ElectraTherm
BY BITZER GROUP

Waste Heat to Power System

Product Data and Specification Guide

Series 4400 Power+ Generator

CONTENTS

DISCLAIMER

Predictions of performance are based on a combination of test data, weather records, thermodynamic modeling, and customer-provided site-specific parameters. In our project evaluation process, we strive to estimate power output conservatively; however, actual net power output will vary with site and weather conditions.

The Power+ is designed to minimize operational hazards; however, there are avoidable conditions which may lead to property damage, injury, or death if not properly managed. It is ultimately the responsibility of the Distributor and Customer to assure operational safety by carefully following the instructions found in the Operations Manual, Service Bulletins, Machine Indicators and Displays, and Training Materials.

Compliance with Local Codes and Utility Company requirements must be assured by the Distributor and Customer throughout product life. Please investigate legal and contractual matters such as operating permits, customs requirements, electrical metering and incentives, and site plan approval prior to purchasing equipment.

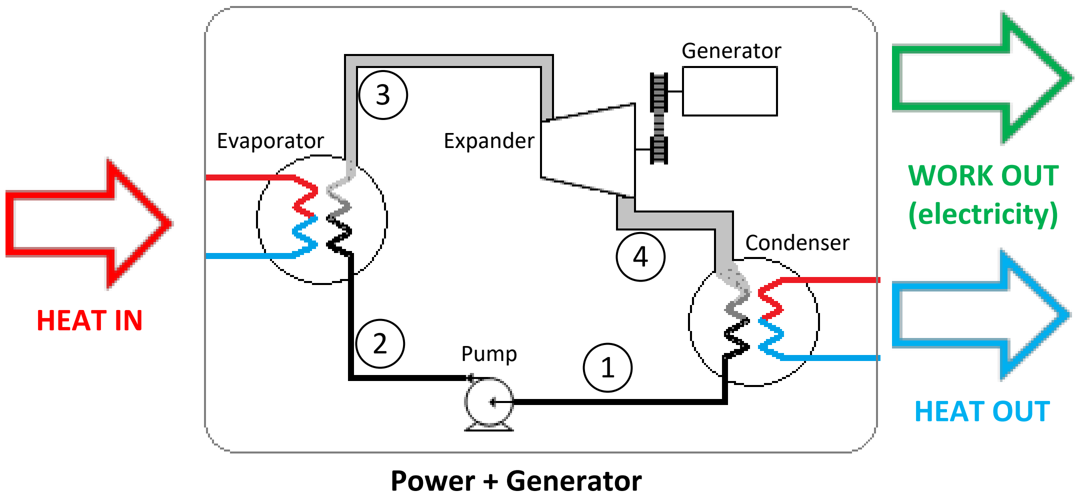
Specifications are subject to change.

REVISION HISTORY

Revision	**Date**	**Reason for change**
01	9/15/2012	Initial Draft
02	4/30/2013	Various Updates
A	2/10/2016	Block 6 update
B	5/14/2020	Update Information

ORGANIC RANKINE CYCLE OVERVIEW

The organic Rankine cycle (ORC) is a thermodynamic cycle which uses an organic fluid to convert low-temperature heat into mechanical work. That mechanical work can then be converted into electricity. An ORC thermodynamic process transfers the heat using an organic working fluid with a different boiling point than that of water. The ElectraTherm Power+ ORC process is shown below in Figure 1.



(1) Low Pressure Liquid

(2) High Pressure Liquid

(3) High Pressure Vapor

(4) Low Pressure Vapor

Figure 1: ElectraTherm ORC

(1)–(2) The low-pressure, low temperature working fluid is pressurized by a pump to the inlet of the evaporator (heat exchanger).

(2)–(3) Heat is transferred from hot water through the heat exchanger to the working fluid (sensible heat) and the temperature increases until the fluid begins to boil. During vaporization, heat is still added to the working fluid (latent heat) without a change in temperature; volume, however, continues to rise. The high-pressure, heated vapor leaves the evaporator and flows to the expander.

(3)–(4) The high-pressure vapor turns a twin-screw type expander, lowering the pressure and the temperature of the vapor, and increasing the volume still further. The work provided by the turning of the twin screw expander is coupled to a generator which produces electricity. The formerly high-pressure vapor leaves the expander as a cooler, low-pressure vapor.

(4)–(1) The low-pressure vapor enters the condenser, where heat is transferred from the vapor to a cooling source. As heat is removed from the vapor, it condenses back into a low-pressure liquid, and returns by gravity to the feed pump. The process is thus continuous and closed loop.

