in order to calculate envelope loads for each space. Lighting and electrical load, occupancy and airflow assumptions, as well as construction for the building envelope, are described in the following sections. All of the input rooms were then assigned to 20 different zones, all of which have their own temperature controls. Multiple zones, served by an air-handling unit, were bounded together and assigned to a system. Figure 3 shows how the zones are assigned to a system.

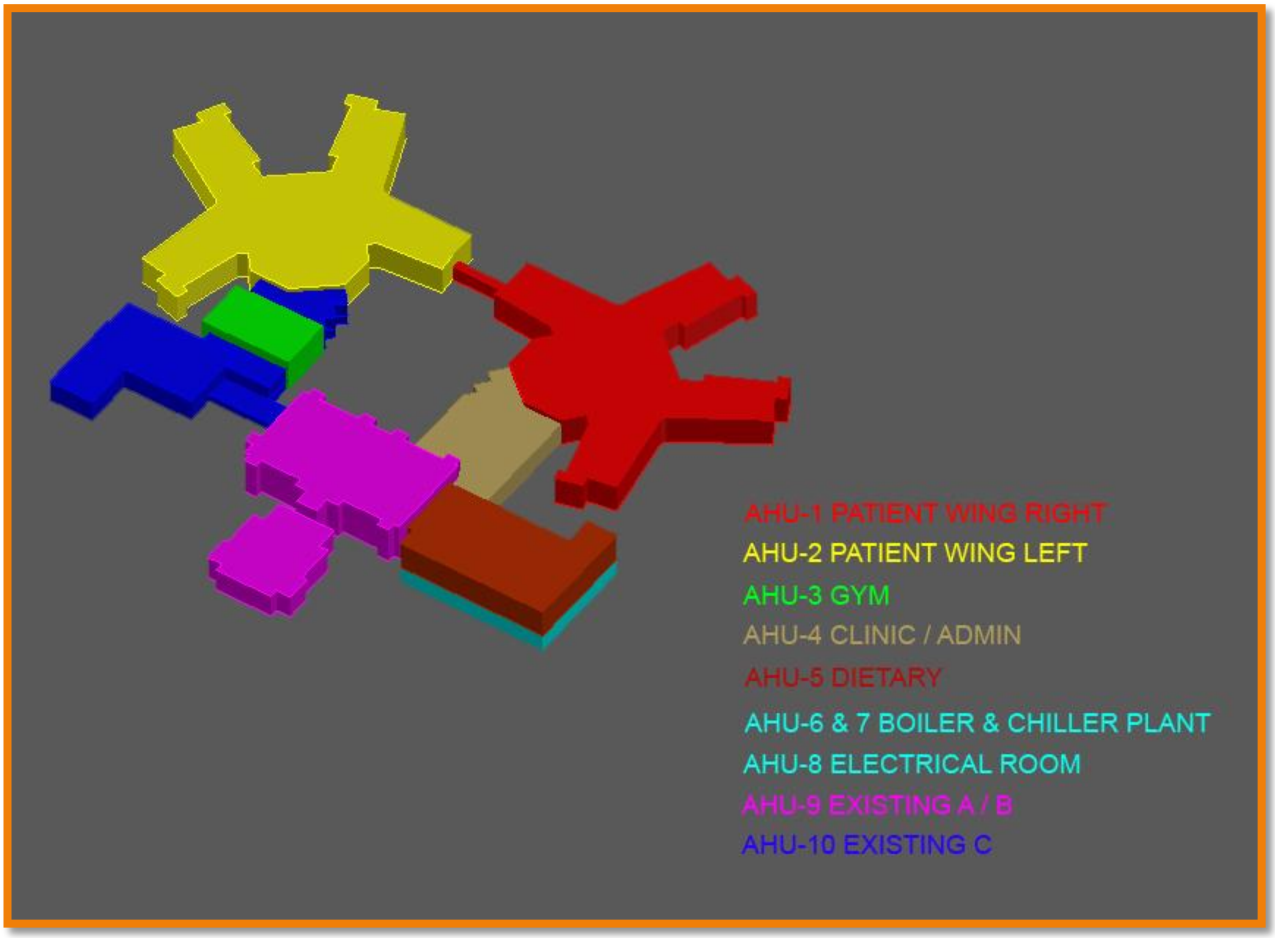


Figure 3: TRACE Energy Model Zoning

1.3.3 LIGHTING AND EQUIPMENT ELECTRICAL LOAD ASSUMPTIONS

24 different templates were created for each of the various space types, which all have assumed lighting and miscellaneous equipment power density values. The assumptions on lighting power density were taken from ASHRAE Standard 90.1-2007. The assumptions on miscellaneous equipment power density are based on nameplate ratings from electrical equipment. Table 2 shows a summary of lighting and electrical load assumptions.

Space Type	LPD (W/SF)	Miscellaneous Loads (W)
Conference Room	1.23	300
Corridor	0.89	0
Exam Room	1.66	150
Gym	0.72	0
Kitchen	0.99	5 W/SF
Lobby	0.9	0
Locker Room	0.75	0
Lounge	1.07	350
Nurse Station	0.87	350
Office	1.11	350
Patient Room	0.62	150
Storage	0.63	0

Table 2: Lighting and Electrical Load Assumptions

1.3.4 OCCUPANCY ASSUMPTIONS

The number of occupants, per square feet, is assumed based on Table 6-1 of ASHRAE 62.1- 2007. The occupancy densities that were not listed in Table 6-1 were estimated based on the number of furniture shown in architectural plans. Table 3 shows the occupancy assumptions used for the TRACE model.

Space Type	Occupancy Density (#/1000SF)	(SF/#)
Conference Room	50	20
Corridor	0	0
Exam Room	25	2 people
Gym	30	33
Kitchen	20	50
Lobby	30	33
Locker Room		6 people
Lounge	25	40
Nurse Station	30	3 people
Office	5	200
Patient Room	10	100
Storage	0	0

Table 3: Occupancy Assumptions

1.3.5 AIRFLOW ASSUMPTIONS

The minimum ventilation rates, for each space type, were obtained from ASHRAE Standard 62.1. The amount of infiltration for hospital spaces were obtained from ASHHRAE Standard 170. The minimum ventilation rate based on the number of people, the minimum ventilation rate based on square feet, and infiltration values are listed on Table 4.

Space Type	Minimum Ventilation Rates (CFM/#)	Minimum Ventilation Rates (CFM/SF)	Infiltration (ACH)
Conference Room	5	0.06	0.6
Corridor	2 CFM	2 CFM	0.6
Exam Room	2 CFM	2 CFM	0.3
Gym	0	0.3	0.6
Kitchen	7.5	0.12	0.6
Lobby	5	0.06	0.6
Locker Room	4 CFM	4 CFM	0.6
Lounge	5	0.06	0.6
Nurse Station	2 CFM	2 CFM	0.6
Office	5	0.06	0.6
Patient Room	25	0.25	0.3
Storage	0	0.12	0.6

Table 4: Airflow Assumptions

1.3.6 CONSTRUCTION OF BUILDING ENVELOPE

The Northfield Mental Healthcare Center is designed with four different wall types and one roof type. However, only one type of wall, roof, and window was used for the analysis, for simplification. U-values for the wall, roof, and window were taken from construction documents and are listed on Table 5, Table 6, and Table 7.

Walls	R-value	Thicknes (ft)	Conductivity
Surface Air Film (Vertical)	0.680	-	-
Common 4" Brick	0.799	0.333	0.4167
Air Layer 3/4" to 4" (Vertical)	0.980	-	-
2" Insulation	6.680	0.167	0.025
1/2" Gypsum or Plaster Board	0.454	0.042	0.0926
Mineral Wool/Fiber, Batt, R-21	22.611	0.511	0.0226
5/8" Gypsum or Plaster Board	0.562	0.052	0.0926
Overall R-Value	32.765		
Overall U-Value	**0.031**		

Table 5: Exterior Wall Construction

Roof	R-value
Outside Film	0.250
3 1/2" Polyiso Rigid	21.700
1" Spray Fire Proof	1.500
Inside Film	0.680
Overall R-Value	24.130
Overall U-Value	**0.041**

Table 6: Roof Construction

Windows	
Overall U-Value	**0.280**
SHGC	0.440
Shading Coefficient	0.505

Table 7: Window Construction

1.3.7 DESIGNED TEMPERATURE CONTROL

A programmable temperature controller attains the temperature for supply air, to a space. Table 8 shows designed temperature set points for each air handler.

Temperature Set Points	
OA	90˚F DB, 71 ˚F WB
RA	72 ˚F DB, 50 % RH
SA	55 ˚F DB
MA	Depends on OA %

Table 8: Temperature Set Points

The supply air temperature would be maintained, at a set point, by modulating the economizer control damper and valve positions. The supply air temperature set point is linearly reset in a range of 5 ˚F, as supply air can be set at a minimum temperature of 55 ˚F. When room temperature indicates below 70 ˚F, the controller would be deactivated. When the mixed air temperature hits below 40 ˚F, the outside air damper would be closed and the return air damper would be opened.

When the outside air temperature is between 65 ˚F and the supply air temperature set point, the return air damper would be fully closed. Additionally, the outside air damper would be positioned at the maximum outdoor air economizer position, and the digital panel would modulate the chilled water valve in order to call for cooling. When the outside air temperature is below 65 ˚F, the return damper would fully open and modulate the chilled water control valve to call for cooling.

When the outside air temperature is below the supply air temperature set point, the chilled water sensor would deactivate in order to maintain the supply air temperature set point. When the outside air temperature is lower than the supply air temperature, the outside air damper would be positioned at the minimum position and the return damper would be opened.

1.4 ENERGY MODELING - OUTPUT

1.4.1 COOLING, HEATING, AND VENTILATION LOAD

Load calculations of the Northfield Mental Healthcare Center, calculated by the engineer of the project, were performed by utilizing the CHVAC program. The CHVAC energy model created by the engineer might use different assumptions for lighting and electrical load, occupancy, and airflow, as well as different methods to separate rooms into zones. Also, the outputs of the CHVAC energy model was re-evaluated by using their own excel program to balance with the minimum outdoor airflow required for the hospital, as well as to take account of the reheating process. The summary of load calculations, provided by the engineer of the project and the output of the TRACE model, is described in Table 9.

ZONES		Design			TRACE		
		Cooling (Btu/hr)	Heating (Btu/hr)	Ventilation (CFM)	Cooling (Btu/hr)	Heating (Btu/hr)	Ventilation (CFM)
AHU-1	Patient Wing (Right)	2,871,500	2,128,464	65,000	2,565,694	3,565,409	57,377
AHU-2	Patient Wing (Left)	2,871,500	2,128,464	65,000	2,601,886	3,631,777	59,361
AHU-3	Gym	172,620	131,690	3,025	122,473	103,633	2,832
AHU-4	clinic/admin	338,530	250,150	7,950	367,611	461,731	9,314
AHU-5	Dietary	320,450	236,510	7,350	386,454	476,020	9,430
AHU 6	boiler plant	-	488,020	-	-	93,002	-
AHU 7	Chiller plant	-	488,020	-			
AHU 8	Electrical Room	262,710	224,920	-	274,841	105,323	-
AHU-9	Existing A/B	2,900,000	1,250,000	70,000	3,027,007	2,119,661	64,056
AHU-10	Existing C	600,000	750,000	14,000	656,227	623,479	13,044
Reheat		-	4,230,000	-	-	-	
Total		10,337,310	12,306,238	232,325	10,002,193	11,180,035	215,414
Tons		**861**			**834**		
MBH			**12,306**			**11,180**	

Table 9: Design Load Values VS. Calculated Load Values

The cooling load, heating load, and ventilation load, calculated by the engineer, seem to be larger than the output of the TRACE model. The comparison of loads, by zones, is unnecessary because zones are divided in a different manner. The difference between the engineer's design values and the TRACE output values is within 10 percent. The major difference can be found in the heating load. A possible reason, for the cause of the difference, is that the reheating process was considered in the CHVAC model. The cooling load and heating load outputs of the TRACE model are 834 tons and 11,180 MBH, respectively. These outputs will be used for mechanical alternatives' analyses. Table 10 contains a summary of load comparisons and differences in loads between the CHVAC model and TRACE model.

	Cooling (Btu/hr)	Heating (Btu/hr)	Ventilation (CFM)
Design	10,337,310	12,306,238	232,325
TRACE	10,002,193	11,180,035	215,414
Difference	335,117	1,126,203	16,911
Difference (%)	3.2	9.2	7.3
	(Underestimated)	(Underestimated)	(Underestimated)

Table 10: Cooling Load, Heating Load, and Ventilation Load Summary

1.4.2 DOMESTIC HOT AND COLD WATER LOAD

The need of domestic cold water and hot water for plumbing fixtures was also estimated by counting plumbing fixtures, which are located in the building. Table 11 shows calculations on the amount of domestic hot and cold water needed. Since all the plumbing fixtures do not run for whole time, the domestic hot water demand was estimated to be 25% of the total hot water needed for plumbing fixtures. The temperature of makeup water entering the domestic water heater was assumed to be at 40˚F, and the temperature of hot water leaving the domestic water heater was assumed to be at 140 ˚F. Based on these assumptions, the total energy consumption for producing domestic hot water was calculated and summarized on Table 12.

FIXTURE TYPE	COUNT	HW FIXTURE UNIT	HW (GPH)	CW FIXTURE UNIT	CW (WSFU)
Water Closet	284	-	-	10	2,840
Urinal	4	-	-	5	20
Lavatory	304	8	2,432	2	456
SINK	87	10	870	2	131
Mop Basin	15	15	225	3	38
Shower	234	20	4,680	2	468
Washing Machine	14	8	112	3	42
TOTALS			8,319		3,994
		TOTAL HW NEED (GPM)	139	TOTAL CW NEED (GPM)	3,994

Table 11: Domestic Water Needs Calculation

Domestic Hot Water: Energy Consumption	
EWT (F)	40
LWT (F)	140
DELTA T (F)	100
HW DEMAND (GPH) -25%	2,080
INPUT RATE (BTUH)	2,165,540
OUTPUT RATE (BTUH)	1,732,432
GAS DEMAND (CFH)	2,165.54
HW STORAGE TANK (GAL)	1,248

Table 12: Domestic Hot water Energy Consumption

1.5 ENERGY CONSUMPTION

The total energy consumption was calculated based on the outputs of the TRACE model. Since the energy consumption rates of mechanical equipment were estimated, based on the general consumption rate specified either on product catalogs or specifications, the actual energy consumption of the mechanical equipment can differ from the estimated total energy consumption given by the TRACE model. Table 13 contains a summary of total annual electricity and gas consumption.

Summary of Load Calculation and Energy Consumption Calculation	
Total SF (SF)	260,000
Cooling (TONS)	834
Space Heating (MBH)	11,180
Chilled Water (GPM) @11F Difference	1,820
Hot Water (GPM) @ 40F Difference	559
Domestic Hot Water (GPM)	139
Total Energy Consumption (KWh)	32,779,802
Total Electricity Consumption (KWh)	14,127,906
Total Natural Gas Consumption (Therms / yr)	636,589

Table 13: Summary of Load Calculation and Energy Consumption Calculation

Energy Usage Breakdown of the TRACE model is described on Table 14. Space cooling requires almost 33% of the total electricity consumption, and space heating requires almost 85% of the total gas consumption. Figure 4 and Figure 5 show electricity consumption breakdowns and natural gas consumption breakdowns, respectively. Multiple ways to reduce energy consumption breakdowns used for the space cooling and heating will be studied in the section two of this report.

Energy Usage Breakdown									
Electricity (%)							Gas (%)		
Heating	Cooling	Lighting	Equipment	Fans	Pumps	Other	Heating	Equipment	Water System
0	33	10	14	27	5	10	85	13	3
100							100		

Table 14: Energy Usage Breakdown

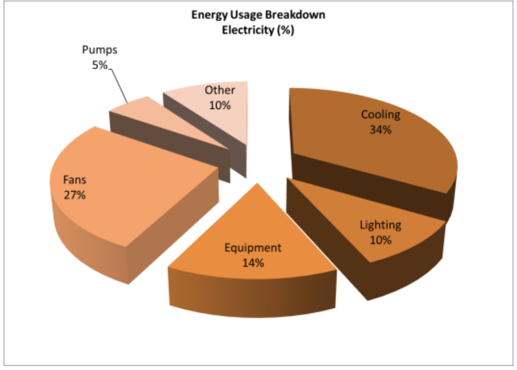


Figure 4: Electricity Usage Breakdown

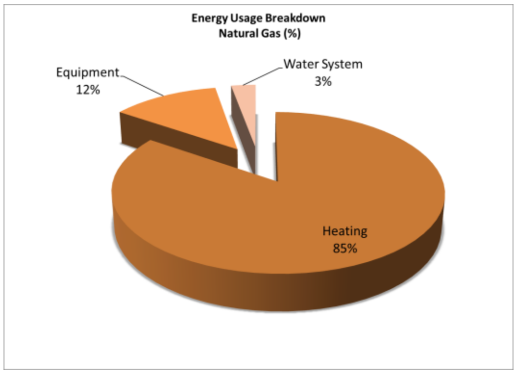


Figure 5: Natural Gas Usage Breakdown

Based on the estimated energy consumption, energy use index was calculated and summarized on Table 15. The EUI values are calculated based on energy consumption with a full load performance. Table 16 describes the typical EUI values of the hospital model, with base load performance, in climate Zone 5A. If a demand factor is applied for the TRACE model, the EUI value will be calculated much closer to the typical EUI value of the hospital model with baseline performance.

EUI Value Calculated		
Electricity EUI	185	kBtu/SF
Natural Gas EUI	250	kBtu/SF
EUI	435	kBtu/SF

Table 15: Calculated EUI Values

EUI Value of Typical Hospital (Baseline Model)		
EUI	388	kBtu/SF

Table 16: EUI Value of Typical Hospital

1.6 EMISSION

Emissions from the energy usage were calculated using emission factors from the Regional Grid Emissions Factors 2007 file. Table 17 shows the mass of each pollutant produced by electricity usage for this building. The Regional Grid Emissions factors 2007 data is referenced in Appendix C.

	Emission for Delivered Electricity		Precombustion Emission for Delivered Natural Gas		On-Site Combustion Emission for Boiler		
	Factor	Mass of Pollutant	Factor	Mass of Pollutant	Factor	Mass of Pollutant	Total
Pollutant	lb/ kWh	lb	lb/ ft^3	lb	lb/ ft^3	lb	lb
CO2e	1.74E+00	9.46E+07	2.78E+01	2.64E+07	1.23E+02	1.17E+08	2.38E+08
CO2	1.64E+00	8.92E+07	1.16E+01	1.10E+07	1.22E+02	1.16E+08	2.16E+08
CH4	3.59E-03	1.95E+05	7.04E-01	6.69E+05	2.50E-03	2.38E+03	8.67E+05
N2O	3.87E-05	2.10E+03	2.35E-04	2.23E+02	2.50E-03	2.38E+03	4.70E+03
NOx	3.00E-03	1.63E+05	1.64E-02	1.56E+04	1.11E-01	1.05E+05	2.84E+05
SOx	8.57E-03	4.66E+05	1.22E+00	1.16E+06	6.32E-04	6.01E+02	1.63E+06
CO	8.54E-04	4.64E+04	1.36E-02	1.29E+04	9.33E-02	8.87E+04	1.48E+05
TNMOC	7.26E-05	3.95E+03	4.56E-05	4.33E+01	6.13E-03	5.82E+03	9.82E+03
Lead	1.39E-07	7.56E+00	2.41E-07	2.29E-01	5.00E-07	4.75E-01	8.26E+00
Mercury	3.36E-08	1.83E+00	5.51E-08	5.24E-02	2.60E-07	2.47E-01	2.13E+00
PM10	9.26E-05	5.04E+03	8.17E-04	7.76E+02	8.40E-03	7.98E+03	1.38E+04
Solid Waste	2.05E-01	1.11E+07	1.60E+00	1.52E+06	0.00E+00	0.00E+00	1.27E+07

Table 17: Emission Calculation

1.7 LEED ANALYSIS

The Northfield Mental Healthcare Center did not aim for a LEED certification. The building, however, utilizes some of the sustainable features, such as a highly insulated exterior envelope, efficient equipment, programmable temperature controllers, and occupancy sensors. Even if this facility was not designed to be LEED certified, a simple LEED analysis was conducted for this report for future reference. This analysis would be helpful to see how many more LEED points are required in order for the building to be LEED certified, if this building will attempt to become a LEED certified building in the future.

The LEED 2009 rating system for New Construction and Major Renovations was used for this analysis. In order to obtain the LEED basic, at least 40 points are required. Since there was insufficient information about the building systems, several points were analyzed ambiguously.

1.7.1 ENERGY AND ATMOSPHERE

EA Prerequisite 1: Fundamental Commissioning of Building Energy Systems (Required)
Intent: To verify that the project's energy-related systems are installed and calibrated to perform according to the owner's project requirements, the basis of design, and construction documents.

Commissioning process activities must be completed by the project team in order to achieve this point. The Northfield Mental Healthcare Center is not constructed yet, so this point would be a pending point.

EA Prerequisite 2: Minimum Energy Performance (Required)
Intent: To establish the minimum level of energy efficiency for the proposed building and systems, in order to reduce environmental and economic impacts associated with excessive energy use.

The Northfield Mental Healthcare Center complies with the mandatory provisions in ASHRAE 90.1.

EA Prerequisite 3: Fundamental Refrigerant Management (Required)
Intent: To reduce stratospheric ozone depletion.

Chlorofluorocarbon (CFC) is not used for any of the HVAC systems at the Northfield Mental Healthcare Center.
EA Credit 1: Optimize Energy Performance (2 Points)

Intent: To achieve increasing levels of energy performance beyond the prerequisite standard, in order to reduce environmental and economic impacts associated with excessive energy use.

Based on the energy consumption performed by the engineer, it can be assumed that 14% of energy reduction is achievable and eligible to obtain 2 points.

1.7.2 INDOOR ENVIRONMENTAL QUALITY

IE Q Prerequisite 1: Minimum Indoor Air Quality Performance (Required)

Intent: To establish minimum indoor air quality (IAQ) performance to enhance indoor air quality in buildings, thus contributing to the comfort and well-being of the occupants.

Mechanical ventilation systems for the Northfield Mental Healthcare Center were designed using the ventilation rate procedure.

IE Q Prerequisite 2: Environmental Tobacco Smoke (ET S) Control (Required)

Intent: To prevent or minimize exposure of building occupants, indoor surfaces, and ventilation air distribution systems from environmental tobacco smoke (ETS).

The Northfield Mental Healthcare Center prohibits smoking in the building and prohibits on-property smoking within 25 feet of entries.

IE Q Credit 2: Increased Ventilation (1 Point)

Intent: To provide additional outdoor air ventilation in order to improve indoor air quality (IAQ) and promote occupant comfort, well-being, and productivity.

The Northfield Mental Healthcare Center mostly deals with mechanically ventilated spaces, and outdoor air ventilation rates for breathing zones were increased by at least 30% above the minimum rates required by ASHRAE Standard 62.1-2007.

IE Q Credit 5: Indoor Chemical and Pollutant Source Control (1 Point)
Intent: To minimize exposure to potentially hazardous particulates and chemical pollutants.