The ElectraTherm Power+ is a heat engine specifically engineered to operate with a comparatively low temperature differential. The Power+ uses waste heat (in the form of hot water) and moves it from a hot source to a cold sink, converting 6-8% of that energy to mechanical work, as shown in Figure 2.

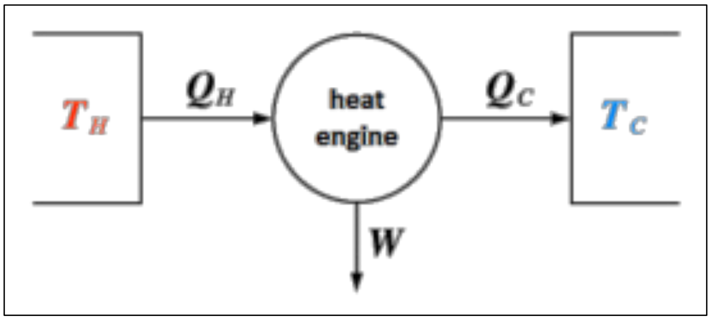


Figure 2: Heat Engine Diagram

In the case of the Power+, the mechanical work produced drives an electrical generator. Some typical heat sources and condensing sources are shown below in Figure 3.

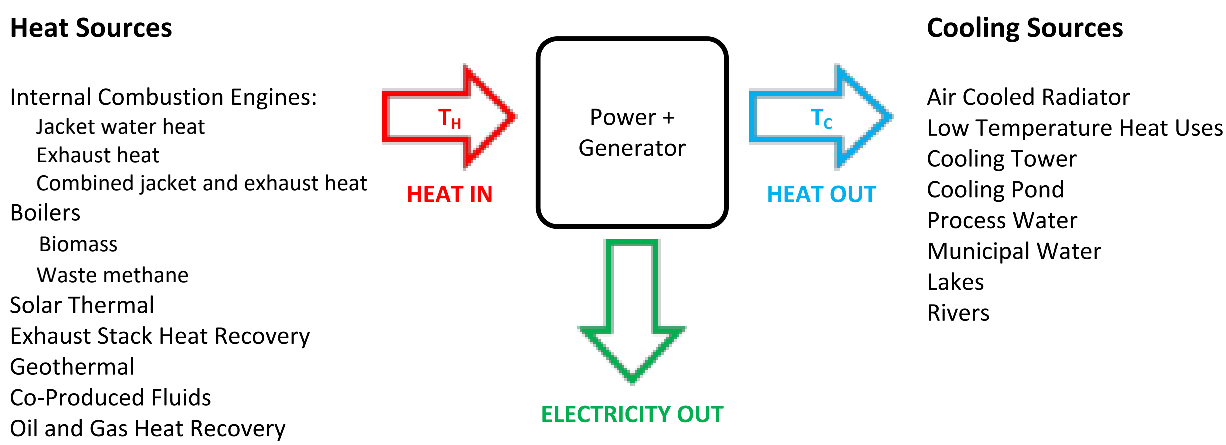


Figure 3: Possible Cooling Sources for ElectraTherm's Power+

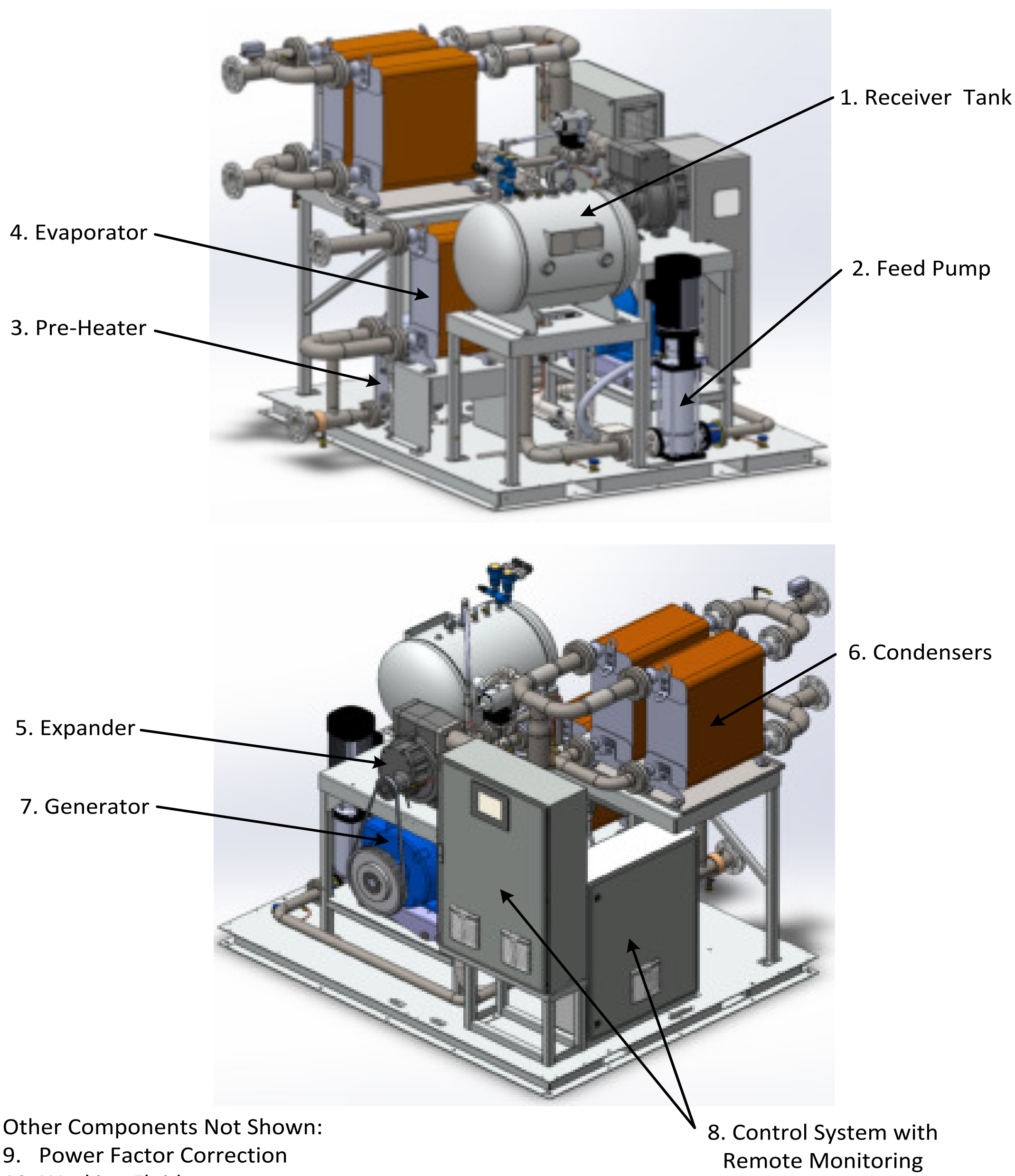
The heat leaving the Power+ may be further utilized in swimming pools, green houses, anaerobic digesters, radiant floors, biomass drying, domestic hot water, building make-up air tempering, and aquaculture facilities.

POWER PLANT OVERVIEW

The Power+ waste heat to power system is a modular skid-mounted power plant capable of converting waste heat into usable power.

System Components

Figure 4 illustrates the major components of the 4400 B-Series Water Cooled Power+.



Other Components Not Shown:
9. Power Factor Correction
10. Working Fluid
11. Lubrication

<u>Figure 4: Major Components of the 4400 Series Power+</u>

1. Receiver Tank
The receiver tank holds a reserve volume of working fluid to account for system fluctuations such as startup and changes in power output due to different hot water resource conditions. The working fluid can be recovered to the receiver tank for maintenance activities; this is also where the pressure relief valves are located.

2. Feed Pump
The feed pump is a multistage centrifugal pump that is composed of a motor and a stack of impellers in a vertical housing. The feed pump on the Power+ is driven by a variable frequency drive (from 0 to 60 Hz) and has a parasitic load ranging from 0-8 kW for the B Model, and ranging from 0-17 kW for the B+ Model, depending on system load. **In CHP mode*

3. Pre-Heater
The pre-heater, evaporator, and water-cooled condensers are all brazed plate heat exchangers. The principle of the heat exchanger is to heat or cool one fluid by transferring heat between it and another fluid, while keeping the two from mixing.

A brazed plate heat exchanger is shown in the Figure 5 below. With the plates vacuum-brazed together, distinct flow channels are formed, effectively maximizing heat transfer in a compact package.

Figure 5: Brazed Plate Heat Exchanger

The pre-heater is used to raise the temperature of the working fluid before it goes through the evaporator. It uses the water exiting the evaporator to capture even more heat, increasing the efficiency of the system.

4. Evaporator
Hot water enters the Power+ and first goes into the evaporator. The evaporator adds heat to the working fluid to cause the phase change and generate the high-pressure vapor to feed to the expander.