The air-handling units used in the Northfield Mental Healthcare Center consist of pre-filters and final-filters, with a minimum of MERV 13. The hazardous areas that use hazardous gases or chemicals are sufficiently exhausted.

IE Q Credit 6.2: Controllability of Systems—Thermal Comfort (1 Point)
Intent: To provide a profusion of thermal comfort systems that can be controlled by individual occupants or groups in multi-occupant spaces (e.g., classrooms or conference areas) and to promote their productivity, comfort, and well-being.

The Northfield Mental Healthcare Center provides comfort system controls for all shared multi-occupant spaces in order to achieve individual occupants or groups’ thermal comforts.

IE Q Credit 7.1: Thermal Comfort—Design (1 Point)
Intent: To provide a comfortable thermal environment that promotes occupant productivity and well-being.

The Northfield Mental Healthcare Center is equipped with a BAS, which monitors thermal conditions, inclusive of temperature and air speeds.

1.8 OVERALL EVALUATION SUMMARY

The mechanical systems of the Northfield Mental Healthcare Center comply with the mandatory provisions in ASHRAE Standards, but the maximum efficiencies of the systems were not achieved due to project budget issues. Some of the energy efficiencies were achieved by equipping programmable temperature controllers, occupancy sensors, BAS controllers, and variable frequency-derive controllers.

Increasing outdoor air intake for mechanical ventilation and equipping pre-filters and final-filters inside of each air-handling unit accomplishes indoor air quality for the Northfield Mental Healthcare Center. Even if routine maintenance is required for those filters and results in higher maintenance costs, those installed filters result in longer equipment life. VAV systems will also enhance the higher indoor air quality of the building; varying the supply air volume will reduce the building energy usage by reducing work done by fans, but it will still increase indoor air quality by producing a very little margin of error from desired temperatures. In addition, VAV systems enable the individually controlled zones to have their own thermostats, which can control their thermal comfort by adjusting the controller.

The cooling and heating loads are also efficiently served by using condensing boilers and electric centrifugal chillers. Also, VFD, installed in pumps and fans, saves energy by controlling their outputs based on the needs of occupants. However, adapting more efficient heating and cooling systems or on-site energy generation systems can reduce high annual total energy consumption.

The approximate construction cost is $62.5 million for the entire project and $312.5 /SF. According to the commercial real estate specialists' online resources, this cost lies in the mid-high region of the range. The figure below shows the construction cost per square foot, for a 4 to 8 story hospital. The first cost, including the costs of equipment, installation, material used for the equipment, and miscellaneous, was calculated to be $81.00 / SF. The first cost of the HVAC equipment, fire protection equipment, and plumbing equipment seems to be average when compared to hospital projects of a similar size.

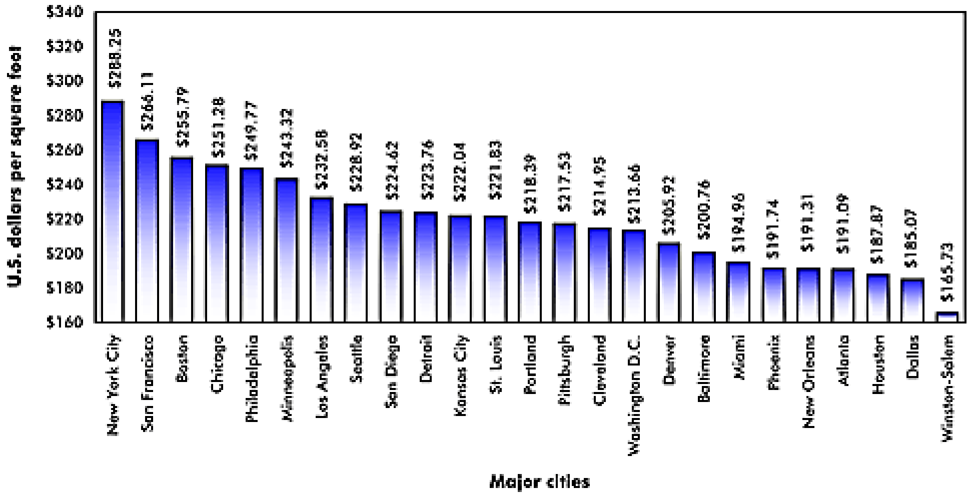


Figure 6: Construction Cost per Square Foot for 4 to 8 Story Hospital

Based on the construction cost, the first installation cost, and performance of the systems, this project is reasonably well designed. The annual operating and fuel costs for all of the mechanical equipment, however, seem to be higher than that of typical, large hospitals. A reduction of annual operating and fuel costs is the primary consideration of this thesis project.

SECTION TWO. MECHANICAL DEPTH

2.1 PROPOSED MECHANICAL REDESIGN

As mentioned in the previous section, a reduction of the annual operating costs and energy consumption is the primary consideration for redesigning the mechanical system. The air side system is already efficiently designed, with DDC-VAV control systems for most of the office and patient wing areas. This paper focuses on water side system improvements rather than air side system improvements that are already equipped with high efficient control devices. On-site energy generation is the most appropriate for reducing energy consumption, as well as emission of pollutants.

The first alternative is the Combined Heat and Power (CHP) system. The second alternative is the Combined Heat, Power and Cooling (CHPC) system. Basic information about both systems is described in the following sections. The CHP system generates thermal energy and electrical energy, at the same time, and it uses the thermal energy as a fuel source for heating equipment. The CHPC system generates thermal energy and electrical energy, and it uses the thermal energy as a fuel source for cooling equipment. The following sections describe the CHP system sizing and module selection procedures, as well as the calculations for system efficiency.

The CHP system was sized properly so that the amount of thermal energy that the CHP system produces is not too short or too excessive. Excessive thermal energy generation can cause energy waste during the season that heating is hardly demanded, as excessive power energy can be sold back to electrical companies. This is the reason that the CHP system is generally sized based upon the base heating demand.

2.2 ALTERNATIVE 1: COGENERATION

2.2.1 COGENERATION – BACKGROUND INFORMATION

The combined Heat and Power System, also known as the cogeneration system, is an integrated mechanical system, which simultaneously generates and utilizes heat and power. The majority of buildings in the world use the SHP system, which is known as the separate heat and power system, due to its low initial cost. The SHP system generates heat and power separately by implementing both power plants and heating equipment. The Northfield Mental Healthcare center also uses the SHP system, consequently with the high output of electricity and gas consumption. A lot of healthcare facilities with high heating and cooling demands use the CHP systems. The CHP system in a healthcare facility reduces a significant amount of electricity and gas consumption by generating energy sources on-site, instead of buying them from energy companies. In addition, since water is used as the refrigerant, there are no harmful chemical pollutants emitted when using the CHP system. Figure 7 shows a comparison of the CHP system to the SHP system.

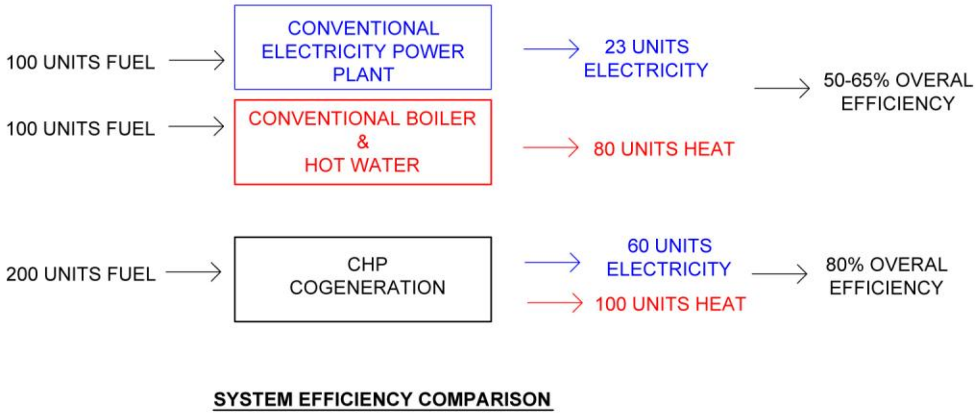


Figure 7: CHP VS. SHP

The efficiency of a typical CHP system is relatively higher than that of a SHP system. The power generation efficiency of the CHP system is approximately 30%, and the thermal energy generation efficiency of the CHP system is approximately 50%. The overall efficiency of the CHP system is about 80%, while overall energy efficiency of the SHP system is around 50%. The efficiency of a CHP system varies for every CHP system, as it depends on the type of equipment installed within the CHP system. The electricity generated from the system can be used for electrical equipment in a building or sold to an energy generation company. The thermal energy generated from the system can be used for space heating, space cooling, or dehumidification.

There are various components of CHP systems, but a typical CHP system consists of mechanical conversion equipment, a prime mover, and a heat recovery system. A prime mover converts fuel energy into mechanical energy and sends the energy to the mechanical conversion equipment. The mechanical energy is then transferred to the mechanical conversion equipment and converted into power. Heat rejected from the prime mover is moved to a heat recovery system and converted into useful thermal energy. The overall efficiency of the system highly depends on the type of prime mover used for a system. The following section contains a simple calculation performed to see if the CHP system has more potential to be a favorable payback for the Northfield Mental Healthcare center, as well as to see which type of prime mover is appropriate for the system

2.2.2 COGENERATION – CHP SYSTEM INTERNAL COMPONENTS SELECTION

The CHP system has more potential to be a favorable payback when the Sparks Spread is more than $12/MMBtu. The Spark Spread value of the Northfield Mental Healthcare center was calculated and described on Table 18. The peak electricity cost and peak gas cost was chosen and used for the Spark Spread calculation. The peak electricity cost and peak gas cost used for the calculation is shown on Table 19.

Spark Spread	
Determine the Average Annual Electric Cost ($/MMBtu)	29.30
Determine the Average Gas Cost ($/MMBtu)	7.550
Spark Spread	22

Table 18: Spark Spread Calculation

Cleveland Area	Dec, 2012
Electricity ($/kwh)	0.10
Gas ($/MMBtu)	7.550

Table 19: Electricity and Gas Cost

The result of the Spark Spread calculation shows that the CHP system is preferable for the Northfield Mental Healthcare center. In addition, the T/P ratio was used to determine which type of prime mover was appropriate for the system. Table 20 shows the T/P ratio calculated for the Northfield Mental Healthcare center. According to Table 21, the recommended prime mover is an engine or a gas turbine. The capacity, installation costs, and operation & maintenance costs for each type of prime mover are summarized on Table 22.

A reciprocating engine seems to be more efficient than a gas turbine for the Northfield Mental Healthcare center, although a reciprocating engine is more expensive to install, operate, and maintain compared to the gas turbine. A reciprocating engine that outputs thermal energy in the form of hot water will be appropriate for the existing heating system. Detailed calculations of the heat recovery performance of the CHP system, with existing boilers, are described in section 2.2.5.

T/P Ratio		
1. Determine Thermal Use		
Total Thermal Energy Delivered/Used	63,658,920,000	**Btu**
2. Determine Electrical Use		
Total Electric	48,218,544,000	**Btu**
3. Determine T/P Ratio		
T/P Ratio - Divide Total Thermal (Btu) by Total Electric (Btu):	**1.32**	

Table 20: T/P Ratio Calculation

Recommended Prime Mover Technology Based on T/P Ratio	
If T/P =	
0.5 to 1.5	**Consider engines**
1 to10	Consider gas turbines
3 to 20	Consider steam turbines

Table 21: Recommended Prime Mover Based on T/P Ratio

	Capacity	Installation Costs	O&M Costs
Reciprocating Engines	**5 kWe - 20 MWe**	**$1,000 to $1,800 per kW**	**$0.010 to $0.015 per kWh**
Gas Turbines	25 kWe – 500 kWe	$800 to $1,500 per kW	$0.005 to $0.008 per kWh
Microturbines	500 kWe – 100 kWe	$1,000 to $2,000 per kW	$0.010 to $0.015 per kWh

Table 22: Capacity, Installation Cost, and O&M Cost Comparison

2.2.3 COGENERATION – CHP SYSTEM MODULE SELECTION

Prior to the CHP module selection, the CHP system size was determined based on the baseline of the heating load. The base heating load was assumed to be 50% of the total heating load. Table 23 shows the calculation of the primary design goal of the CHP system. The design goal of the on-site CHP system for Northfield Mental Healthcare center is calculated to be 5,640 MBH, which is about 1,600 KW$_{T}$. The CHP module was selected based on the design goal.

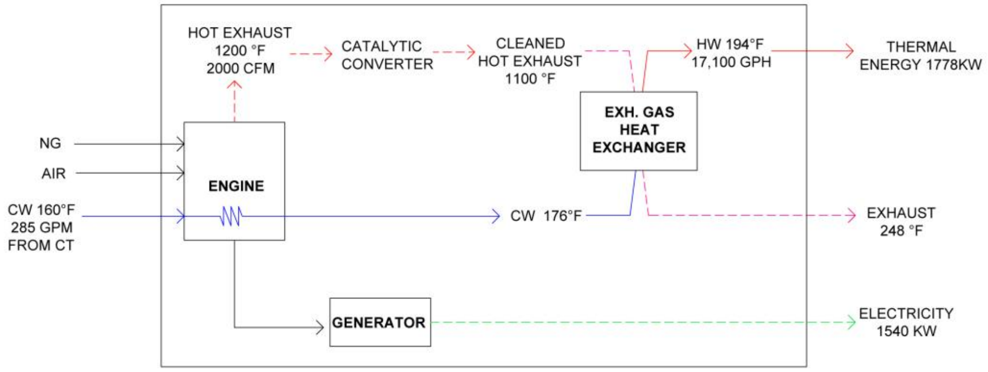
Primary Design		
Building Size (SF)	Heating Baseline (MBH)	Heating Load (MBH)
260,000	5,640	11,180
Heating Baseline = Total Heating Load X 50%		

Table 23: Primary Design of CHP System

The specification of the selected CHP module, 2G 1540 NG, is summarized on Table 24. The module consists of a generator set with the reciprocating engine, MWM TCG 2020, as well as with an exhaust gas heat exchanger. Figure 8 shows the internal structure of the module, 2G 1540 NG. The technical data sheet of the selected CHP module can be found in Appendix B.

CHP COGENERATION MODULE - 2G 1540 NG	
Reciprocating engine MWM® TCG2020	
Configuration	Natural Gas Optimized
Speed	1500 RPM
Frequency / Phase	60 Hz / 3 Phase
Voltage	480 V
Electrical Output	1540 KW
Thermal Output	1778 KW
Electrical Efficiency	42.00%
Thermal Efficiency	44.06%
Total efficiency	80.06%
Thermal Heat	6,066,787 Btu/h (Usable)
Water Flow rate High Temp	17,100 Gph
Water Temp	194F
Fuel Consumption	12508 MBtu/h
Energy Consumption	8,122 Btu / kW

Table 24: CHP Module Selection



CHP COGENERATION MODULE - 2G 1540 NG

Figure 8: Internal Structure of Selected CHP Module

The module outputs 1778 KW_T of thermal energy and 1540 KW_e of electrical energy. The electrical efficiency of the module is 43%, and the thermal efficiency of the module is 44%. The overall efficiency of the module is almost 80%.

2.2.4 COGENERATION – CHP SYSTEM SIMPLE PAYBACK CALCULATION

Payback Period Calculation		
Operating Schedule	8,760	hrs/yr
Heat Recovery		
Heat Recovery	6,068,314	Btu/hr
Heating Load	11,180,000	Btu/hr
Heat Recovery Basis Efficiency	60	%
Energy Generation & Fuel Consumption		
Annual Electric Generation	13,490,400	kWh
Annual Thermal Generation	53,158	MMBtu
Annual Fuel Consumption	109,570.08	MMBtu
Revenue		
Electric Revenue	1,349,040	$
Thermal Revenue	401,346	$
Total Revenue	1,750,386	$
Expenses		
Fuel Expenses	827,254	$
O&M Costs	168,630	$
Standby Charge	55,440	$
Total Expenses	1,051,324	$
Saving		
Total Saving	699,062	$
Payback		
First Cost	2,310,000	$
Simple Payback	**3.30**	yrs

Table 25: Simple Payback Period Calculation

The simple payback was calculated with the full heat recovery performance and summarized on Table 25. The total amount of recovered heat is almost 60% of the total heating load of the building. The total expenses and total revenue from energy generation on both electrical and thermal sides, including fuel expenses, operating & maintenance costs, and standby charge costs, were analyzed to determine the total savings of the system. The first costs of the equipment, including the equipment cost and installation cost, are applied to calculate the simple payback. The simple payback of the system is 3.30 years, which is relatively a short payback period for large hospital projects.

2.2.5 COGENERATION – CHP SYSTEM ENERGY SAVING ANALYSIS

Figure 9 is a schematic drawing of the cogeneration system, which is coordinated with the existing heating system. Heat rejected from the engine is used to heat the hot water coming in from the exhaust gas heat exchanger, which is within the CHP module. 6,066 MBH of thermal energy is recovered in the form of water. The temperature of hot water coming out from the CHP module is set up as 194 ˚F, and the hot water can directly be used for the existing boilers.

Referring to Figure 2 for the existing heating system, the four existing boilers need to heat 599 GPM of water to 40 ˚F. With the cogeneration system, only three boilers with smaller sizes are needed to meet the heating load. During cooling season, only one of them will be in use, while during heating season, all three boilers will be in use. Instead of heating water by 40 ˚F, only one boiler needs to heat 285 GPM of water to only 6 ˚F. An additional 274 GPM of hot water is needed for the heating season and is served by the two other boilers. The system is efficient for both heating and cooling seasons, since it can provide enough heat during heating season and can reduce heat waste during cooling season.

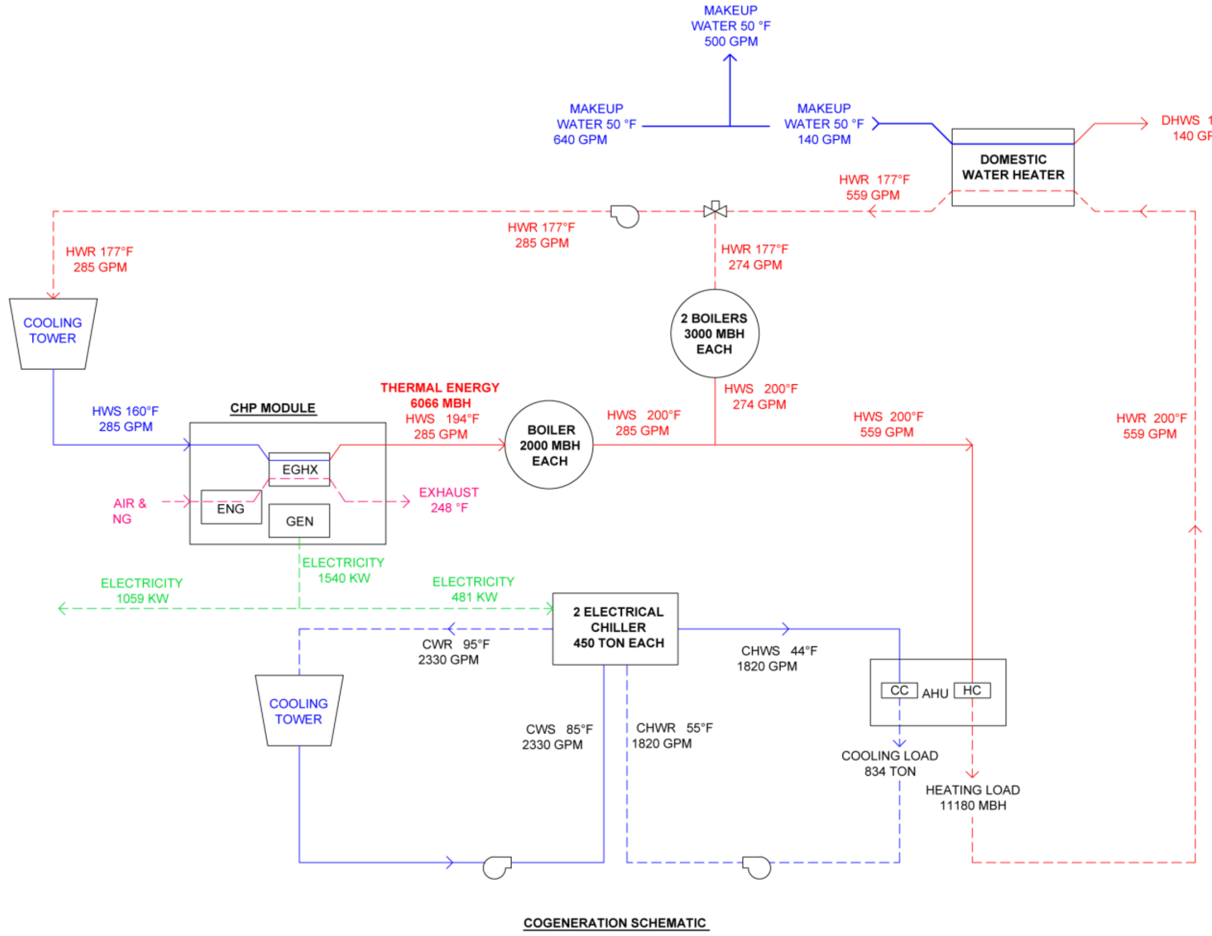


Figure 9: Cogeneration - CHP System Coordination with Existing Heating System.

Table 26 shows a comparison of the alternative 1 heating system with the existing heating system and how many natural gas combustion boilers are needed for alternative 1. According to the energy balancing calculation, only three boilers are needed to serve the total heating load. Also, the boilers are downsized, as well. One 2000 MBH boiler and two 3000 MBH boilers are needed for alternative 1, while four 4000 MBH boilers are needed for the existing heating system. The input energy for alternative 1 is also reduced almost by half.

Table 27 shows a comparison of the alternative 1 cooling system to the existing cooling system. Since the energy generated from the CHP module is not used for cooling, the amount of energy input remains the same. However, the electricity generated from the CHP module that will be used for the electric chillers is large enough to serve the full cooling load; no electricity needs to be bought from an electricity company to run the electric chillers. Only 30% of the total electricity generated will be used to meet the full cooling load, as the other 70% of the total electricity generated will be used for other equipment. Further analysis on the electrical side will be described in the section four of this report.

Downsizing Boiler								
Case	**Make / Model**	**Function**	**Output Temp (F)**	**Flow (GPM)**	**Delta T (F)**	**NG Consumption (Therm)**	**Input (MBH)**	**Output (MBH)**
Existing Boilers	MACH C-4000	Heating Water	200	140	40	3,033	2,942	2,795
	MACH C-4000	Heating Water	200	140	40	3,033	2,942	2,795
	MACH C-4000	Heating Water	200	140	40	3,033	2,942	2,795
	MACH C-4000	Heating Water	200	140	40	3,033	2,942	2,795
	MACH C-4000	Backup	-	-	-	-	-	-
	MACH C-4000	Backup	-	-	-	-	-	-
	Total		200	**559**		12,133	**11,768**	11,180
Alternative 1: Cogeneration	MACH C-2000	Heating Water	200	285	6	928	900	855
	MACH C-3000	Heating Water	200	137	23	1,710	1,658	1,576
	MACH C-3000	Heating Water	200	137	23	1,710	1,658	1,576
	MACH C-4000	Backup	-	-	-	-	-	-
	MACH C-4000	Backup	-	-	-	-	-	-
	Total		200	**559**		4,348	**4,217**	4,006

Table 26: Comparison of Alternative 1 Heating System with Existing Heating System

Energy Balance for Chillers													
			Chilled Water				**Cold Water**				**Input**		**Output**
Case	**Make / Model**	**Type**	**Inlet Temp (F)**	**Outlet Temp (F)**	**Flow Rate (GPM)**	**Qe In (Bhu/h)**	**Inlet Temp (F)**	**Outlet Temp (F)**	**Flow Rate (GPM)**	**Qc Out (Bhu/h)**	**COP**	**KW**	**TON**
Existing Chillers	TRACE CVHF 450	Electric Chiller	55	44	910	5,004,000	85	95	1,165	5,823,120	6.10	240	417
	TRACE CVHF 450	Electric Chiller	55	44	910	5,004,000	85	95	1,165	5,823,120	6.10	240	417
	Total				1,820	10,008,000			2,330	11,646,240		480	834
Alternative 1	TRACE CVHF 450	Electric Chiller	55	44	910	5,004,000	85	95	1,165	5,823,120	6.10	240	417
	TRACE CVHF 450	Electric Chiller	55	44	910	5,004,000	85	95	1,165	5,823,120	6.10	240	417
	Total				1,820	10,008,000			2,330	11,646,240		480	834

Table 27: Comparison of Alternative 1 Cooling System with Existing Cooling System

Table 28 shows the total energy consumption comparison and the total annual net savings of alternative 1 to the existing system. A total of $183,098 in natural gas costs can be saved annually, and a total of $1,349,040 in electricity costs can be saved annually. The total net savings for alternative 1 is $1,532,138.

		Annual Energy Generated		Annual Energy Consumption (Space Heating &Space Cooling)	
		Thermal (MMBtu)	Electricitiy (KWh)	Thermal (MMBtu)	Electricitiy (KWh)
Existing	Heating	-	-	103,091.37	-
	Cooling			-	4,204,800
Alternative 1	Heating	53,138	13,490,400	78,840.00	-
	Cooling			-	4,204,800

	Annual Net Saving				
	Thermal (MMBtu)	Electricitiy (KWh)	Thermal ($)	Electricitiy ($)	Total ($)
Existing vs. Alternative1	24,251	13,490,400	183,098	1,349,040	1,532,138

Table 28: Total Energy Consumptions and Net Saving Comparison- Existing System vs. Alternative 1

2.3 ALTERNATIVE 2: TRI-GENERATION

2.3.1 TRI-GENERATION – BACKGROUND INFORMATION

Alternative 2 is the Combined Heat, Power, and Cooling (CHPC) system, also known as the tri-generation system. With the similar manner of the cogeneration system, the same on-site energy-generating module is used for the tri-generation system. The major difference between cogeneration and tri-generation is the usage of thermal energy output from the CHP module. While the thermal energy from the CHP module is used for the heating process for the cogeneration system, the thermal energy from the CHP module is used for the cooling process for the tri-generation system. The tri-generation system utilizes energy in three forms: electricity, heat, and chilled water. However, the tri-generation system requires cooling equipment, which uses hot water or heat as a source, such as steam fired absorption chillers or hot water fired absorption chillers.

2.3.2 TRI-GENERATION – COOLING SYSTEM DESIGN

For tri-generation systems, a combination of a Lithium Bromide-Water absorption chiller and an electric chiller will be used. An electric chiller is placed parallel to the absorption chiller, just in case the CHP system does not run properly; the cooling system still produces 85% of chilled water when the CHP system breaks down because a certain amount of hot water is still supplied by boilers.

Since natural gas combustion boilers are placed after the absorption chiller, in series, more heat production from the absorption chiller will maximize the efficiency of the heating system. Thus, a single effect absorption chiller will be used, even if a double effect absorption chiller has higher C.O.P values. Table 29 shows a comparison between the performance data of a single effect absorption chiller and that of a double effect absorption chiller.

Chiller Type	Heat Production (Brtu/kWh)		Absorber COP		Cooling Available (Tons/kW)	
	Min.	Max.	Min.	Max.	Min.	Max.
Single Effect Absorption Chiller	3,800	6,000	0.70	0.78	0.22	0.35
Double Effect Absorption Chiller	1,500	2,000	1.10	1.30	0.15	0.20

Table 29: Single Effect Absorption Chiller vs. Double Effect Absorption Chiller

Prior to the selection process of an absorption chiller, the percentage of the cooling load, driven from each chiller, needs to be designed. 30% of the cooling load is designed to be served by the absorption chiller, while 70% of the cooling load is designed to be served by the existing electric chiller. The specification of the selected absorption chiller is summarized on Table 30. The technical data sheet of the selected absorption chiller can also be found in Appendix C.

Absorption Chiller Selection Carrier 16JLR 47 (Single Effect Lithium Bromide - Water Absorption Chiller)	
Cooling Capacity	450 Tons
Chilled Water Temp	54 / 44 F
Max. Chilled Water Flow rate	1080 GPM
Cooling Water Temp	85 / 95 F
Max. Cooling Water Flow rate	1620 GPM
Hot Water Temp	203 / 185 F
Max. Hot Water Flow rate	820 GPM
Steam Consumption	11.4 GPM
Electric power	3Φ, 380V, 50Hz
Solution Pump	3.7kW
Refrigerant Pump	0.8 kW
Capacity	6.75 kVA
COP	0.7

Table 30: Absorption Chiller Selection

2.3.3 TRI-GENERATION – ABSORPTION CHILLER BASIC THEORY

The absorption chiller uses lithium bromide solution, hot water, and cool water for the heat exchanging process to provide chilled water. The absorption chiller consists of five different components within the equipment: a generator, a condenser, an evaporator, an absorber, and a solution heat exchanger. In the generator, heat energy from hot water is used to boil a dilute solution of lithium bromide and water. Water vapor is released, and the lithium bromide solution is concentrated after the boiling process. In the condenser, the water vapor released from the concentrator is moved to condenser section, and cold water, flowing through the condenser water loop, condensates the water vapor. In the evaporator, liquid water flows through an orifice into the evaporator and flashes on the chilled water loop to create chilled water.

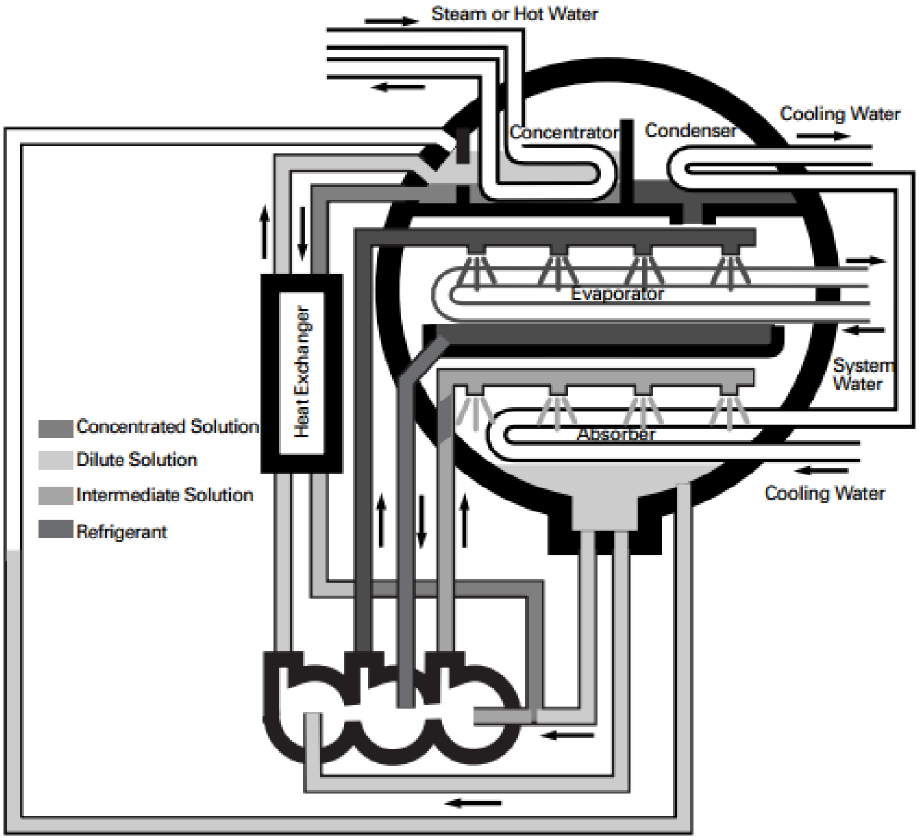


Figure 10: Single Stage Absorption Chiller System

2.3.3 TRI-GENERATION – CHP SYSTEM ENERGY SAVING ANALYSIS

Since hot water, rejected from the CHP module, is not enough to supply the absorption chiller, the combustion boilers generate more hot water in order to make enough hot water to feed the absorption chiller. Figure 11 shows a schematic drawing of the tri-generation system. The tri-generation system is designed with a lithium bromide absorption (hot water fired) chiller that is described on Table 30.

285 GPM of hot water (194 ˚F), exhausted from the CHP module, is mixed with 274 GPM of hot water (212 ˚F), which is served by boilers, and creates 599 GPM of hot water (203 ˚F). The mixed hot water then enters a concentrator and condenser within the absorption chiller to run the chiller. The water left from the absorption chiller is still high enough to make the performance of the heating system efficient enough. The hot water, leaving the absorption chiller at 185 ˚F, enters the combustion boilers and is heated to 200 ˚F. Since the boilers need to heat the water by only 15 ˚F, the total thermal energy used will be reduced, not as much as alternative 1, but still by a significant amount.

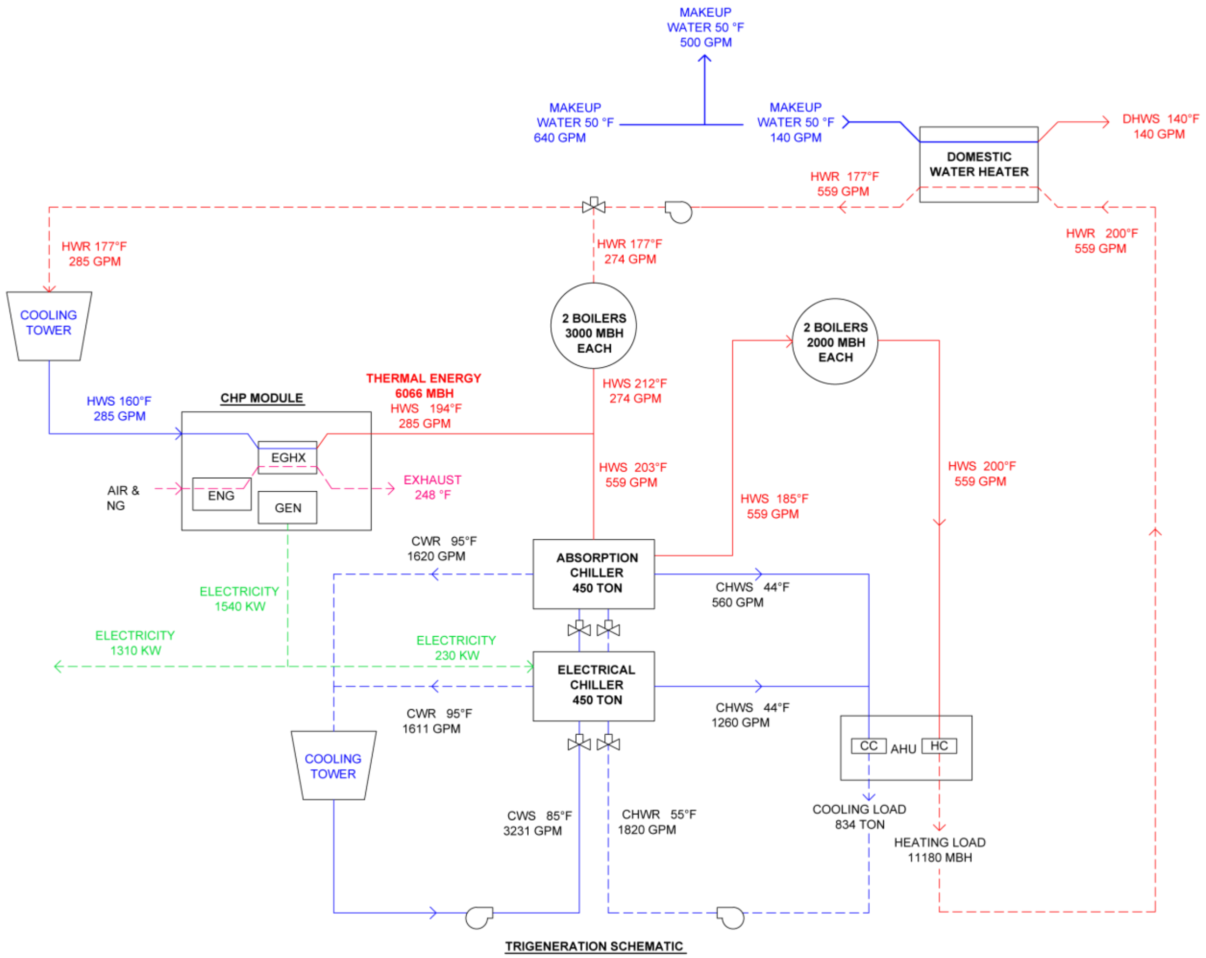


Figure 11: **Tri-Generation - CHP System Coordination with Existing Heating System**

Table 31 shows a comparison of the alternative 2 heating system to the existing heating system, and it also shows how many natural gas combustion boilers are needed for alternative 2. According to the energy balancing calculation, four boilers are needed to serve the total heating load, but all of the boilers are downsized to 3000 MBH. The input energy for alternative 2 is not as reduced, compared to alternative 1, but it is still reduced by 2,602 MBH.

Table 32 shows a comparison of the alternative 2 cooling system to the existing cooling system. Since only one electric chiller is used for alternative 2, the total electricity consumed by the cooling system is reduced by half, and the electricity required for the electric chiller will be provided by the CHP module. Thus, electricity required for the electric chiller is only 15% of the total electricity generated from the CHP module, and the other 85% of the total electricity generated will be used for other equipment.

Downsizing Boiler								
Case	**Make / Model**	**Function**	**Output Temp (F)**	**Flow (GPM)**	**Delta T (F)**	**NG Consumption (Therm)**	**Input (MBH)**	**Output (MBH)**
Existing Boilers	MACH C-4000	Heating Water	200	140	40	3,033	2,942	2,795
	MACH C-4000	Heating Water	200	140	40	3,033	2,942	2,795
	MACH C-4000	Heating Water	200	140	40	3,033	2,942	2,795
	MACH C-4000	Heating Water	200	140	40	3,033	2,942	2,795
	MACH C-4000	Backup	-	-	-	-	-	-
	MACH C-4000	Backup	-	-	-	-	-	-
	Total		200	**559**		12,133	**11,768**	11,180
Alternative 2: Trigeneration	MACH C-3000	Heating Water	212	137	35	2,602	2,524	2,398
	MACH C-3000	Heating Water	200	137	35	2,602	2,524	2,398
	MACH C-3000	Heating Water	200	280	14	2,123	2,059	1,957
	MACH C-3000	Heating Water	200	280	14	2,123	2,059	1,957
	MACH C-4000	Backup	-	-	-	-	-	-
	MACH C-4000	Backup	-	-	-	-	-	-
	Total		200	**599**		9,450	**9,166**	8,708

Table 31: Comparison of Alternative 2 Heating System with Existing Heating System

Energy Balance for Chiller																	
		Chilled Water					Cold Water				Hot Water				Input		Output
Case	**Make / Model**	**Type**	**Inlet Temp (F)**	**Outlet Temp (F)**	**Flow Rate (GPM)**	**Qe In (Bhu/h)**	**Inlet Temp (F)**	**Outlet Temp (F)**	**Flow Rate (GPM)**	**Qc Out (Bhu/h)**	**Inlet Temp (F)**	**Outlet Temp (F)**	**Flow Rate (GPM)**	**Qe In (Bhu/h)**	**COP**	**KW or Therms/Hr**	**TON**
Existing Chillers	TRACE CVHF 450	Electric Chiller	55	44	910	5,004,000	85	95	1,165	5,823,120	-	-	-	-	6.10	240	417
	TRACE CVHF 450	Electric Chiller	55	44	910	5,004,000	85	95	1,165	5,823,120	-	-	-	-	6.10	240	417
	Total				1,820	10,008,000			2,330	11,646,240						480	834
Alternative 2	Carrier 16JLR 47	Absorption Chiller	55	44	560	3,080,000	85	95	1,620	8,111,000	203	185	559	5,031,000	0.70	4.1	257
	TRACE CVHF 640	Electric Chiller	55	44	1,260	6,928,000	85	95	1,611	8,054,290	-	-	-		6.10	330	577
	Total				1,820	10,008,000			3,231	16,165,290							834

Table 32: Comparison of Alternative 2 Cooling System with Existing Cooling System

Table 33 compares the total energy consumption and total annual net savings of alternative 2 to the existing system. A total of $172,098 in natural gas costs can be saved annually, and a total of $1,480,440 in electricity costs can be saved annually. The total net savings for alternative 1 is $1,652,538.

		Annual Energy Generated		Annual Energy Consumption (Space Heating &Space Cooling)	
		Thermal (MMBtu)	Electricitiy (KWh)	Thermal (MMBtu)	Electricitiy (KWh)
Existing	Heating	-	-	103,091.37	-
	Cooling			-	4,204,800
Alternative 2	Heating	53,138	13,490,400	80,296.93	-
	Cooling				2,890,800

	Annual Net Saving				
	Thermal (MMBtu)	Electricitiy (KWh)	Thermal ($)	Electricitiy ($)	Total ($)
Existing vs. Alternative2	22,794	14,804,400	172,098	1,480,440	**1,652,538**

Table 33: Total Energy Consumptions and Net Saving Comparison- Existing System vs. Alternative 2

2.4 EMISSION

Table 34 shows a summary of annual emissions for each alternative. These analyses were done using the CHP emissions calculator developed by Energy and Environmental Analysis Inc. and ICF International Company. The actual spreadsheet, with input data, is attached in Appendix D. Table 34 suggests that alternative 2 is the most effective system, with the lowest emission of pollutants. About 4,408 tons of carbon dioxide is reduced by employing alternative 1, while about 9,425 tons of carbon dioxide is reduced by employing alternative 2.

Annual Emissions Analysis - Alternative 1					
	CHP System	2 Electric Chillers	Natural Gas Boilers	Emissions/Fuel Reduction	Percent Reduction
NOx (tons/year)	13.9515	8.0914	1.4085	(4.4516)	(0.4686)
SO2 (tons/year)	0.0385	22.2274	0.0165	22.2054	0.9983
CO2 (tons/year)	7,698.1510	8,773.6541	3,293.0347	4,368.5378	0.3620
CH4 (tons/year)	0.1451	0.1734	0.0621	0.0903	0.3836
N2O (tons/year)	0.0145	0.1304	0.0062	0.1221	0.8938
Total GHGs (CO2e tons/year)	7,705.6982	8,817.7267	3,296.2632	**4,408.2916**	0.3639
Carbon (metric tons/year)	1,903.4413	2,169.3697	814.2342	1,080.1626	0.3620
Fuel Consumption (MMBtu/year)	131,704.8932	97,663.7472	56,339.3449	22,298.1989	0.1448
Number of Cars Removed				**765**	

Annual Emissions Analysis - Alternative 2					
	CHP System	Absorption Chiller & Electric Chiller	Natural Gas Boilers	Emissions/Fuel Reduction	Percent Reduction
NOx (tons/year)	13.9515	14.8757	0.3929	1.3171	0.0863
SO2 (tons/year)	0.0385	40.8644	0.0046	40.8305	0.9991
CO2 (tons/year)	7,698.1510	16,130.0838	918.4846	9,350.4174	0.5485
CH4 (tons/year)	0.1451	0.3188	0.0173	0.1909	0.5681
N2O (tons/year)	0.0145	0.2398	0.0017	0.2270	0.9399
Total GHGs (CO2e tons/year)	7,705.6982	16,211.1099	919.3850	**9,424.7967**	0.5502
Carbon (metric tons/year)	1,903.4413	3,988.3171	227.1041	2,311.9799	0.5485
Fuel Consumption (MMBtu/year)	131,704.8932	179,551.6916	15,714.0216	63,560.8200	0.3255
Number of Cars Removed				**1,637**	

Table 34: Emission

2.3 OVERALL EVALUATION

Table 35 shows the initial equipment cost comparisons and shows how much money can be saved by adapting each alternative system. If alternative 1, the cogeneration system, is installed, the initial cost for boilers will be reduced by $893,000. If alternative 2, the tri-generation system, is installed, both the initial cost for boilers and electric chillers will be reduced by $532,000. However, the starting cost for the absorption chiller is $180,000, resulting in the total savings being less than that of alternative 1. All of the starting costs of backup boilers were considered in this calculation, but the rest of the mechanical equipment, which would not be changed by adapting either system, was not considered in this calculation.

Table 36 shows the annual net savings comparison of alternative 1 and alternative 2. If alternative 2 is selected, a total of $131,400 in electricity costs can be saved annually. The total net savings for alternative 1 is $120,400. Although the total equipment starting cost is more expensive for alternative 2, compared to that of alternative 1, higher annual net savings for alternative 2 will provide a shorter payback period than alternative 1 will.

First Cost	Existing	Alternative 1	Alternative 2
Boilers	$2,280,000	$1,387,000	$1,900,000
Electric Chiller	$304,000	$304,000	$152,000
Absorption Chiller	$0	$0	$180,000
Pumps	$400,000	$400,000	$400,000
Total	$2,984,000	$2,091,000	$2,632,000
Saving On First cost	$0	$893,000	$352,000

Table 35: Equipment First Cost Comparison

	Annual Net Saving				
	Thermal (MMBtu)	Electricitiy (KWh)	Thermal ($)	Electricitiy ($)	Total ($)
Existing vs. Alternative1	24,251	13,490,400	183,098	1,349,040	1,532,138
Existing vs. Alternative2	22,794	14,804,400	172,098	1,480,440	**1,652,538**
Alternative2 vs. Alternative 1	(1,457)	1,314,000	(11,000)	131,400	**120,400**

Table 36: Annual Net Saving Comparison

SECTION THREE. ACOUSTICAL BREADTH

The CHP module will be located outside of the building, as close to the boiler plant and chiller plant. Figure 12: CHP Module Location shows the location of the module. The module will be installed inside of a container box, which is covered with weather resistant material. For easier access to the equipment, clearance distance from the building to the equipment is followed by the local code.

The engine, cooling fan, generator, and engine exhaust produce noise, which are all within the CHP module. The noise is transferred to the surrounding through air movement or structures. Since the CHP module is located outside of the building on a slab-on-grade, the structural borne noise is not a concern for this condition. However, the air-borne noise from the exhaust air pipe is a big concern for this condition. The engine produces the most severe sound. The air-borne noise levels and the exhaust noise levels of the engine are provided in the data sheet of the engine catalog. The catalog can be found in Appendix B.