5. Expander

The Power+ uses a twin screw expander as its power block, which effectively is a screw compressor running in reverse. The working fluid comes in at high-pressure; as the screws turn, the fluid expands, eventually reaching a lower pressure at the exit. The twin screw expander design is robust and simple, with the advantage of a greater than 4:1 turn-down ratio, with reasonable efficiency. Due to a specific rotor profile, seals are accomplished with predominately rolling contact, and no gears are required to synchronize the rotors. Sliding contact as in other positive displacement machines, i.e., scroll, or piston expanders, is eliminated in this design. The operating speed of the Power+ expander is approximately 5000 RPM, which is very low compared to that required by small-scale turbine technology. A belt drive to the generator reaches 1500/1800 RPM (for 50Hz and 60Hz operation respectively), obviating the need for frequency conversion electronics to feed power to the grid. Because relative velocities within the expander are low, "wet" operating conditions are permitted; the working fluid does not have to be 100% vapor. One major advantage of the BITZER integration is a semi-hermetic design which couples the expander and generator as one assembly. This results in no shaft seal between the expander and generator, greatly enhancing reliability. In addition, the BITZER expander is designed for dual phase flow; both vapor and partial vapor mixtures are easily handled by the robust twin screws.. Figure 6 shows the new robust, HSE 85 expander.

Figure 6: Bitzer HSE 85 Expander

6. Generator

The ElectraTherm Power+ uses an induction generator for electrical energy production. Induction generators have no slip rings, brushes, or field control; they are electro-mechanically very similar to induction motors, having the same reliability and value. Their operation is similarly simple; being asynchronous, they do not require synchronization to the grid prior to connection. Voltage and frequency are determined from the site grid conditions. Because induction generators are not self-excited and have no magnetization or terminal voltage prior to coming on-grid, synchronization is rendered meaningless. (Often users confuse the induction generator with a synchronous generator or alternator which has stand-alone terminal voltage when it rotates, and requires synchronization before being placed on-grid, or active throttle and excitation control as a stand-alone device). Power+ cannot be operated without a grid connection.

7. Condenser

The low-pressure vapor leaving the expander goes through the condensers. Here, remaining heat is transferred out of the working fluid via additional brazed plate heat exchangers, causing the vapor to condense back into a liquid.

8. Control System with Remote Monitoring

The onboard programmable logic controller (PLC) and human machine interface (HMI – a touch screen device) provide both remote and local access to all operational controls, as well as selected machine parameters such as temperatures, pressures, and electrical metering. An internet connection is required for operation.

9. Power Factor Correction

The Power+ is equipped with power factor correction via a delta-connected capacitor and associated discharge and control circuitry. Power factor remains above 0.93 over the entire operating range, and typically is in the 0.96-0.99 range.

10. Working Fluid

The Power+ uses HFC-245fa as a working fluid for the ORC. HFC-245fa (1,1,1,3,3 pentafluoropropane) is an EPA-approved member of the hydrofluorocarbon (HFC) family of refrigerants, permitted under the Montreal Protocol. This non-flammable, low-toxicity, environmentally safe fluid boils at ~ 60°F (15.5°C) at atmospheric pressure. HFC-245fa is ozone safe and generally safe to handle.

11. Lubrication

The twin screw expander is lubricated by a synthetic ISO 100 Alkylbenzene refrigeration oil. This oil is mixed with the working fluid as part of ElectraTherm's proprietary in-process lubrication technology.

Physical Data

The following figures (

Figure 7 & Mating flanges and gaskets provided for water connections

Figure 8) are provided to give a general overview of the 4400 B-Series Power+. Standard drawings are available upon request.

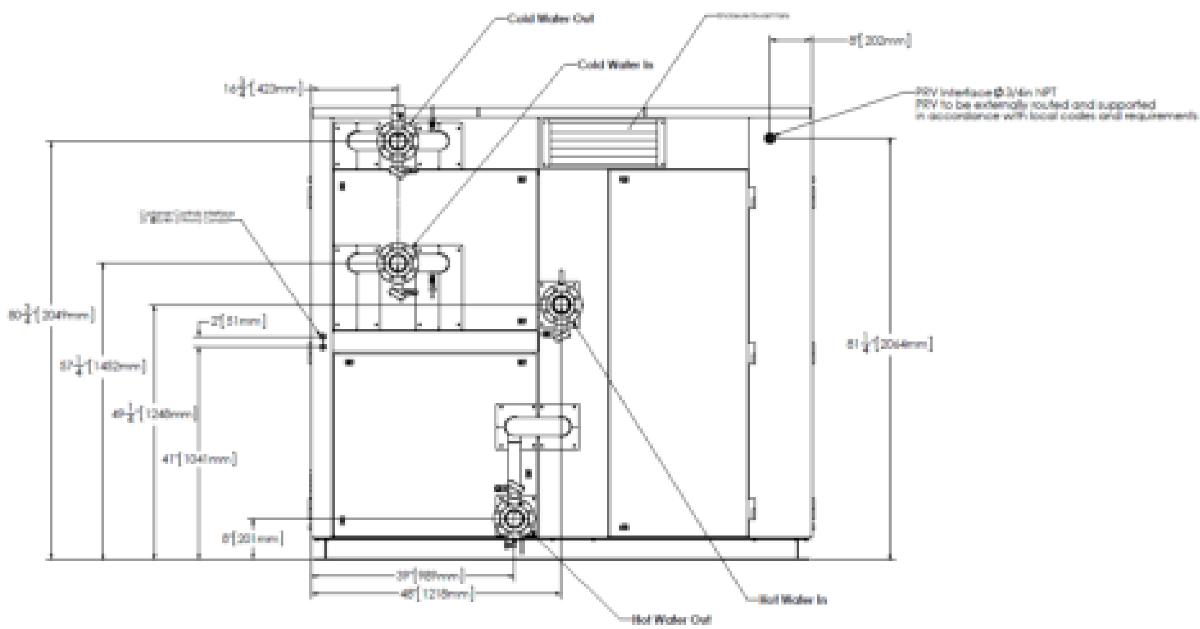
Status Lights
Red – Ready / Enabled
Yellow – In Startup / Restarting
Green – On Grid