The yellow area in Figure 12: CHP Module Location is the design of a small courtyard. Noise transmission through the face brick wall is critical for this design. The exhaust noise needs to be reduced, prior to the exposure of the environment. According to the catalog of the CHP module, the CHP system is equipped with an exhaust air silencer, but the type and sound attenuation level of the silencer is not provided. Thus, a possible silence that can be used for the CHP module was selected by analyzing the exhaust airflow and the area of the exhaust pipe. In addition, combine absorber and barrier layers were selected to reduce the noise level before the sound moves to the exhaust gas pipe.

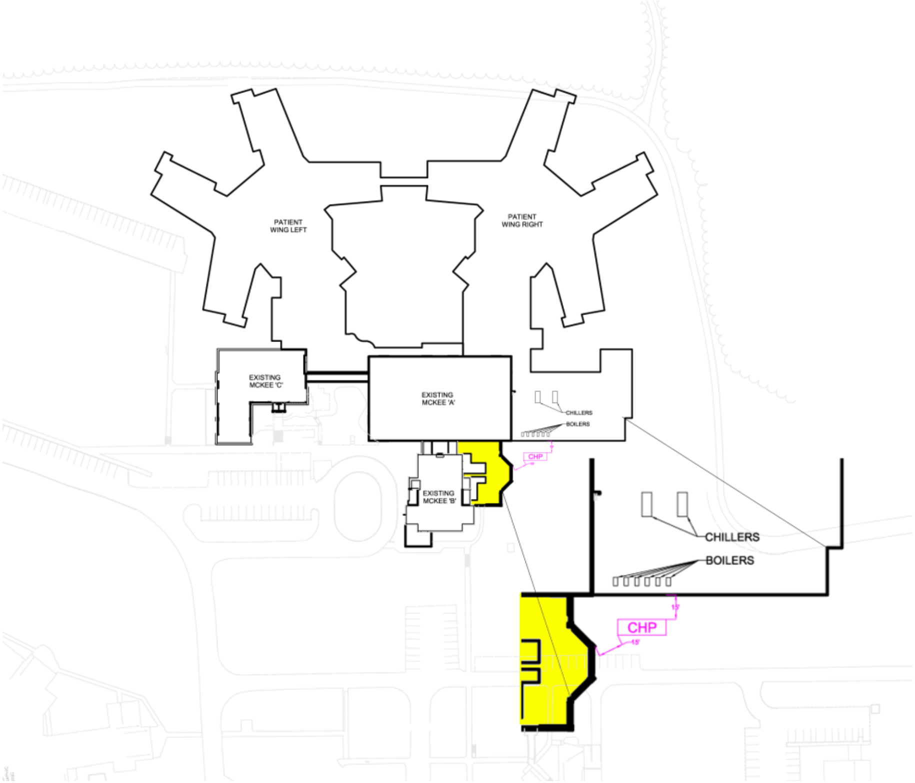


Figure 12: CHP Module Location

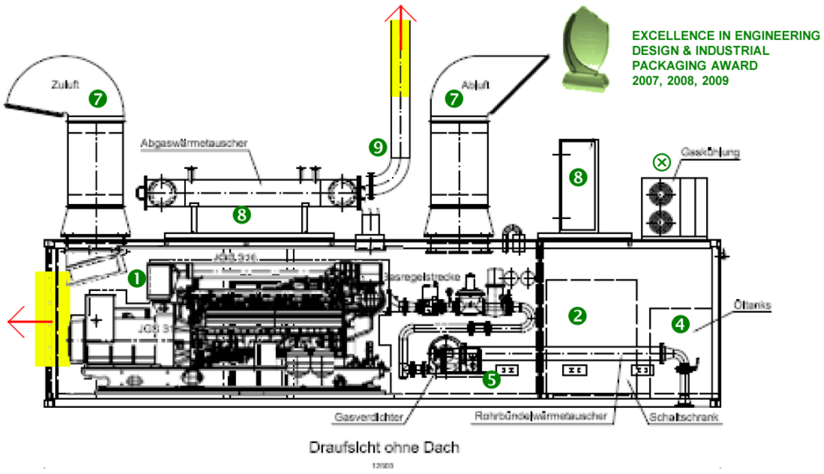


Figure 13: Noise Sources

A hospital grade silencer was chosen. All of the data on Table 37 was found from the engine catalog.

Silencer Selection Step.1 Given Data		T	ΔP	c
EN Series Silencers (Multi-Chamber Silencers)	Silence Type	Exhaust Gas Temperature (F)	Back pressure (in. H2O)	Silencer pressure drop coefficient
	Hospital grade	248	12.2	5.3

Table 37: Silencer Selection Given Data

Then, the gas velocity was determined by using Equation 1. The calculated gas velocity and the engine exhaust flow, found in the engine catalog, is summarized on Table 38. Then, the flow area required for the airflow is determined by using Equation 2. The flow area requirement calculations and actual area selection procedures are summarized on Table 39.

$$V = 4005\sqrt{\frac{\triangle P}{c\left(\frac{530}{T+460}\right)}}$$

V = gas velocity
$\triangle P$ = back pressure, inches of water
c = silencer pressure drop coefficient (Table 1)
T = exhaust gas temperature, °F

Equation 1: Gas Velocity

Silencer Selection Step.2 Solve for Gas		V	CFM
EN Series Silencers (Multi-Chamber Silencers)	Silence Type	Gas Velocity (ft/m)	Engine Exhuast Flow (CFM)
	Hospital grade	7020	4520

Table 38: Gas Velocity and Exhaust Airflow Rate

$$\text{Flow Area Required (ft}^2\text{)} = \frac{CFM}{V}$$

Equation 2: Flow Area Required

Silencer Selection Step.3 Size Selection		A	AS	DS
EN Series Silencers (Multi-Chamber Silencers)	Silence Type	Flow Area (ft^2)	Flow Area Selected (ft^2)	Diameter Selected (in)
	Hospital grade	0.64	0.79	12

Table 39: Size Selection

Based on the data of the selected silencer, actual gas velocity and the back pressure difference is calculated and summarized on Table 40. Sound attenuation levels of each silencer are summarized on Table 41. According to the sound attenuation level of each silencer type, EN5 seems to be the most appropriate for the CHP system. The actual dimension of EN5 is summarized on Table 42. The technical data sheet of the selected exhaust noise silencer can also be found in Appendix E.

Silencer Selection Step.4 Obtain Actual Data		V	ΔP
EN Series Silencers (Multi-Chamber Silencers)	Silence Type	Gas Velocity (ft/m)	Back pressure (in. H2O)
	Hospital grade	5722	8.1

Table 40: Actual Silencer Data

Sound Attenuation Device - Silencer	Octave-Band Frequencies (Hz)								
	63	125	250	500	1000	2000	4000	8000	Overall Sound
EN2	12	20	28	22	18	16	15	15	30
EN3	16	25	33	26	22	21	20	20	35
EN4	20	30	34	30	26	24	23	23	38
EN5	22	34	39	34	30	29	28	28	42

Table 41: Sound Attenuation Level of Each Silencer Type

Silencer Selection	
EN5	
SIZE	12
D (in)	36
L (in)	138
N (in)	3.5
H (in)	131
WEIGHT (lb)	1050

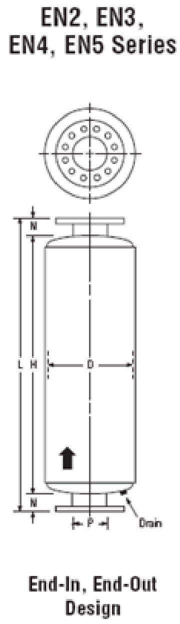


Table 42: Silencer Dimension

Combine absorber and barrier layers are selected and installed inside of the container in order to reduce the noise level before the noise is exhausted through the exhaust gas pipe. The technical data sheet of the selected combine absorber and barrier layers can also be found in Appendix E. Then noise level will be further reduced after the sound passes through the selected silencer. The overall sound level of exhaust noise is reduced to 46 dBA after sound attenuation, through the silencer, EN5. The noise reduction procedure is summarized on Table 43.

	Octave-Band Frequencies (Hz)						
	125	250	500	1000	2000	4000	Overall Sound
Air-Borne Noise (dBA)	96	99	100	102	100	107	**110**
ABAC-R111N	19	20	28	42	56	62	**63**
Silencer EN5	34	39	34	30	29	28	**42**
Noise Reduced to (dBA)	43	40	38	30	15	17	**46**

Table 43: Noise Reduction Calculation

SECTION FOUR. ELECTRICAL DEPTH

The CHP system generates electricity, which will be used on-site. This section will examine if the CHP generator can replace one of the existing emergency generators connected to the existing parallel switchgear. The simplified schematic of the existing electrical system is shown on Figure 14. In order to replace the existing emergency generator with the CHP generator, the NEC code needs to be evaluated.

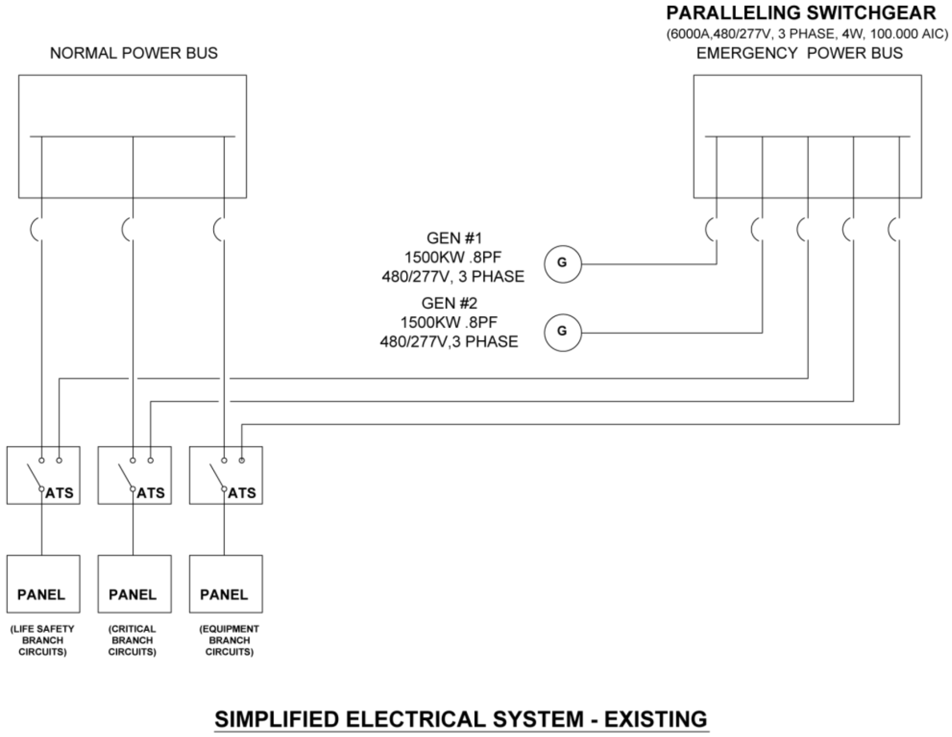


Figure 14: Existing Electrical Schematic

In accordance of NEC 517.31 and NFPA 99 3-4.3.1, the emergency generator Startup time for the Healthcare facility is restricted to be less than 10 seconds. Startup time for the generator is not provided. In order to perform further analysis on the electrical part of the CHP system, the startup time for the CHP system was assumed to be less than 10 second. In addition the CHP system cannot serve for the life safety branch circuits and critical branch circuits. It was essential to examine how the existing emergency generators distribute the load to the life safety branch circuits, critical branch circuits, and equipment branch circuits. Figure 15 shows the existing parallel switchgear distribution diagram.

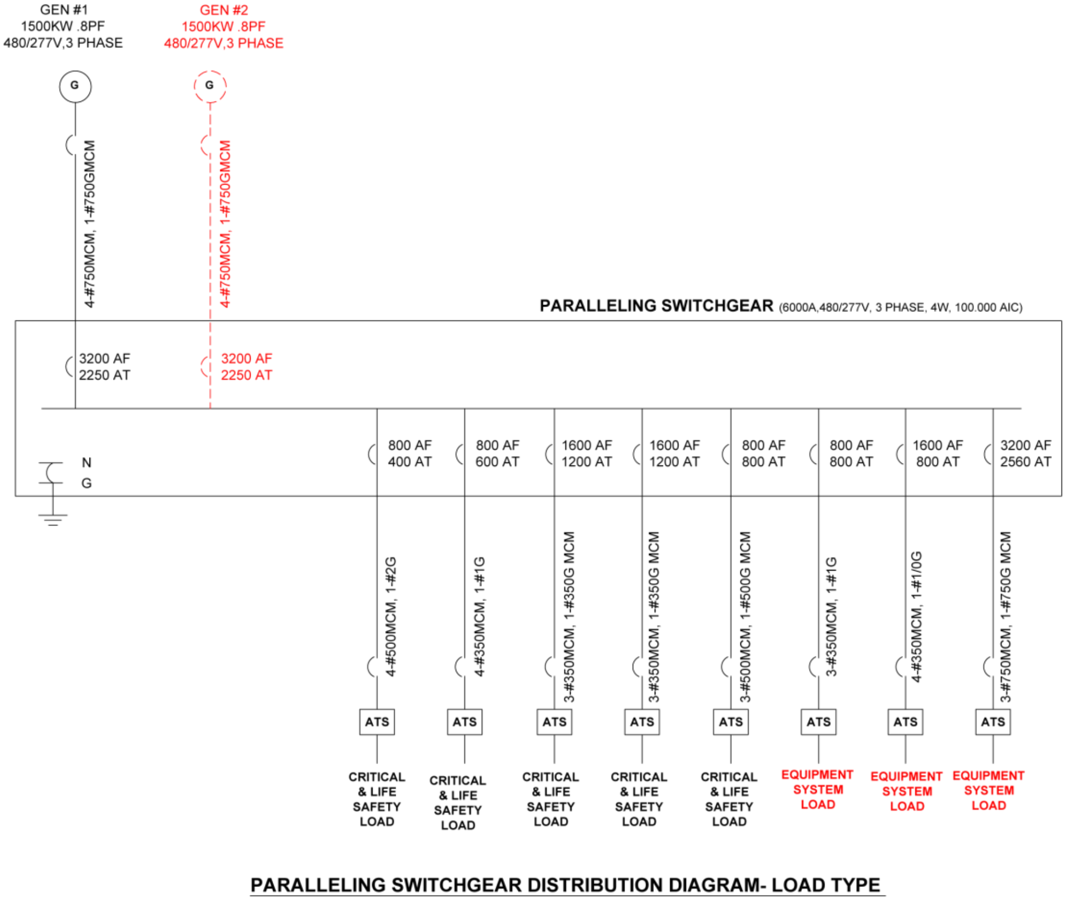


Figure 15: Existing Paralleling Switchgear Distribution Diagram

Almost half of the loads supplied by the emergency generators are equipment system loads. Since the CHP generator cannot serve as both the life safety load and critical load, the only load type that the CHP generator can serve as is the equipment system load. One of the existing emergency generators can be replaced with the CHP generator, since the other existing emergency generator is big enough to serve as the life safety load and critical load.

Figure 16 is a newly designed one-line diagram for the emergency power distribution. The current carrying conductors used for the CHP generator are oversized (with 115%), in accordance to NEC 445.13. According to the electrical specification provided by the engineer, the temperature rating of the conductor is 167 ˚F. The sizing of the current carrying conductors, connecting the CHP generator with the existing switchgear, is summarized on Table 44.

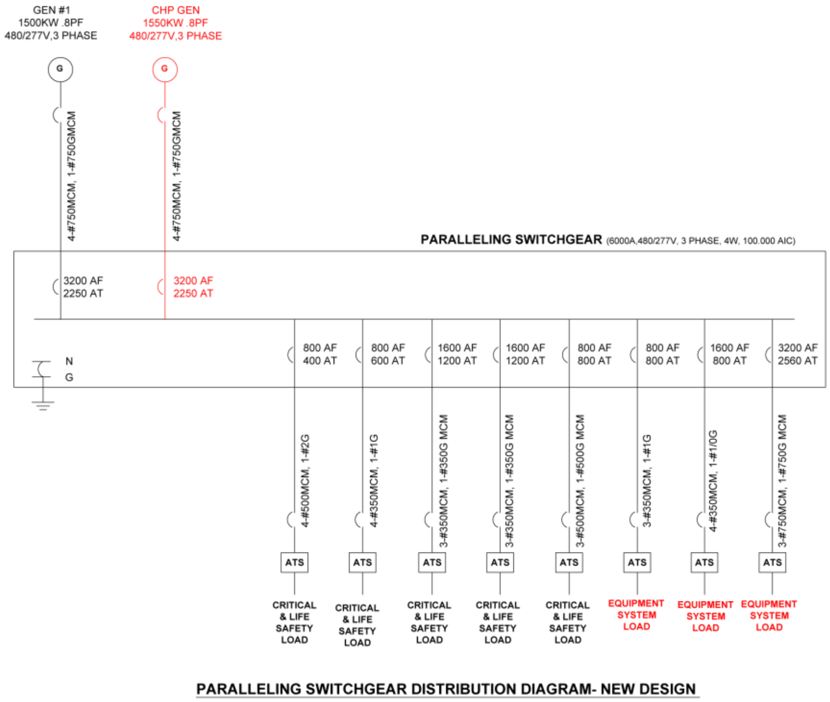


Figure 16: Paralleling Switchgear Distribution Diagram - New Design

Sizing Conductors		
Electrical Output	1,540	KW
Power Factor	0.90	
Voltage	480	V
Amps	1,667	A
Over Current Protection (115%)	1,917	A
Up sized: 4 set of # 750 MCM, 1 set of #750 G MCM		

Table 44: Sizing Conductors for the CHP Generator

CONCLUSION

Alternative 1, the cogeneration system, and alternative 2, the tri-generation system, are evaluated in this report. The CHP module was selected based on the base-heating load in order to prevent the excessive thermal energy from being wasted during cooling season. The selected CHP module consists of a reciprocating engine, a generator, and an exhaust air heat exchanger.

The CHP module outputs 1,540 KW of electrical energy and 6,066 MBH of thermal energy. The thermal and electrical efficiencies of the selected CHP module are 44% and 42%, respectively. The overall efficiency of the module is almost 80%. The simple payback period of the CHP module was calculated to be 3.3 years, which is preferable for owners who have long-term goals of saving money.

For alternative 1, the energy generated on-site from the CHP module will be used for one 2,000MBH boiler, three 3,000MBH boilers, and two 450 Ton electric chillers. For alternative 2, the energy generated on-site from the CHP module will be used for four 3,000MBH boilers, one 450 Ton electric chiller, and one 270 Ton absorption chiller.

The initial cost of the downsized boilers for alternative 1 will be reduced by $893,000. The starting cost of the downsized boilers and of the 450 Ton electric chillers for alternative 2 will be reduced by $532,000. However, the starting cost of the absorption chiller results in the total savings of the first cost of alternative 2 to be less than that of alternative 1.

A total of $4,468 in natural gas costs and a total of $1,349,040 in electricity costs can be saved annually by using alternative 1. The total net savings for alternative 1 is $1,353,508. A total of $172,098 in natural gas costs and a total of $1,480,440 in electricity costs can be saved annually for alternative 2. The total net savings for alternative 2 is $1,652,538. Even if the initial cost for the total equipment is more expensive for alternative 2, the higher annual net savings for alternative 2 will provide shorter payback periods compared to that of alternative 1.

For acoustic breadth analysis, a silencer of the CHP system was selected based on the exhaust gas temperature, back pressure, and engine exhaust flow rate. By the use of combine absorber and barrier layers within the container, further noise reduction was achieved to prevent the engine noise from being exhausted into the surroundings. The overall sound level of exhaust air is reduced from 111dBA to 46dBA.

For the electrical breadth analysis, one of the existing emergency generators was replaced by the CHP generator. The NEC code requirements for an emergency generator and for a CHP generator are evaluated to see if the CHP generator can actually replace the existing emergency generator. How the emergency loads are distributed from the existing parallel switchgear was examined. In conclusion, the selected CHP generator can replace one of the existing emergency generators and serve equipment loads only.