Control Buttons
Black – Enable / Reset
Green – Start
Red – Stop
Red (mushroom) – Emergency Stop

4400 B-Series Power+
Height = 7’3” [2216 mm]
Length = 6’6” [1981 mm]
Width = 8’ [2438 mm]
Weight = 7245 Lbs [3290 kg]

Figure 7: Power+ Dimensions

Connections



Customer Connections	
	ASME
Cold Water In	3”#150
Cold Water Return	3”#150
Hot Water In	3”#150
Hot Water Return	3”#150

Mating flanges and gaskets provided for water connections

<u>Figure 8: Power+ Connections</u>

Pressure & Temperature Rating

All pipe manifolds are fabricated in accordance with ASME B31.3-2008 process piping code, and are designed to the following criteria:

	PRESSURE RATING	TEMPERATURE (4400 B Model)	TEMPERATURE (4400 B+ Model
Water Manifold, Cold Water	150 PSI [10.3 BAR]	150 °F [65 °C]	150 °F [65 °C]
Water Manifold, Hot Water	150 PSI [10.3 BAR]	240 °F [116 °C]	302 °F [150 °C]
Working Fluid Manifold, High Side	240 PSI [16.6 BAR]	240 °F [116 °C]	302 °F [150 °C]
Working Fluid Manifold, Low Side	150 PSI [10.3 BAR]	122 °F [50 °C]	122 °F [50 °C]

Applicable Codes

1. CE Low Voltage Directive 2006/95/EC
2. Machinery Directive 2006/42/EC
3. Electromagnetic Compatibility Directive 2004/108/EC
4. Pressurized Equipment Directive 97/23/EC
5. ASME B31.1 - Power Piping Code, Mechanical
6. ASME B31.3 - Process Piping Code
7. Receiver complies with ASME Boiler and Pressure Vessel Code Section VIII Div. I
8. Built in accordance with UL 508A - Control Panel Wiring
9. Sound pressure tested in accordance with the requirements of EN/ISO 3744:2010

SPECIFICATIONS

The Power+ is designed to operate across a wide range of thermal input conditions and varying power output levels detailed in the following specifications.

Performance Parameters

Table 1 - Hot Water to Power Metric Units (4400 B Model)

Electrical Output*	Hot Water Conditions			Condensing Conditions		
kW	Inlet Water Temp [°C]	Thermal Input [kW]	Flow Rate [l/s]	Inlet Water Temp [°C]	Ambient Air Temp [°C]	Condensing Load [kW]
20 - 75	77 - 116	380 - 1050	3.8 - 12.6	4 - 65	< 38	380 - 980

Gross output

Table 2 - Hot Water to Power US Units (4400 B Model)

Electrical Output*	Hot Water Conditions			Condensing Conditions		
kW	Inlet Water Temp [°F]	Thermal Input [BTU/hr]	Flow Rate [GPM]	Inlet Water Temp [°F]	Ambient Air Temp [°F]	Condensing Load [BTU/hr]
20 - 75	170 - 240	1,300,000 - 3,500,000	60 – 220	40 - 150	< 100	1,300,000 - 3,300,000

Gross output

Table 3 - Hot Water to Power Metric Units (4400 B+ Model)

Electrical Output*	Hot Water Conditions			Condensing Conditions		
kW	Inlet Water Temp [°C]	Thermal Input [kW]	Flow Rate [l/s]	Inlet Water Temp [°C]	Ambient Air Temp [°C]	Condensing Load [kW]
20 - 75	77 - 150	380 - 1050	3.8 - 12.6	4 - 65	< 48	380 - 980

Gross output

Table 4 - Hot Water to Power US Units (4400 B+ Model)

Electrical Output*	Hot Water Conditions			Condensing Conditions		
kW	Inlet Water Temp [°F]	Thermal Input [BTU/hr]	Flow Rate [GPM]	Inlet Water Temp [°F]	Ambient Air Temp [°F]	Condensing Load [BTU/hr]
20 - 75	170 - 302	1,300,000 - 3,500,000	60 – 220	40 - 110	< 100	1,300,000 - 3,300,000

Gross output

Performance Data

The performance curves of Figure shows the net power output across the allowable range of hot water conditions with constant cooling water conditions of 70°F [21°C] and 220 GPM [13.9 l/s].

For all performance estimates it is assumed that the site will provide adequate cooling capacity based on the required condensing load for the application. Performance mapping was tested under constant condensing flow of 220 GPM [13.9 l/s]; reduction of condensing flow will affect machine power output.

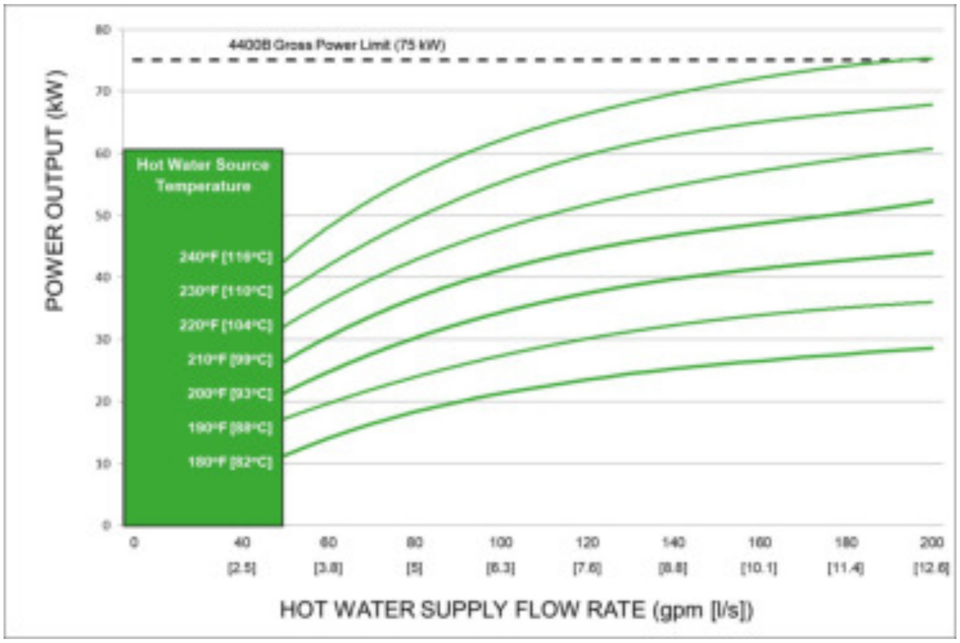


Figure 9: Power+ Water Cooled System Performance

System Sound Levels

The machine's main noise sources are the pump, expander, and belt/pulley system. These noises themselves cannot be eliminated; however, measures can be taken to mitigate and reduce the transmission of these noises outside of the ORC container. The noises heard are simply pressure waves traveling at various frequencies. The values of these noise levels are measured in frequency-dependent pressure quantities. Machinery noises are generally assessed using an A-weighted sound scale. For factory testing these measurements were taken at a distance of 3.28 ft (1 m) from the machine's external skins in accordance with the requirements of EN/ISO 3744:2010 as specified by 2000/14/EC.

At full load (75 ± 1 kW gross), the 4400 B-Series produces a time-averaged sound pressure level of 78 dBA.

ElectraTherm offers a sound attenuated enclosure that lowers the time-averaged sound pressure level to 71.6 dBA.

SITE DESIGN REQUIREMENTS

Plumbing Connections

All site water connections (hot and cold) are made with 3" 150 class flanges. The mating flange for these connections is provided with the machine. These water connections are coupled to the brazed plate heat exchangers which cannot take any flange loads. Pipe supports and allowance for thermal expansion must be designed in by the Distributor or Customer. Bellows style expansion joints are recommended on the water connections.

In addition to the water connections, the Pressure Relief Valves (PRV's) are routed to the enclosure in ¾" NPT pipe. This PRV discharge must be externally routed and supported in accordance with local codes and requirements.