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APPENDIX

APPENDIX A

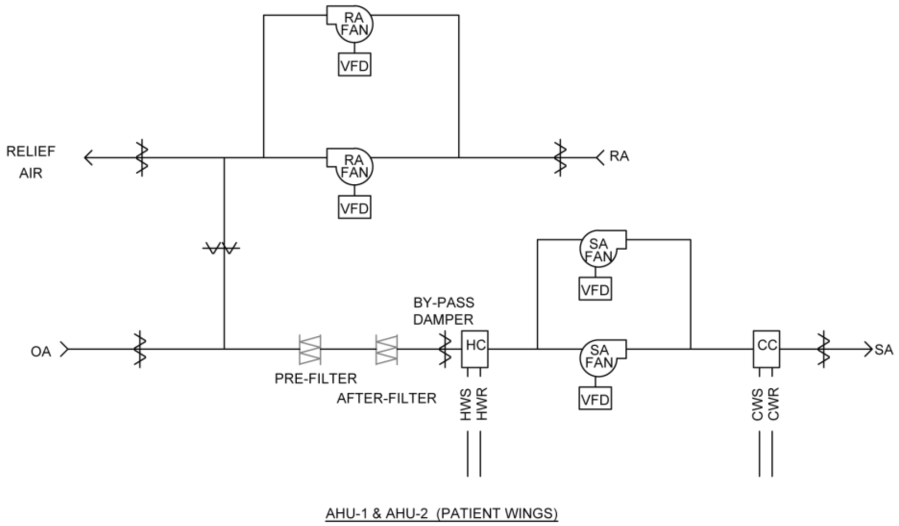


Figure 17: AHU 1 & 2 Control

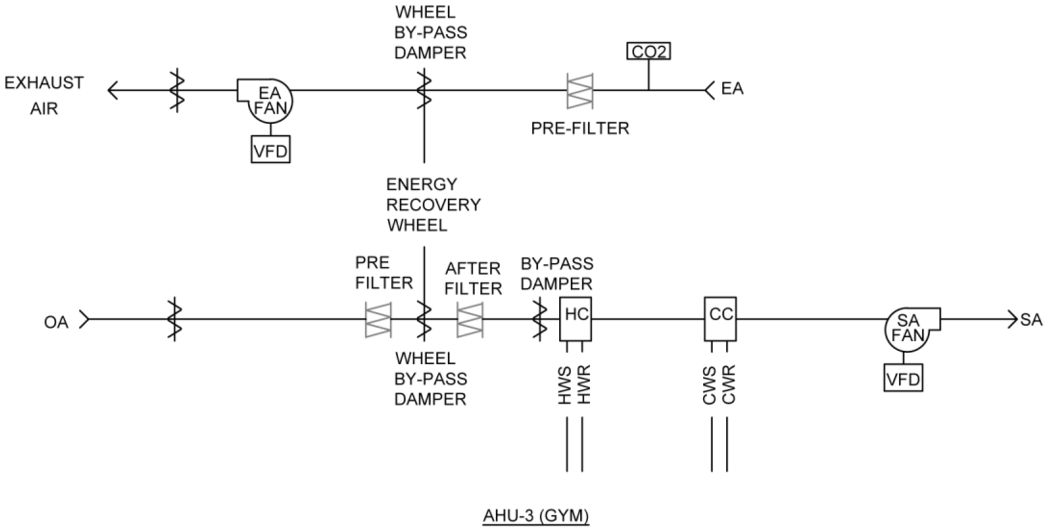


Figure 18: AHU3 Control

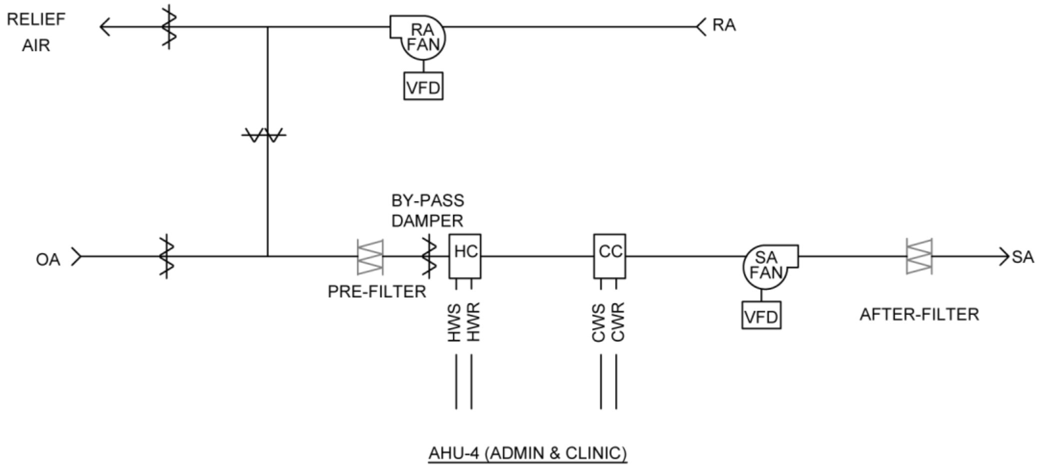


Figure 19: AHU 4 Control

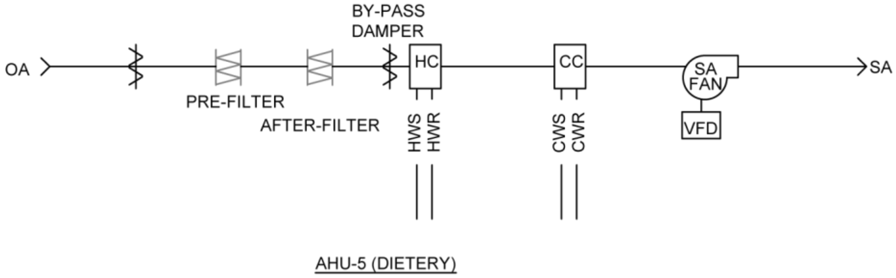


Figure 20: AHU 5 Control

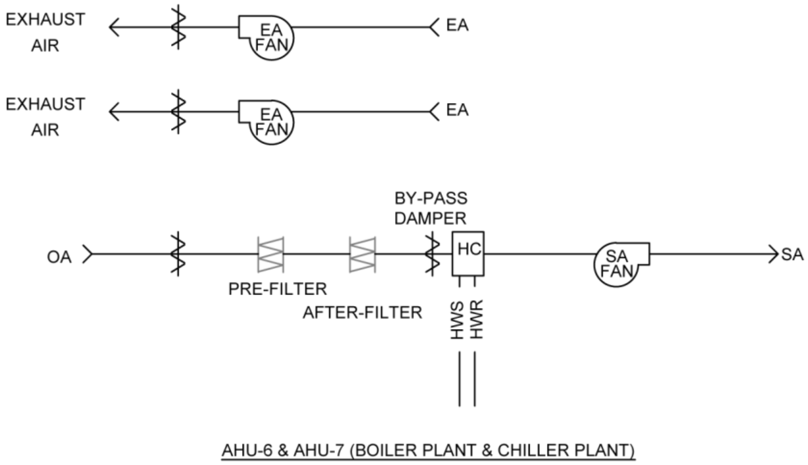


Figure 21: AHU 6 & 7 Control

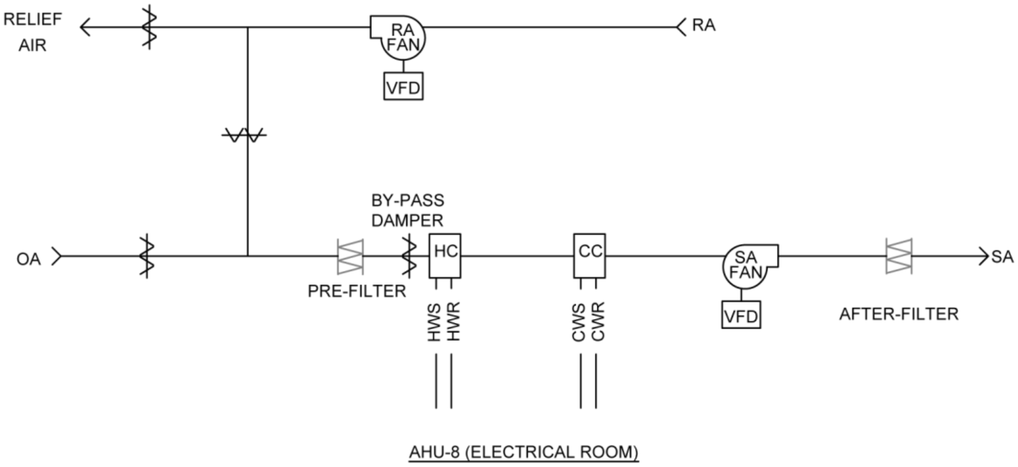


Figure 22: AHU 8 Control

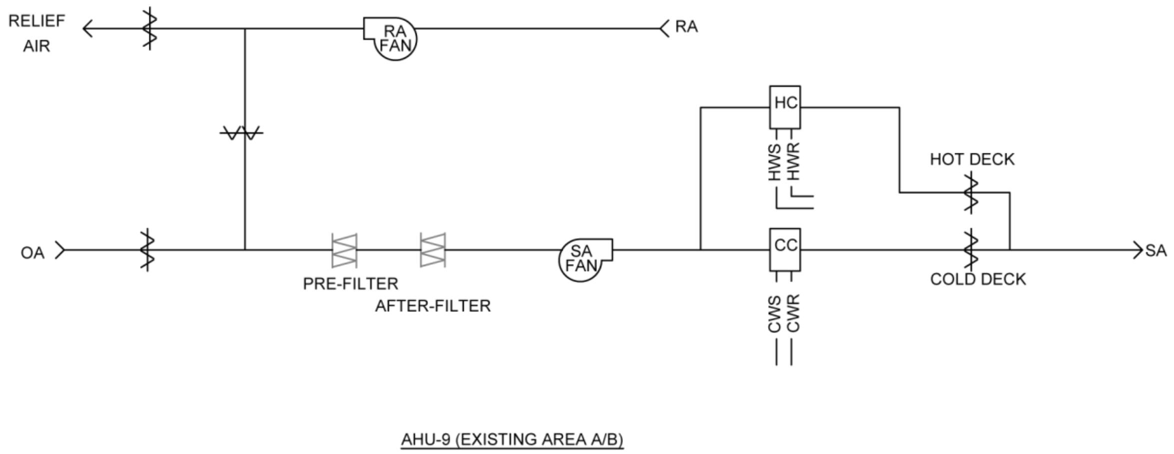


Figure 23: AHU 9 Control

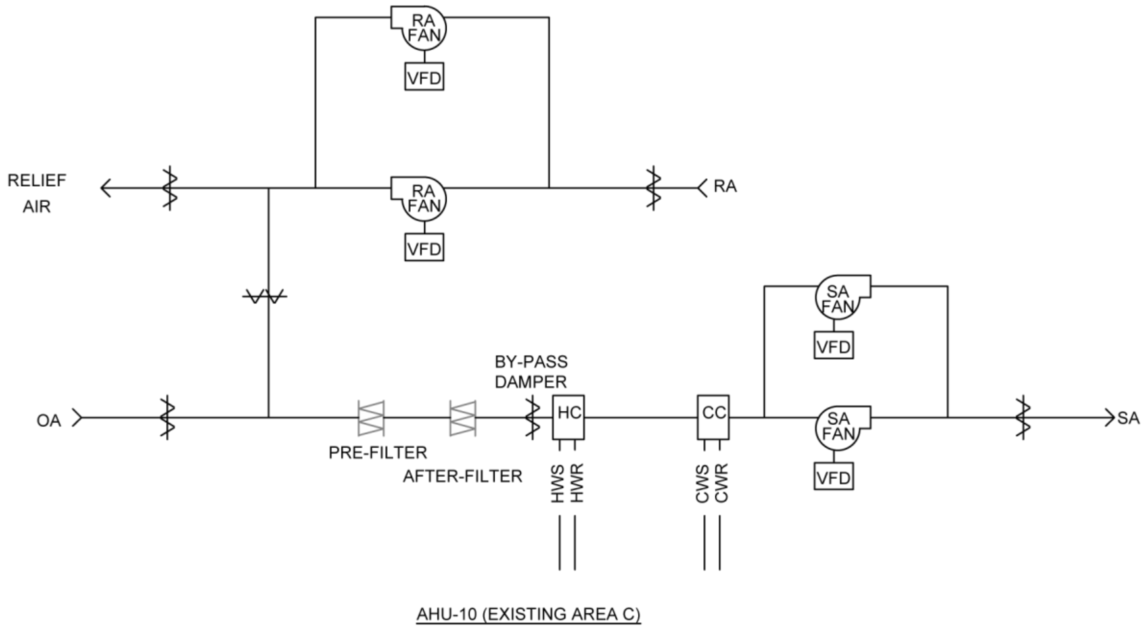


Figure 24: AHU 10 Control

APPENDIX B

2G CENERGY®
Advanced Clean Energy Technologies

2G 1540 NG – 1540ekW Natural Gas
CHP Cogeneration Module
Lean Combustion Technology

Reliable, rugged and highly durable factory-designed, production line assembled, professionally packaged, and post-production tested **2G® Natural Gas Cogeneration Module**, supplied in an "all-in-one" package that is "connection-ready". Manufactured at 2G® ISO compliant production facilities in Germany, especially made for the U.S. cogeneration market.

This CHP (Combined Heat & Power) cogeneration equipment is a fully integrated power generation system, with state-of-the-art technology that results in optimum performance and efficiency. The 2G® CHP module integrates all cogeneration components into one unique package that converts energy more efficiently than conventional CHP systems.

The robust design utilizes full authority electronic engine management, incl. CHP performance monitoring that provides prolonged life, low maintenance, and high efficiency. Items such as, engine & system controls, synchronizing and paralleling switchgear, heat recovery (both for engine jacket water and exhaust), the entire thermal heat technology system, pumps, piping, plumbing, etc., are all included "within the module" dramatically reducing the risk of cost overruns and performance issues associated with conventional "site built" systems.

The 2G® CHP module allows for optimized efficiency by maximizing heat recovery and applying a more efficient combustion technology, leading to a higher electrical output.

Open Inside Installation

Compact & Small Foot-Print

Thermal Heat Distribution

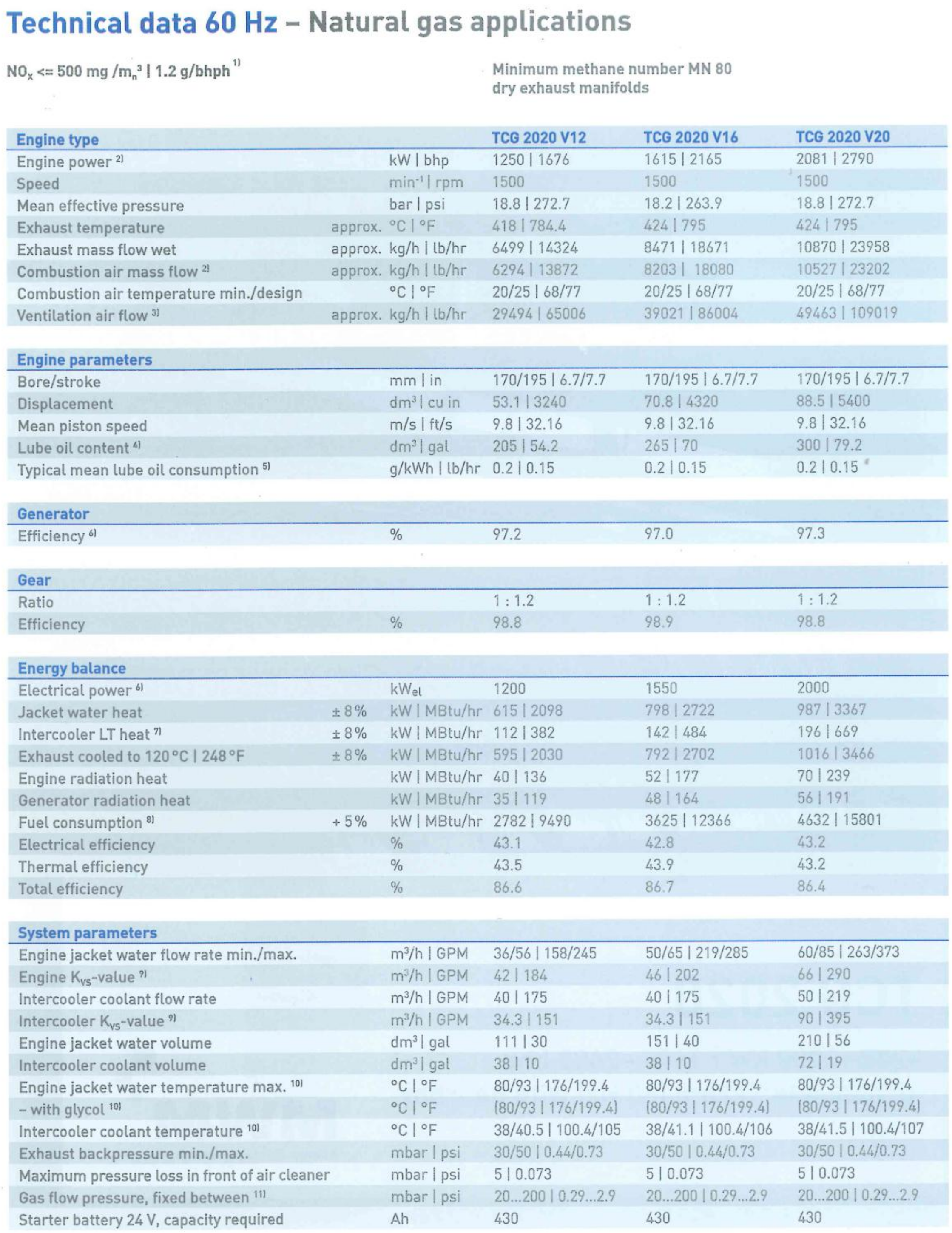
Heat Recovery Included

Natural Gas

2G® CHP Module
NG Optimized Package

Prime Mover	MWM®
Core Engine Type	TCG 2020
Configuration	2G® Natural Gas Optimized
Arrangement / Cylinders	V 16
Displacement / BHP	70.8 L / 2,146 BHP
Compression Ratio	13.5:1
Speed	1500/1800 RPM
Frequency / Phase	60 Hz / 3-Phase
Voltage*	480 V
Electrical Output	1,540 ekW continuous
Thermal Output	1,778 kW continuous
Combined Output	3,318 kW continuous
Thermal Heat BTU	6,066,787 (usable)
Ø Water Flow HT	17,100 gph / 64,730 L/h
Hot Water Flow LT	12,120 gph / 45,879 L/h
Water Temperature	90°C / 194°F
Electrical Efficiency	42.00 %
Thermal Efficiency	44.06 %
Total Efficiency	86.06 %
Consumption Mbtu/h	12508 MBtu/h
Heat Value	950 Btu/ft³/h
Consumption cf/m	219.4 ft³/m
Cons. BTU / ekW	8,122
Exhaust Gas Mass (Wet)	8,259 kg / 18,203 lbs
Exhaust Gas Volume	7,020 m³/h / 247,908 ft³/h

*(*Other Voltages are available).*

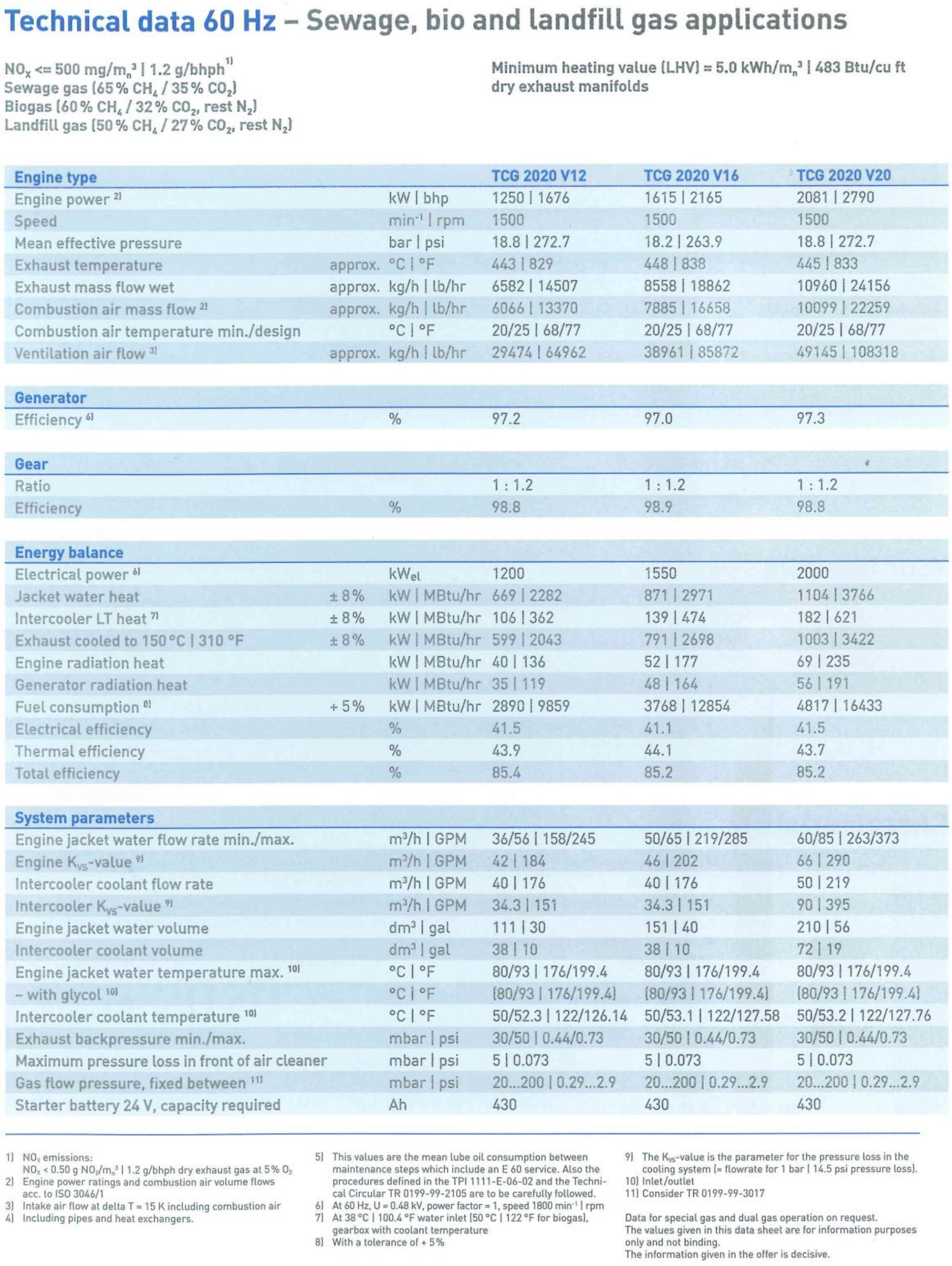


Technical data 60 Hz – Natural gas applications

NO_x <= 500 mg /m_n^3 | 1.2 g/bhph 1)

Minimum methane number MN 80
dry exhaust manifolds

Engine type			**TCG 2020 V12**	**TCG 2020 V16**	**TCG 2020 V20**
Engine power 2)		kW | bhp	1250 | 1676	1615 | 2165	2081 | 2790
Speed		min⁻¹ | rpm	1500	1500	1500
Mean effective pressure		bar | psi	18.8 | 272.7	18.2 | 263.9	18.8 | 272.7
Exhaust temperature	approx.	°C | °F	418 | 784.4	424 | 795	424 | 795
Exhaust mass flow wet	approx.	kg/h | lb/hr	6499 | 14324	8471 | 18671	10870 | 23958
Combustion air mass flow 2)	approx.	kg/h | lb/hr	6294 | 13872	8203 | 18080	10527 | 23202
Combustion air temperature min./design		°C | °F	20/25 | 68/77	20/25 | 68/77	20/25 | 68/77
Ventilation air flow 3)	approx.	kg/h | lb/hr	29494 | 65006	39021 | 86004	49463 | 109019
Engine parameters					
Bore/stroke		mm | in	170/195 | 6.7/7.7	170/195 | 6.7/7.7	170/195 | 6.7/7.7
Displacement		dm³ | cu in	53.1 | 3240	70.8 | 4320	88.5 | 5400
Mean piston speed		m/s | ft/s	9.8 | 32.16	9.8 | 32.16	9.8 | 32.16
Lube oil content 4)		dm³ | gal	205 | 54.2	265 | 70	300 | 79.2
Typical mean lube oil consumption 5)		g/kWh | lb/hr	0.2 | 0.15	0.2 | 0.15	0.2 | 0.15
Generator					
Efficiency 6)		%	97.2	97.0	97.3
Gear					
Ratio			1 : 1.2	1 : 1.2	1 : 1.2
Efficiency		%	98.8	98.9	98.8
Energy balance					
Electrical power 6)		kW_{el}	1200	1550	2000
Jacket water heat	± 8 %	kW | MBtu/hr	615 | 2098	798 | 2722	987 | 3367
Intercooler LT heat 7)	± 8 %	kW | MBtu/hr	112 | 382	142 | 484	196 | 669
Exhaust cooled to 120 °C | 248 °F	± 8 %	kW | MBtu/hr	595 | 2030	792 | 2702	1016 | 3466
Engine radiation heat		kW | MBtu/hr	40 | 136	52 | 177	70 | 239
Generator radiation heat		kW | MBtu/hr	35 | 119	48 | 164	56 | 191
Fuel consumption 8)	+ 5 %	kW | MBtu/hr	2782 | 9490	3625 | 12366	4632 | 15801
Electrical efficiency		%	43.1	42.8	43.2
Thermal efficiency		%	43.5	43.9	43.2
Total efficiency		%	86.6	86.7	86.4
System parameters					
Engine jacket water flow rate min./max.		m³/h | GPM	36/56 | 158/245	50/65 | 219/285	60/85 | 263/373
Engine K_{VS}-value 9)		m³/h | GPM	42 | 184	46 | 202	66 | 290
Intercooler coolant flow rate		m³/h | GPM	40 | 175	40 | 175	50 | 219
Intercooler K_{VS}-value 9)		m³/h | GPM	34.3 | 151	34.3 | 151	90 | 395
Engine jacket water volume		dm³ | gal	111 | 30	151 | 40	210 | 56
Intercooler coolant volume		dm³ | gal	38 | 10	38 | 10	72 | 19
Engine jacket water temperature max. 10)		°C | °F	80/93 | 176/199.4	80/93 | 176/199.4	80/93 | 176/199.4
– with glycol 10)		°C | °F	(80/93 | 176/199.4)	(80/93 | 176/199.4)	(80/93 | 176/199.4)
Intercooler coolant temperature 10)		°C | °F	38/40.5 | 100.4/105	38/41.1 | 100.4/106	38/41.5 | 100.4/107
Exhaust backpressure min./max.		mbar | psi	30/50 | 0.44/0.73	30/50 | 0.44/0.73	30/50 | 0.44/0.73
Maximum pressure loss in front of air cleaner		mbar | psi	5 | 0.073	5 | 0.073	5 | 0.073
Gas flow pressure, fixed between 11)		mbar | psi	20...200 | 0.29...2.9	20...200 | 0.29...2.9	20...200 | 0.29...2.9
Starter battery 24 V, capacity required		Ah	430	430	430