A bypass is required on the hot water connections so that the hot water resource may be diverted when the Power+ is turned off. Leaving the hot water on when the Power+ is not running will lead to a buildup of pressure in the working fluid that can exceed the set point on the pressure relief valves resulting in a loss of working fluid.

Contact ElectraTherm for a complete drawing of the piping connections. Verify with ElectraTherm prior to planning that these are the most recent drawings and pertain to your project.

Water Side Pressure Drop

It is necessary to consider the Power+ heat exchanger pressure drops, in addition to all the site plumbing pressure loss, for the hot and cold water supply pump sizing. Figure 10 shows the heat exchanger water side pressure drops as a function of flow rate.

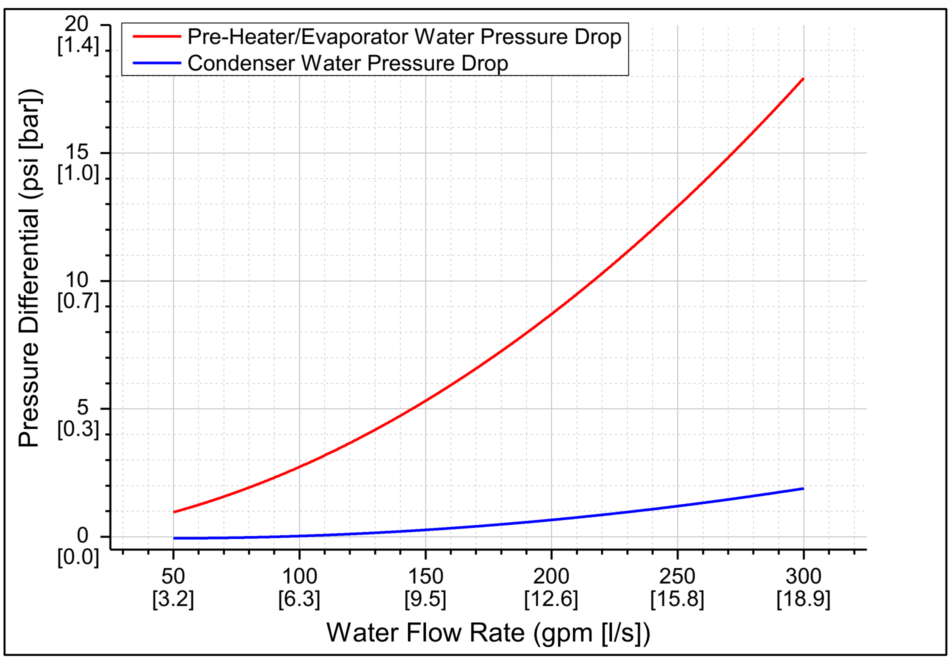


Figure 10: Power+ Heat Exchanger Water Pressure Differentials

Water Quality

Avoiding corrosion and scaling in the Power+ heat exchangers are critical to both machine longevity and efficiency. Each prospective site should be evaluated for adherence to water quality requirements, as described below. Table 5 shows typical limit values for the water to be used in the Power+ heat exchangers. There are different types of corrosion that may occur in a plate heat exchanger; these are described in Table 6. Table 7 offers specific guidance on the most hazardous form of corrosion, chloride-induced stress corrosion cracking and pitting. Table 8 addresses scaling.

Table 5 - Recommended Water Quality Limits for Water on Primary Side

Quality Class	Untreated	Softened	Partly Desalinated	Desalinated
Description	Tap Water	Softened	Softened or desalinated	Desalinated
Appearance	Clear	Clear	Clear	Clear
Smell	No Smell	No Smell	No Smell	No Smell
Particles	< 10mg/L	< 10mg/L	< 5mg/L	< 1mg/L
Oil and Grease	< 1mg/L	< 1mg/L	< 1mg/L	< 1mg/L
pH at 25°C	8.0 ± 1.0	9.8 ± 0.2	9.8 ± 0.2	9.8 ± 0.2
Residual Water Hardness	< 0.5 dH	< 0.5 dH	< 0.2 dH	< 0.1 dH
Conductivity at 25°C	< 1500 μS/cm	< 1500 μS/cm	< 500 μS/cm	< 25 μS/cm
Oxygen Levels	---	< 0.02mg/L	< 0.02mg/L	< 0.02mg/L
Chloride Levels	< 300mg/L	< 300mg/L	< 50mg/L	< 3mg/L
Sulphate Levels	< 100mg/L	---	---	< 2mg/L
Sulphide Levels	< 1mg/L	< 1mg/L	< 1mg/L	< 1mg/L
Nitrate Concentration	< 100mg/L	---	---	---
Free Chlorine Levels	< 0.5mg/L	---	---	---
Ammonia Levels	---	< 10mg/L	< 5mg/L	< 5mg/L
Total Iron Content	---	< 0.1mg/L	< 0.1mg/L	< 0.05mg/L
Total Copper Content	---	< 0.02mg/L	< 0.02mg/L	< 0.01mg/L