Technical data 60 Hz – Sewage, bio and landfill gas applications

NO_x <= 500 mg/m_n^3 | 1.2 g/bhph 1)
Sewage gas (65 % CH_4 / 35 % CO_2)
Biogas (60 % CH_4 / 32 % CO_2, rest N_2)
Landfill gas (50 % CH_4 / 27 % CO_2, rest N_2)

Minimum heating value (LHV) = 5.0 kWh/m_n^3 | 483 Btu/cu ft
dry exhaust manifolds

Engine type			**TCG 2020 V12**	**TCG 2020 V16**	**TCG 2020 V20**
Engine power 2)		kW | bhp	1250 | 1676	1615 | 2165	2081 | 2790
Speed		min^{-1} | rpm	1500	1500	1500
Mean effective pressure		bar | psi	18.8 | 272.7	18.2 | 263.9	18.8 | 272.7
Exhaust temperature	approx.	°C | °F	443 | 829	448 | 838	445 | 833
Exhaust mass flow wet	approx.	kg/h | lb/hr	6582 | 14507	8558 | 18862	10960 | 24156
Combustion air mass flow 2)	approx.	kg/h | lb/hr	6066 | 13370	7885 | 16658	10099 | 22259
Combustion air temperature min./design		°C | °F	20/25 | 68/77	20/25 | 68/77	20/25 | 68/77
Ventilation air flow 3)	approx.	kg/h | lb/hr	29474 | 64962	38961 | 85872	49145 | 108318
Generator					
Efficiency 6)		%	97.2	97.0	97.3
Gear					
Ratio			1 : 1.2	1 : 1.2	1 : 1.2
Efficiency		%	98.8	98.9	98.8
Energy balance					
Electrical power 6)		kW_{el}	1200	1550	2000
Jacket water heat	± 8 %	kW | MBtu/hr	669 | 2282	871 | 2971	1104 | 3766
Intercooler LT heat 7)	± 8 %	kW | MBtu/hr	106 | 362	139 | 474	182 | 621
Exhaust cooled to 150 °C | 310 °F	± 8 %	kW | MBtu/hr	599 | 2043	791 | 2698	1003 | 3422
Engine radiation heat		kW | MBtu/hr	40 | 136	52 | 177	69 | 235
Generator radiation heat		kW | MBtu/hr	35 | 119	48 | 164	56 | 191
Fuel consumption 8)	+ 5 %	kW | MBtu/hr	2890 | 9859	3768 | 12854	4817 | 16433
Electrical efficiency		%	41.5	41.1	41.5
Thermal efficiency		%	43.9	44.1	43.7
Total efficiency		%	85.4	85.2	85.2
System parameters					
Engine jacket water flow rate min./max.		m^3/h | GPM	36/56 | 158/245	50/65 | 219/285	60/85 | 263/373
Engine K_{VS}-value 9)		m^3/h | GPM	42 | 184	46 | 202	66 | 290
Intercooler coolant flow rate		m^3/h | GPM	40 | 176	40 | 176	50 | 219
Intercooler K_{VS}-value 9)		m^3/h | GPM	34.3 | 151	34.3 | 151	90 | 395
Engine jacket water volume		dm^3 | gal	111 | 30	151 | 40	210 | 56
Intercooler coolant volume		dm^3 | gal	38 | 10	38 | 10	72 | 19
Engine jacket water temperature max. 10)		°C | °F	80/93 | 176/199.4	80/93 | 176/199.4	80/93 | 176/199.4
– with glycol 10)		°C | °F	(80/93 | 176/199.4)	(80/93 | 176/199.4)	(80/93 | 176/199.4)
Intercooler coolant temperature 10)		°C | °F	50/52.3 | 122/126.14	50/53.1 | 122/127.58	50/53.2 | 122/127.76
Exhaust backpressure min./max.		mbar | psi	30/50 | 0.44/0.73	30/50 | 0.44/0.73	30/50 | 0.44/0.73
Maximum pressure loss in front of air cleaner		mbar | psi	5 | 0.073	5 | 0.073	5 | 0.073
Gas flow pressure, fixed between 11)		mbar | psi	20...200 | 0.29...2.9	20...200 | 0.29...2.9	20...200 | 0.29...2.9
Starter battery 24 V, capacity required		Ah	430	430	430

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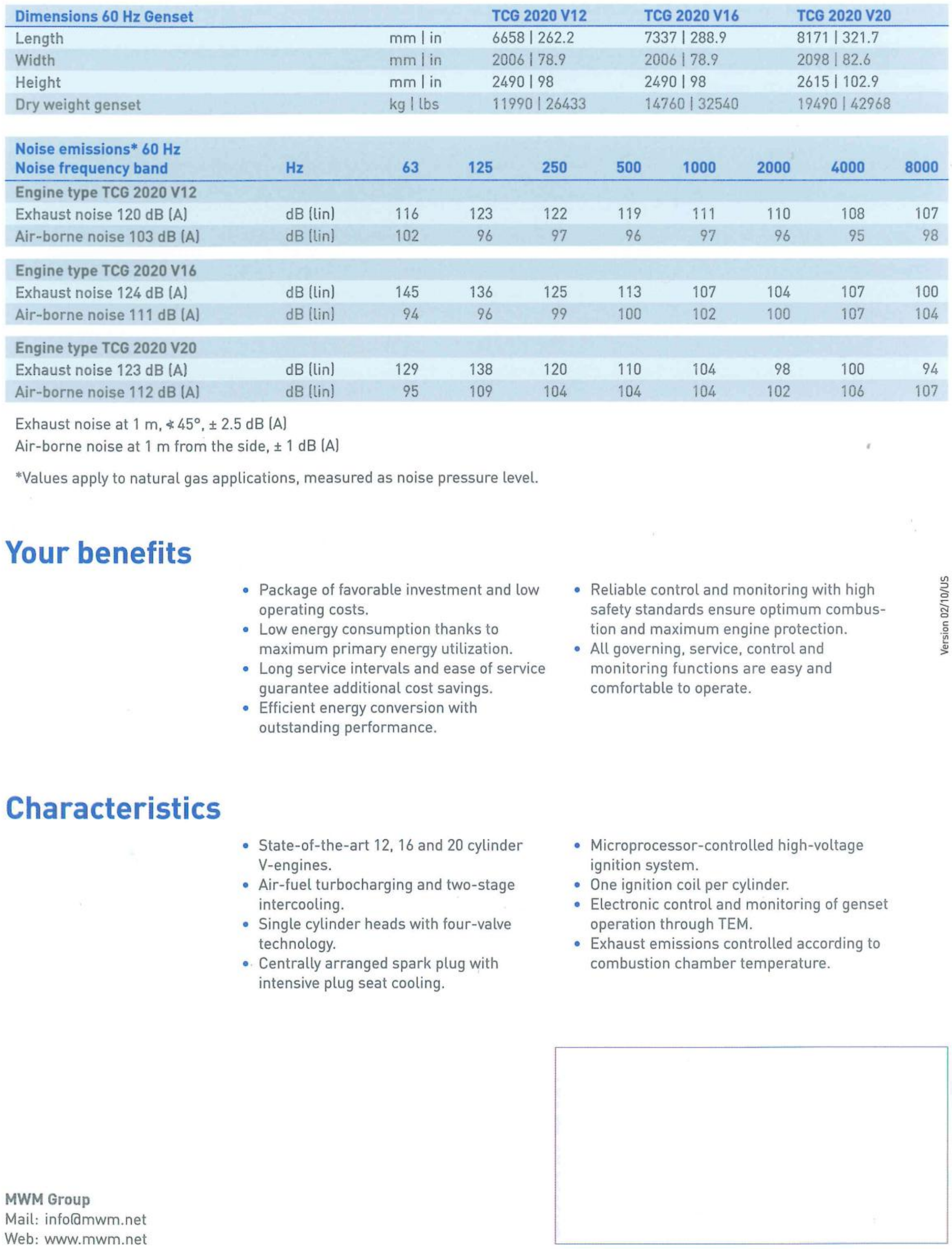
1) NO_x emissions:
NO_x < 0.50 g NO_2/m_n^3 | 1.2 g/bhph dry exhaust gas at 5 % O_2
2) Engine power ratings and combustion air volume flows acc. to ISO 3046/1
3) Intake air flow at delta T = 15 K including combustion air
4) Including pipes and heat exchangers.
5) This values are the mean lube oil consumption between maintenance steps which include an E 60 service. Also the procedures defined in the TPI 1111-E-06-02 and the Technical Circular TR 0199-99-2105 are to be carefully followed.
6) At 60 Hz, U = 0.48 kV, power factor = 1, speed 1800 min^{-1} | rpm
7) At 38 °C | 100.4 °F water inlet (50 °C | 122 °F for biogas), gearbox with coolant temperature
8) With a tolerance of + 5 %
9) The K_{VS}-value is the parameter for the pressure loss in the cooling system (= flowrate for 1 bar | 14.5 psi pressure loss).
10) Inlet/outlet
11) Consider TR 0199-99-3017

Data for special gas and dual gas operation on request.
The values given in this data sheet are for information purposes only and not binding.
The information given in the offer is decisive.



Dimensions 60 Hz Genset		TCG 2020 V12	TCG 2020 V16	TCG 2020 V20
Length	mm | in	6658 | 262.2	7337 | 288.9	8171 | 321.7
Width	mm | in	2006 | 78.9	2006 | 78.9	2098 | 82.6
Height	mm | in	2490 | 98	2490 | 98	2615 | 102.9
Dry weight genset	kg | lbs	11990 | 26433	14760 | 32540	19490 | 42968

Noise emissions* 60 Hz Noise frequency band	Hz	63	125	250	500	1000	2000	4000	8000
Engine type TCG 2020 V12									
Exhaust noise 120 dB (A)	dB (lin)	116	123	122	119	111	110	108	107
Air-borne noise 103 dB (A)	dB (lin)	102	96	97	96	97	96	95	98
Engine type TCG 2020 V16									
Exhaust noise 124 dB (A)	dB (lin)	145	136	125	113	107	104	107	100
Air-borne noise 111 dB (A)	dB (lin)	94	96	99	100	102	100	107	104
Engine type TCG 2020 V20									
Exhaust noise 123 dB (A)	dB (lin)	129	138	120	110	104	98	100	94
Air-borne noise 112 dB (A)	dB (lin)	95	109	104	104	104	102	106	107

Exhaust noise at 1 m, ∢ 45°, ± 2.5 dB (A)
Air-borne noise at 1 m from the side, ± 1 dB (A)

*Values apply to natural gas applications, measured as noise pressure level.

Your benefits

- Package of favorable investment and low operating costs.
- Low energy consumption thanks to maximum primary energy utilization.
- Long service intervals and ease of service guarantee additional cost savings.
- Efficient energy conversion with outstanding performance.
- Reliable control and monitoring with high safety standards ensure optimum combustion and maximum engine protection.
- All governing, service, control and monitoring functions are easy and comfortable to operate.

Version 02/10/US

Characteristics

- State-of-the-art 12, 16 and 20 cylinder V-engines.
- Air-fuel turbocharging and two-stage intercooling.
- Single cylinder heads with four-valve technology.
- Centrally arranged spark plug with intensive plug seat cooling.
- Microprocessor-controlled high-voltage ignition system.
- One ignition coil per cylinder.
- Electronic control and monitoring of genset operation through TEM.
- Exhaust emissions controlled according to combustion chamber temperature.

MWM Group
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Web: www.mwm.net

APPENDIX C

Carrier

Product Data

16JL/JLR Steam/Hot Water Single Effect, Hermetic Absorption Liquid Chiller

16JL: 150 to 1000 Nominal Tons (528 to 3516kW)
16JLR: 110 to 750 Nominal Tons (387 to 2637kW)

16JL/JLR SERIES

Carrier's 16JL/JLR steam/hot single-effect, hermetic absorption liquid chiller is an efficient and functional alternative to traditional electric driven chillers. By utilizing low-pressure steam or low-temperature hot water, 16JL/JLR chillers avoid high-cost electricity and qualify for utility rebates and incentives as a gas cooling product. The 16JL/JLR absorption chiller offers functional flexibility in a variety of installations:

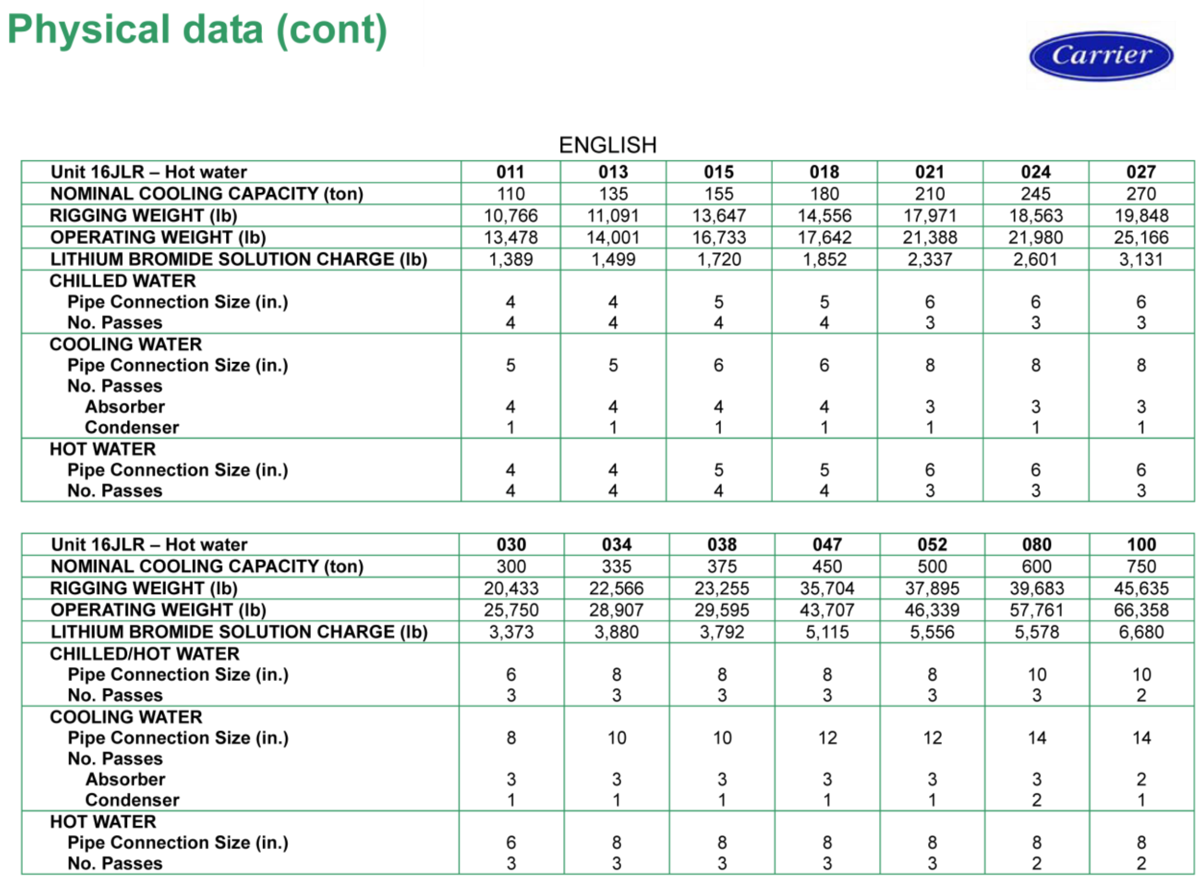
- no CFCs; environmentally friendly
- single stage design for simple, dependable operation
- nominal full-load steam rate of 16.65 lb/hr-ton for 16JL; nominal coefficient of performance (COP) of 0.73 for 16JLR
- quiet, vibration-free operation
- high reliability with few moving parts

Features/Benefits

Single-effect absorption cycle provides efficient, economical water chilling and/or process cooling with minimal use of electricity.

Cost-effective cooling

Alternative-energy chiller — The 16JL/JLR offers an alternative to chillers driven by increasingly expensive electrical energy. The use of steam/hot water powered absorption chiller not only eliminates demand charges and high cost electrical usage, but also allows the owner to take advantage of gas cooling rebates and incentive programs offered by many local utility companies.



Physical data (cont)

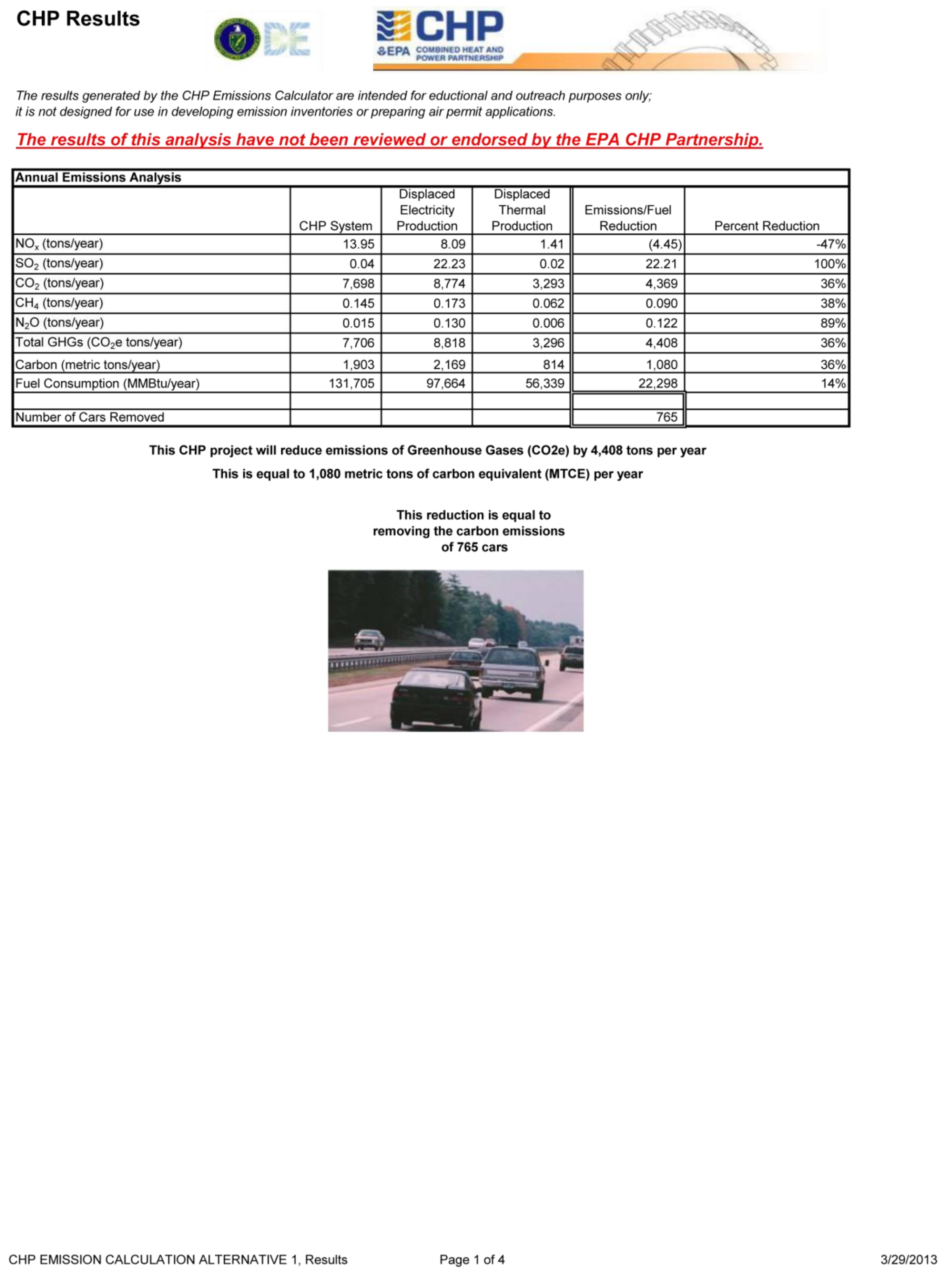
Carrier

ENGLISH

Unit 16JLR – Hot water	011	013	015	018	021	024	027
NOMINAL COOLING CAPACITY (ton)	110	135	155	180	210	245	270
RIGGING WEIGHT (lb)	10,766	11,091	13,647	14,556	17,971	18,563	19,848
OPERATING WEIGHT (lb)	13,478	14,001	16,733	17,642	21,388	21,980	25,166
LITHIUM BROMIDE SOLUTION CHARGE (lb)	1,389	1,499	1,720	1,852	2,337	2,601	3,131
CHILLED WATER							
Pipe Connection Size (in.)	4	4	5	5	6	6	6
No. Passes	4	4	4	4	3	3	3
COOLING WATER							
Pipe Connection Size (in.)	5	5	6	6	8	8	8
No. Passes							
Absorber	4	4	4	4	3	3	3
Condenser	1	1	1	1	1	1	1
HOT WATER							
Pipe Connection Size (in.)	4	4	5	5	6	6	6
No. Passes	4	4	4	4	3	3	3

Unit 16JLR – Hot water	030	034	038	047	052	080	100
NOMINAL COOLING CAPACITY (ton)	300	335	375	450	500	600	750
RIGGING WEIGHT (lb)	20,433	22,566	23,255	35,704	37,895	39,683	45,635
OPERATING WEIGHT (lb)	25,750	28,907	29,595	43,707	46,339	57,761	66,358
LITHIUM BROMIDE SOLUTION CHARGE (lb)	3,373	3,880	3,792	5,115	5,556	5,578	6,680
CHILLED/HOT WATER							
Pipe Connection Size (in.)	6	8	8	8	8	10	10
No. Passes	3	3	3	3	3	3	2
COOLING WATER							
Pipe Connection Size (in.)	8	10	10	12	12	14	14
No. Passes							
Absorber	3	3	3	3	3	3	2
Condenser	1	1	1	1	1	2	1
HOT WATER							
Pipe Connection Size (in.)	6	8	8	8	8	8	8
No. Passes	3	3	3	3	3	2	2

APPENDIX D



CHP Results

*The results generated by the CHP Emissions Calculator are intended for eductional and outreach purposes only;
it is not designed for use in developing emission inventories or preparing air permit applications.*

The results of this analysis have not been reviewed or endorsed by the EPA CHP Partnership.

Annual Emissions Analysis

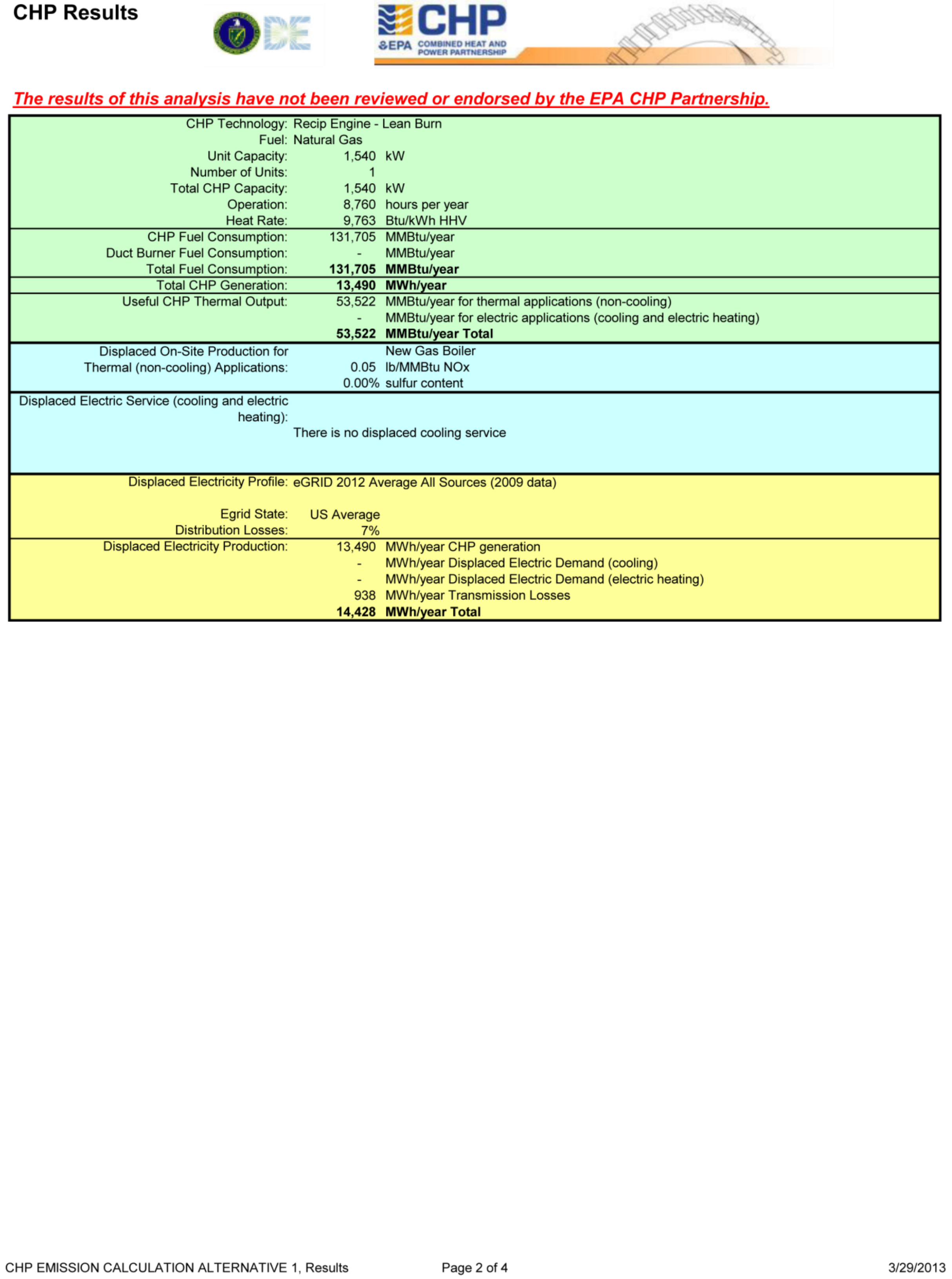
	CHP System	Displaced Electricity Production	Displaced Thermal Production	Emissions/Fuel Reduction	Percent Reduction
NO_x (tons/year)	13.95	8.09	1.41	(4.45)	-47%
SO_2 (tons/year)	0.04	22.23	0.02	22.21	100%
CO_2 (tons/year)	7,698	8,774	3,293	4,369	36%
CH_4 (tons/year)	0.145	0.173	0.062	0.090	38%
N_2O (tons/year)	0.015	0.130	0.006	0.122	89%
Total GHGs (CO_2e tons/year)	7,706	8,818	3,296	4,408	36%
Carbon (metric tons/year)	1,903	2,169	814	1,080	36%
Fuel Consumption (MMBtu/year)	131,705	97,664	56,339	22,298	14%
Number of Cars Removed				765	

This CHP project will reduce emissions of Greenhouse Gases (CO2e) by 4,408 tons per year

This is equal to 1,080 metric tons of carbon equivalent (MTCE) per year

**This reduction is equal to
removing the carbon emissions
of 765 cars**

CHP EMISSION CALCULATION ALTERNATIVE 1, Results Page 1 of 4 3/29/2013

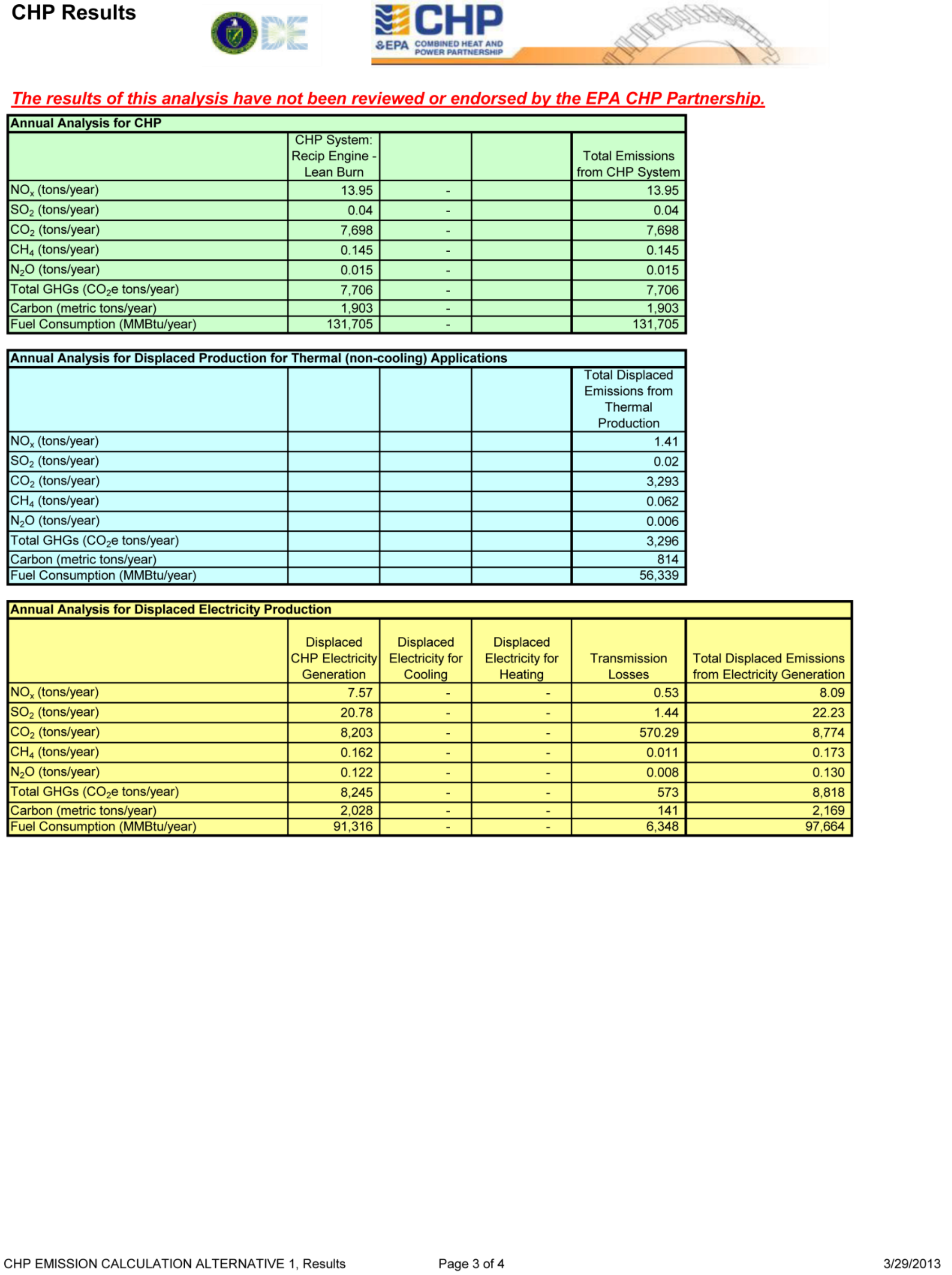


CHP Results

The results of this analysis have not been reviewed or endorsed by the EPA CHP Partnership.

CHP Technology:	Recip Engine - Lean Burn	
Fuel:	Natural Gas	
Unit Capacity:	1,540	kW
Number of Units:	1	
Total CHP Capacity:	1,540	kW
Operation:	8,760	hours per year
Heat Rate:	9,763	Btu/kWh HHV
CHP Fuel Consumption:	131,705	MMBtu/year
Duct Burner Fuel Consumption:	-	MMBtu/year
Total Fuel Consumption:	**131,705**	**MMBtu/year**
Total CHP Generation:	**13,490**	**MWh/year**
Useful CHP Thermal Output:	53,522	MMBtu/year for thermal applications (non-cooling)
	-	MMBtu/year for electric applications (cooling and electric heating)
	53,522	**MMBtu/year Total**
Displaced On-Site Production for Thermal (non-cooling) Applications:		New Gas Boiler
	0.05	lb/MMBtu NOx
	0.00%	sulfur content
Displaced Electric Service (cooling and electric heating):		
	There is no displaced cooling service	
Displaced Electricity Profile:	eGRID 2012 Average All Sources (2009 data)	
Egrid State:	US Average	
Distribution Losses:	7%	
Displaced Electricity Production:	13,490	MWh/year CHP generation
	-	MWh/year Displaced Electric Demand (cooling)
	-	MWh/year Displaced Electric Demand (electric heating)
	938	MWh/year Transmission Losses
	14,428	**MWh/year Total**

CHP EMISSION CALCULATION ALTERNATIVE 1, Results Page 2 of 4 3/29/2013



CHP Results

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Annual Analysis for CHP				
	CHP System: Recip Engine - Lean Burn			Total Emissions from CHP System
NO_x (tons/year)	13.95	-		13.95
SO_2 (tons/year)	0.04	-		0.04
CO_2 (tons/year)	7,698	-		7,698
CH_4 (tons/year)	0.145	-		0.145
N_2O (tons/year)	0.015	-		0.015
Total GHGs (CO_2e tons/year)	7,706	-		7,706
Carbon (metric tons/year)	1,903	-		1,903
Fuel Consumption (MMBtu/year)	131,705	-		131,705

Annual Analysis for Displaced Production for Thermal (non-cooling) Applications				
				Total Displaced Emissions from Thermal Production
NO_x (tons/year)				1.41
SO_2 (tons/year)				0.02
CO_2 (tons/year)				3,293
CH_4 (tons/year)				0.062
N_2O (tons/year)				0.006
Total GHGs (CO_2e tons/year)				3,296
Carbon (metric tons/year)				814
Fuel Consumption (MMBtu/year)				56,339

Annual Analysis for Displaced Electricity Production					
	Displaced CHP Electricity Generation	Displaced Electricity for Cooling	Displaced Electricity for Heating	Transmission Losses	Total Displaced Emissions from Electricity Generation
NO_x (tons/year)	7.57	-	-	0.53	8.09
SO_2 (tons/year)	20.78	-	-	1.44	22.23
CO_2 (tons/year)	8,203	-	-	570.29	8,774
CH_4 (tons/year)	0.162	-	-	0.011	0.173
N_2O (tons/year)	0.122	-	-	0.008	0.130
Total GHGs (CO_2e tons/year)	8,245	-	-	573	8,818
Carbon (metric tons/year)	2,028	-	-	141	2,169
Fuel Consumption (MMBtu/year)	91,316	-	-	6,348	97,664

CHP EMISSION CALCULATION ALTERNATIVE 1, Results Page 3 of 4 3/29/2013

CHP Results

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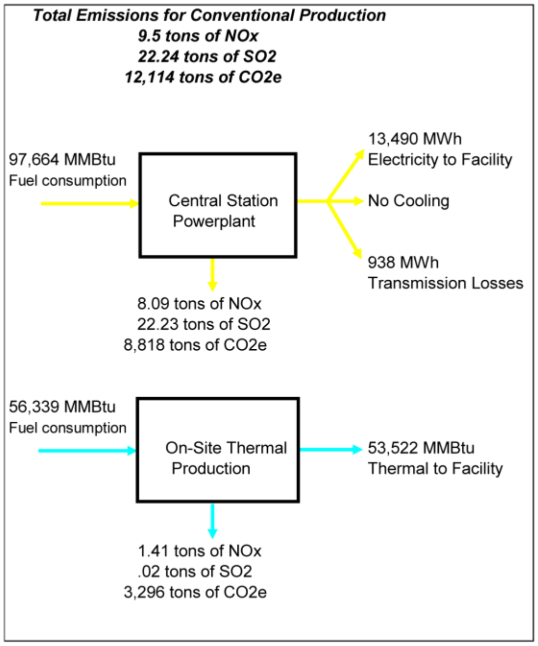

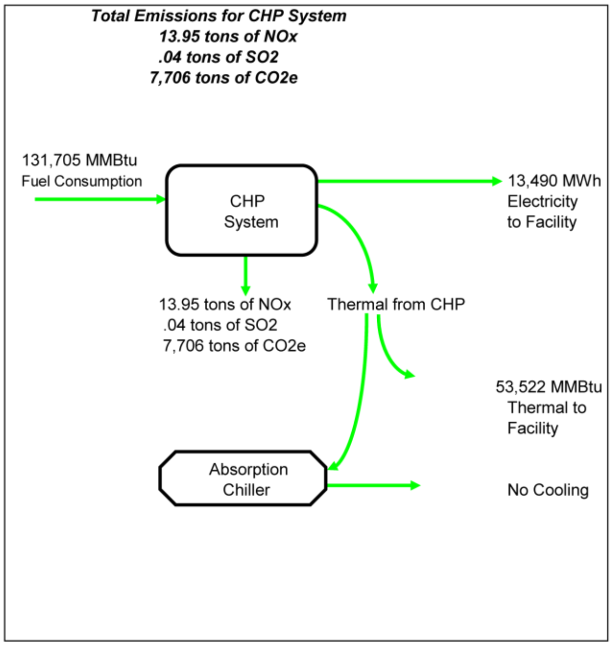

Emission Rates	CHP System including Duct Burners	Recip Engine - Lean Burn Alone	Displaced Electricity
NOx (lb/MWh)	2.07	2.07	1.12
SO2 (lb/MWh)	0.01	0.01	3.08
CO2 (lb/MWh)	1,141	1,141	1,216

Emission Rates	Displaced Thermal Production
NOx (lb/MMBtu)	0.05
SO2 (lb/MMBtu)	0.00059
CO2 (lb/MMBtu)	116.9

CHP Results

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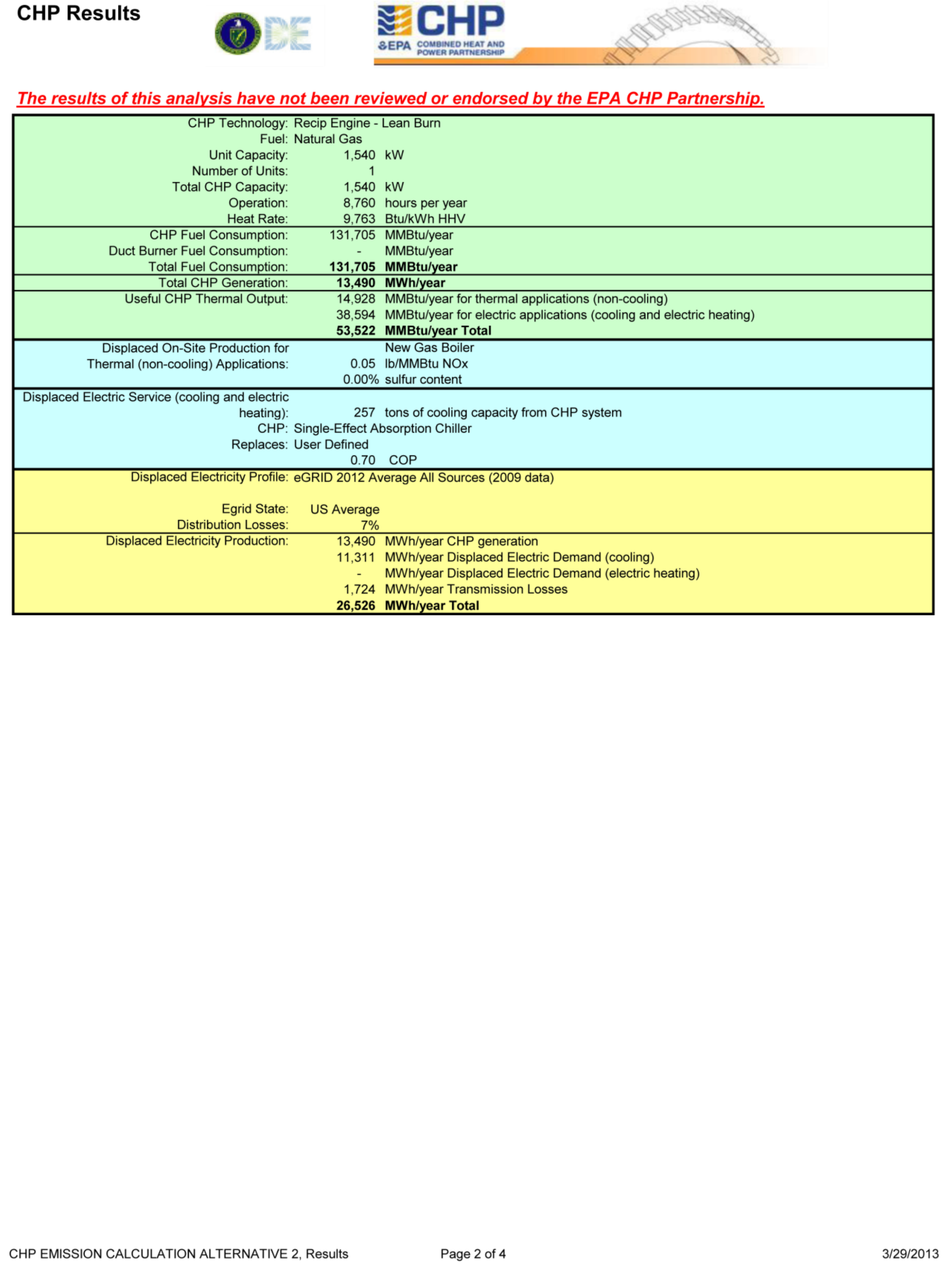
Annual Emissions Analysis

	CHP System	Displaced Electricity Production	Displaced Thermal Production	Emissions/Fuel Reduction	Percent Reduction
NO_x (tons/year)	13.95	14.88	0.39	1.32	9%
SO_2 (tons/year)	0.04	40.86	0.00	40.83	100%
CO_2 (tons/year)	7,698	16,130	918	9,350	55%
CH_4 (tons/year)	0.145	0.319	0.017	0.191	57%
N_2O (tons/year)	0.015	0.240	0.002	0.227	94%
Total GHGs (CO_2e tons/year)	7,706	16,211	919	9,425	55%
Carbon (metric tons/year)	1,903	3,988	227	2,312	55%
Fuel Consumption (MMBtu/year)	131,705	179,552	15,714	63,561	33%
Number of Cars Removed				1,637	

This CHP project will reduce emissions of Greenhouse Gases (CO2e) by 9,425 tons per year

This is equal to 2,312 metric tons of carbon equivalent (MTCE) per year

This reduction is equal to
removing the carbon emissions
of 1,637 cars

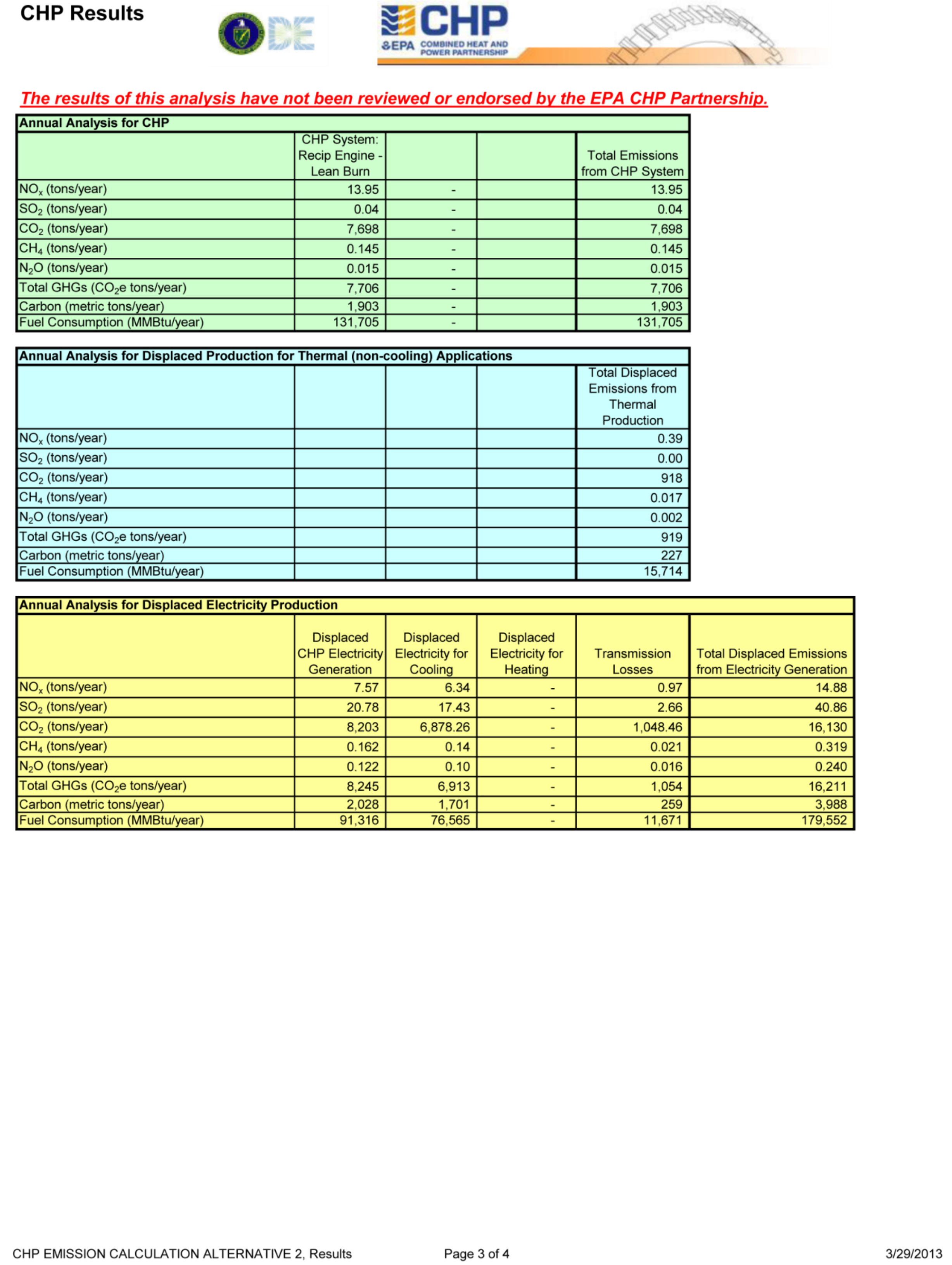


CHP Results

The results of this analysis have not been reviewed or endorsed by the EPA CHP Partnership.

CHP Technology:	Recip Engine - Lean Burn	
Fuel:	Natural Gas	
Unit Capacity:	1,540	kW
Number of Units:	1	
Total CHP Capacity:	1,540	kW
Operation:	8,760	hours per year
Heat Rate:	9,763	Btu/kWh HHV
CHP Fuel Consumption:	131,705	MMBtu/year
Duct Burner Fuel Consumption:	-	MMBtu/year
Total Fuel Consumption:	**131,705**	**MMBtu/year**
Total CHP Generation:	**13,490**	**MWh/year**
Useful CHP Thermal Output:	14,928	MMBtu/year for thermal applications (non-cooling)
	38,594	MMBtu/year for electric applications (cooling and electric heating)
	53,522	**MMBtu/year Total**
Displaced On-Site Production for		New Gas Boiler
Thermal (non-cooling) Applications:	0.05	lb/MMBtu NOx
	0.00%	sulfur content
Displaced Electric Service (cooling and electric heating):	257	tons of cooling capacity from CHP system
CHP:	Single-Effect Absorption Chiller	
Replaces:	User Defined	
	0.70	COP
Displaced Electricity Profile:	eGRID 2012 Average All Sources (2009 data)	
Egrid State:	US Average	
Distribution Losses:	7%	
Displaced Electricity Production:	13,490	MWh/year CHP generation
	11,311	MWh/year Displaced Electric Demand (cooling)
	-	MWh/year Displaced Electric Demand (electric heating)
	1,724	MWh/year Transmission Losses
	26,526	**MWh/year Total**

CHP EMISSION CALCULATION ALTERNATIVE 2, Results Page 2 of 4 3/29/2013



CHP Results

The results of this analysis have not been reviewed or endorsed by the EPA CHP Partnership.

Annual Analysis for CHP				
	CHP System: Recip Engine - Lean Burn			Total Emissions from CHP System
NO_x (tons/year)	13.95	-		13.95
SO_2 (tons/year)	0.04	-		0.04
CO_2 (tons/year)	7,698	-		7,698
CH_4 (tons/year)	0.145	-		0.145
N_2O (tons/year)	0.015	-		0.015
Total GHGs (CO_2e tons/year)	7,706	-		7,706
Carbon (metric tons/year)	1,903	-		1,903
Fuel Consumption (MMBtu/year)	131,705	-		131,705

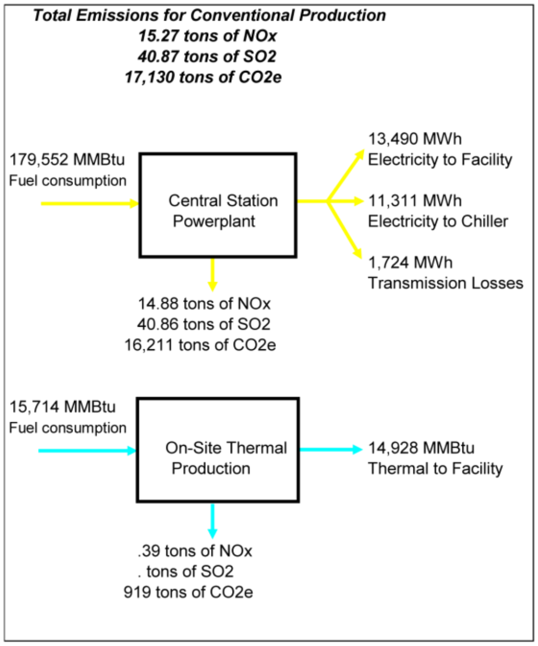
Annual Analysis for Displaced Production for Thermal (non-cooling) Applications				
				Total Displaced Emissions from Thermal Production
NO_x (tons/year)				0.39
SO_2 (tons/year)				0.00
CO_2 (tons/year)				918
CH_4 (tons/year)				0.017
N_2O (tons/year)				0.002
Total GHGs (CO_2e tons/year)				919
Carbon (metric tons/year)				227
Fuel Consumption (MMBtu/year)				15,714

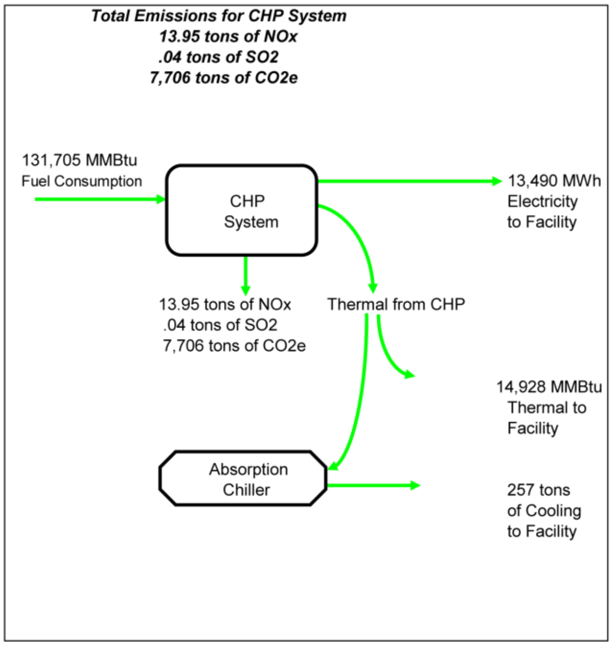
Annual Analysis for Displaced Electricity Production					
	Displaced CHP Electricity Generation	Displaced Electricity for Cooling	Displaced Electricity for Heating	Transmission Losses	Total Displaced Emissions from Electricity Generation
NO_x (tons/year)	7.57	6.34	-	0.97	14.88
SO_2 (tons/year)	20.78	17.43	-	2.66	40.86
CO_2 (tons/year)	8,203	6,878.26	-	1,048.46	16,130
CH_4 (tons/year)	0.162	0.14	-	0.021	0.319
N_2O (tons/year)	0.122	0.10	-	0.016	0.240
Total GHGs (CO_2e tons/year)	8,245	6,913	-	1,054	16,211
Carbon (metric tons/year)	2,028	1,701	-	259	3,988
Fuel Consumption (MMBtu/year)	91,316	76,565	-	11,671	179,552

CHP EMISSION CALCULATION ALTERNATIVE 2, Results Page 3 of 4 3/29/2013

CHP Results

The results of this analysis have not been reviewed or endorsed by the EPA CHP Partnership.



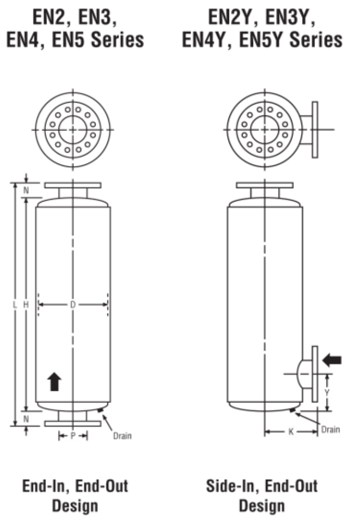


Emission Rates			
	CHP System including Duct Burners	Recip Engine - Lean Burn Alone	Displaced Electricity
NOx (lb/MWh)	2.07	2.07	1.12
SO2 (lb/MWh)	0.01	0.01	3.08
CO2 (lb/MWh)	1,141	1,141	1,216

Emission Rates	
	Displaced Thermal Production
NOx (lb/MMBtu)	0.05
SO2 (lb/MMBtu)	0.00059
CO2 (lb/MMBtu)	116.9

CHP EMISSION CALCULATION ALTERNATIVE 2, Results Page 4 of 4 3/29/2013

APPENDIX E



End-In, End-Out Design

Side-In, End-Out Design

EN Series

Multi-Chamber Silencers

EN2, EN3, and EN4 Series Engine Exhaust Silencers are heavy-duty, fully welded units constructed of carbon steel sheet and plate. Each silencer is equipped with flanged connections drilled to match 125/150 lb ANSI specifications. Exterior surfaces receive a coat of heat resistant paint.

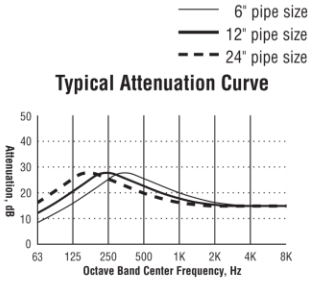
For EN5 Series, 1"–3.5" are sizes equipped with standard male pipe thread connections. Sizes 4" and larger have flanged connections drilled to match 125/150 lb ANSI specifications.

The addition of “Y” in the model designation indicates a side inlet. Both configurations are fundamentally alike and performance is identical.

EN2

Size	Part Number	D	L	N	H	K	Y		Weight
							Min.	Max.	
4	19-104-AA	12	40	3	34	9	6	15	60
5	19-105-AA	14	46	3	40	10	6.5	19	70
6	19-106-AA	16	59	3	53	11	7.5	25	130
8	19-108-AA	20	61	3.5	54	13.5	9	25	190
10	19-110-AA	24	74	3.5	67	15.5	11	30	280
12	19-112-AA	28	75	3.5	68	17.5	12.5	30	420
14	19-114-AA	36	77	3.5	70	21.5	14.5	30	650
16	19-116-AA	36	113	3.5	106	21.5	15.5	40	900
18	19-118-AA	42	127	3.5	120	24.5	17.5	50	1,400
20	19-120-AA	48	130	4.5	121	28.5	19	55	1,600
22	19-122-AA	48	142	4.5	133	28.5	20	60	1,800
24	19-124-AA	54	156	4.5	147	31.5	22.5	70	2,500
26	19-126-AA	60	169	4.5	160	34.5	24.5	80	3,200
28	19-128-AA	60	181	4.5	172	34.5	25.5	80	3,400
30	19-130-AA	60	194	4.5	185	37.5	27	90	4,700

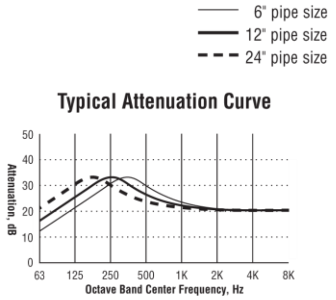
Note: Dimensions and weights are nominal and may vary slightly with production models. Request certified drawings of specific models for exact dimensions.



EN3

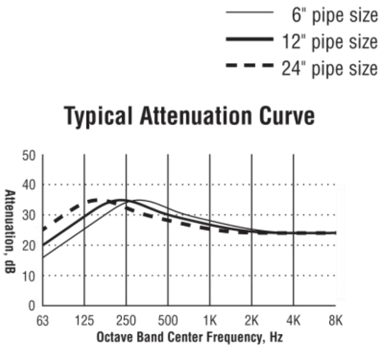
Size	Part Number	D	L	N	H	K	Y		Weight
							Min.	Max.	
4	20-104-AA	14	47	3	41	10	6	20	70
5	20-105-AA	16	59	3	53	11	7	24	130
6	20-106-AA	18	60	3	54	12	8	24	150
8	20-108-AA	22	73	3.5	66	14.5	9.5	32	250
10	20-110-AA	26	86	3.5	79	16.5	11	36	390
12	20-112-AA	30	111	3.5	104	18.5	12.5	52	700
14	20-114-AA	36	113	3.5	106	21.5	14.5	52	900
16	20-116-AA	42	127	3.5	120	24.5	16.5	62	1,200
18	20-118-AA	48	129	3.5	122	27.5	18	62	1,450
20	20-120-AA	48	142	4.5	133	28.5	19	62	1,600
22	20-122-AA	54	156	4.5	147	31.5	21.5	72	2,300
24	20-124-AA	60	181	4.5	172	34.5	23.5	82	3,050
26	20-126-AA	66	195	4.5	186	37.5	25	92	4,400
28	20-128-AA	72	209	4.5	200	40.5	27	103	5,000
30	20-130-AA	72	220	4.5	211	40.5	28	103	5,400

Note: Dimensions and weights are nominal and may vary slightly with production models. Request certified drawings of specific models for exact dimensions.



EN Series

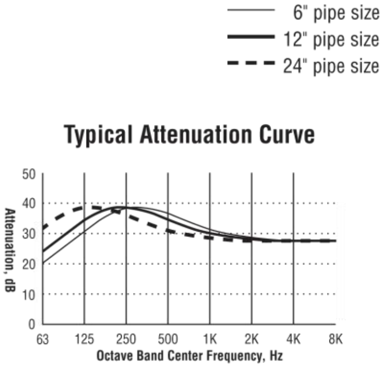
Multi-Chamber Silencers



EN4

Size	Part Number	D	L	N	H	K	Y Min.	Y Max.	Weight
4	21-104-AA	14	59	3	53	10	6	26	85
5	21-105-AA	16	71	3	65	11	7	33	120
6	21-106-AA	18	72	3	66	12	8	33	170
8	21-108-AA	24	93	3.5	86	15.5	9.5	42	400
10	21-110-AA	28	111	3.5	104	17.5	11.5	52	550
12	21-112-AA	36	114	3.5	107	21.5	14	52	950
14	21-114-AA	36	125	3.5	118	21.5	14.5	63	1,100
16	21-116-AA	42	139	3.5	132	24.5	16.5	63	1,350
18	21-118-AA	48	176	3.5	169	27.5	18	86	2,200
20	21-120-AA	48	190	4.5	181	28.5	19	96	2,500
22	21-122-AA	54	192	4.5	183	31.5	21.5	96	3,000
24	21-124-AA	60	217	4.5	208	34.5	23.5	107	3,800
26	21-126-AA	66	231	4.5	222	37.5	25	117	5,850
28	21-128-AA	72	257	4.5	248	40.5	27	128	6,750
30	21-130-AA	72	280	4.5	271	40.5	28	139	7,500

Note: Dimensions and weights are nominal and may vary slightly with production models.
Request certified drawings of specific models for exact dimensions.



EN5

Size	Part Number	D	L	N	Y H	Y K	Min.	Max.	Weight
1	22-101-AA	6	25.5	3	19.5	6	2.5	9	10
1.5	22-115-AA	8	27	3	21	7	3.5	9	20
2	22-102-AA	10	34	3	28	8	4.5	13	30
2.5	22-125-AA	12	40	3	34	9	5	16	50
3	22-103-AA	12	46	3	40	9	5	18	60
3.5	22-135-AA	14	59	3	53	10	5.5	24	90
4	22-104-AA	16	71	3	65	11	6	33	110
5	22-105-AA	18	72	3	66	12	8	33	160
6	22-106-AA	22	85	3	79	14	9	40	300
8	22-108-AA	26	111	3.5	104	16.5	10	50	480
10	22-110-AA	30	136	3.5	129	18.5	11.5	65	800
12	22-112-AA	36	138	3.5	131	21.5	14	46	1,050
14	22-114-AA	36	168	3.5	161	21.5	14.5	64	1,200
16	22-116-AA	42	193	3.5	186	24.5	16.5	75	1,750
18	22-118-AA	48	213	3.5	206	27.5	18	85	2,750
20	22-120-AA	48	227	4.5	218	28.5	19	85	3,050
22	22-122-AA	54	240	4.5	231	31.5	21.5	96	3,550
24	22-124-AA	60	278	4.5	269	34.5	23.5	106	5,100
26	22-126-AA	66	292	4.5	283	37.5	25	115	6,500
28	22-128-AA	72	329	4.5	320	40.5	27	128	7,600
30	22-130-AA	72	352	4.5	343	40.5	28	139	8,300

Note: Dimensions and weights are nominal and may vary slightly with production models.
Request certified drawings of specific models for exact dimensions.

Toll-Free: 1-888-300-4272
www.universalAET.com
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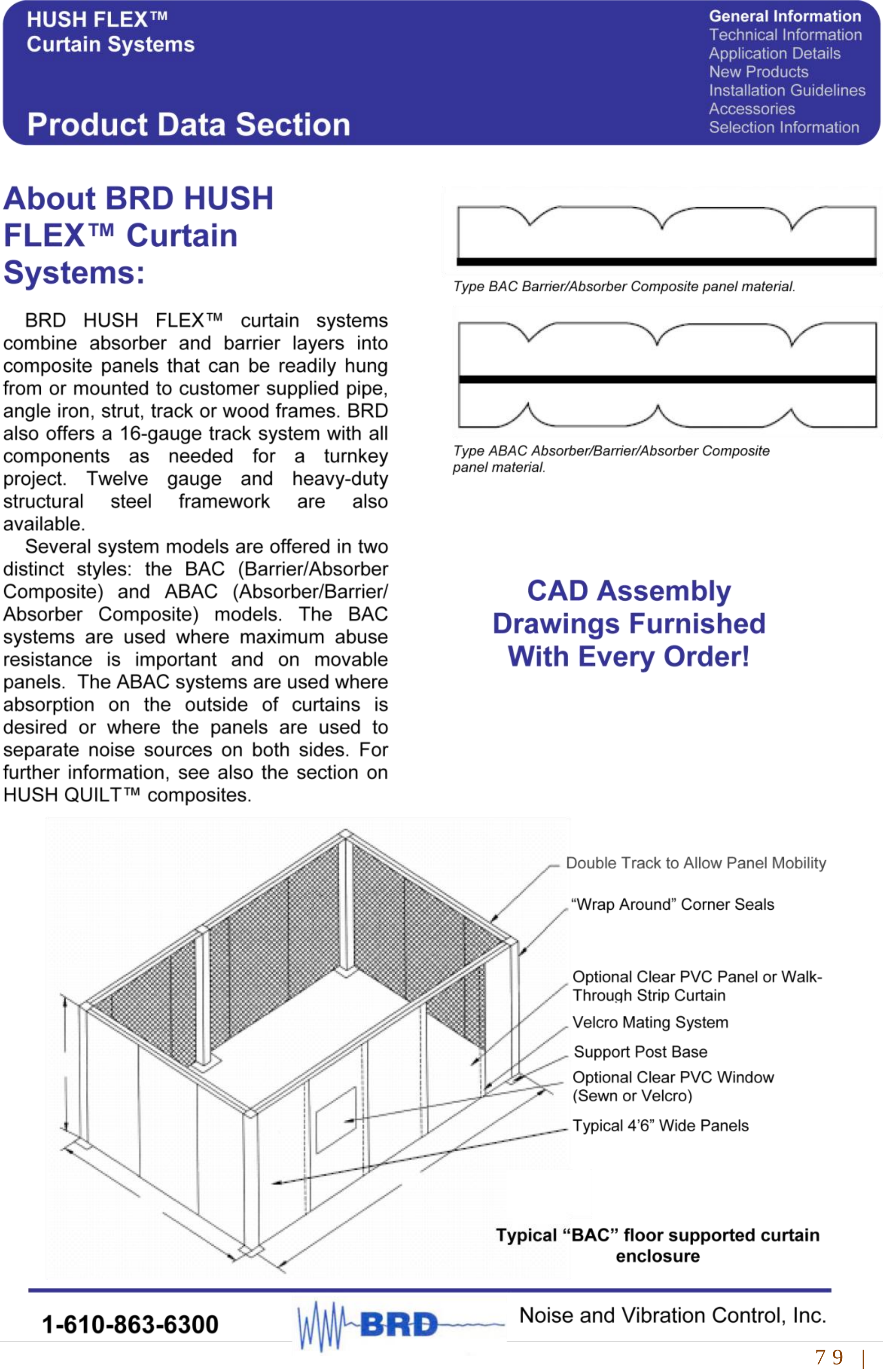

HUSH FLEX™
Curtain Systems

Product Data Section

General Information
Technical Information
Application Details
New Products
Installation Guidelines
Accessories
Selection Information

About BRD HUSH FLEX™ Curtain Systems:

BRD HUSH FLEX™ curtain systems combine absorber and barrier layers into composite panels that can be readily hung from or mounted to customer supplied pipe, angle iron, strut, track or wood frames. BRD also offers a 16-gauge track system with all components as needed for a turnkey project. Twelve gauge and heavy-duty structural steel framework are also available.

Several system models are offered in two distinct styles: the BAC (Barrier/Absorber Composite) and ABAC (Absorber/Barrier/Absorber Composite) models. The BAC systems are used where maximum abuse resistance is important and on movable panels. The ABAC systems are used where absorption on the outside of curtains is desired or where the panels are used to separate noise sources on both sides. For further information, see also the section on HUSH QUILT™ composites.

Type BAC Barrier/Absorber Composite panel material.

Type ABAC Absorber/Barrier/Absorber Composite panel material.

CAD Assembly Drawings Furnished With Every Order!

Double Track to Allow Panel Mobility
“Wrap Around” Corner Seals
Optional Clear PVC Panel or Walk-Through Strip Curtain
Velcro Mating System
Support Post Base
Optional Clear PVC Window (Sewn or Velcro)
Typical 4’6” Wide Panels

Typical “BAC” floor supported curtain enclosure

1-610-863-6300 BRD Noise and Vibration Control, Inc.

HUSH FLEX™
Curtain Systems

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Product Data Section

Acoustic Performance Test Results

Model No.	Thickness (In.)	Wt. Lb./Ft.^{2}	Sound Transmission Loss (dB) Octave Band Center Frequencies						STC
			125	250	500	1000	2000	4000	
BAC-110R	.75-1	1.3	11	16	24	30	35	35	27
BAC-210R	1.5-2	1.5	13	20	29	40	50	55	32
ABAC-111N	1.5-2	1.5	12	16	27	40	44	43	29
ABAC-121N	1.5-2	2.5	19	22	28	40	56	61	33
ABAC-R111N	2-2.5	2.6	19	20	28	42	56	62	31

Model No.	Sound Absorption Data Absorber Component Random Incident Sound Absorption						
	Octave Band Center Frequencies						
	125	250	500	1000	2000	4000	NRC
BAC Products	.12	.47	.85	.84	.64	.62	.70
ABAC & 2" BAC Products	.07	.27	.96	1.13	1.08	.99	.85

NOTE:

1) Acoustical testing per ASTM C-423-77, C-423-90A; ASTM E-90-75; E-90-90. Copies available upon request.
2) Actual noise reduction will vary with application, enclosure design, features and peak frequency of the sound source.

ABAC high temperature 12' high curtains protect a welder from brake and shear noise in a machine shop.

Typical double track design sliding panel access for compressor enclosure.