Table 6 - Typical Corrosion Phenomena in Copper Brazed Stainless Steel Plate Heat Exchangers

Corrosion Mechanism	Description
Localized Corrosion	Normally the heat exchanger is free of crevices, but crevices can be formed under deposits from scaling as well as imperfect brazing joints.
General Corrosion	If general corrosion takes place, typically copper corrodes preferentially over the stainless steel. Severe loss of copper will result in loss of mechanical strength and leaks in the heat exchanger.
Galvanic Corrosion	The metallic contact between copper and stainless steel in the surrounding water can initiate a corrosive attack on the more electronegative metal, in this case copper. Some allowance is made for copper to act as a protective anode.
Stress Corrosion	Stress corrosion can occur in stainless steel if tensile stresses and a high amount of chloride are present. An increase in temperature will furthermore increase the risk of stress corrosion, particularly above 60 °C.
Intergranular Corrosion	Stainless steel can experience intergranular corrosion due to formation of chrome carbide in the grain boundaries during an improper heat treatment. Areas with decreased chrome content will be vulnerable to corrosion.

The limits given above are general guidelines to avoid most corrosion mechanisms. Since stainless steel is less likely to corrode in tap water than copper, these levels were determined mainly by copper corrosion. Normally, stainless steel will only corrode in tap water with both high chloride levels and elevated temperature. The parameters that determine corrosion and additional species-specific guidance (including a special caution on chloride, Table) are detailed below:

- Temperature: In general, an increase in temperature will increase the corrosion rate. For copper, the likelihood of pitting is higher at temperatures above 60°C. Stainless steel is also at risk of stress corrosion cracking at temperatures above 60°C. This applies mainly to the pre-heater and evaporator of the Power+. See additional discussion of temperature and chloride pitting of stainless steel below.
- pH: The risk of corrosion due to pH is lowest when the pH is between 9.0 and 9.5. In normal tap water, pH is around 7.0; it is recommended to avoid acidic water (pH below 7.0). Ammonia should not be used for pH conditioning due to the risk of copper corrosion. Sodium hydroxide (NaOH) or tri-sodium phosphate (Na_3PO_4) may be used to increase the pH of the water.
- Water Hardness: Copper is susceptible to corrosion in very soft water and the [Ca^{2+}, Mg^{2+}] / [HCO_3] ratio should be less than 0.5. See next section on deposits and scaling.
- Conductivity: High conductivity in tap water indicates that the water has a high concentration of ionic substances in general. An increase in conductivity will increase the galvanic corrosion rate. A maximum conductivity of 500µS/cm is an appropriate limit value for most metals.
- Alkalinity: If the amount of hydrogen carbonate is very low (i.e. below 60 mg/L), products from copper corrosion will dissolve and be released into the system. It is also recommended to not exceed an HCO_3^- concentration of 300 mg/L. See next section on deposits and scaling.
- Oxygen: If the oxygen content is high, the risk of corrosion will increase. The recommended oxygen level is less than 0.02 mg/L; however, the oxygen content is often higher in practice, especially for evaporative cooling towers. To limit the risk of corrosion due to high oxygen levels, meeting the other guidelines of Table and Table is generally sufficient.
- Chloride: The presence of chloride in water increases the risk of localized corrosion (pitting) of stainless steel. The limit is temperature dependent as shown in Table .

Table 7 - Recommended Chloride Limits at Various Temperatures

Temperature	Chloride Limit
25°C	1000mg/L
50°C	300mg/L
80°C	100mg/L
>100°C	0mg/L

- Sulfate: High concentrations of sulfate will increase the risk of pitting in copper. A maximum sulphate concentration of 100 mg/L is recommended, but corrosion can also take place at lower concentrations if [HCO_3^-] / [SO_4^{2-}] is less than 1.
- Nitrate: Nitrate ions have an influence similar to that of sulfate. A maximum concentration of 100 mg/L is recommended.
- Free Chlorine: Chlorine is commonly added to tap water for sanitary reasons. Chlorine is highly oxidizing and lowers the corrosion resistance of stainless steel. The concentration of free chlorine should be kept below 0.5 mg/L.

Water Hardness, Deposits and Scaling

The ability to transfer heat in plate heat exchangers can be reduced by deposits. Solid particles greater than 2 mm across tend to be screened by the channels in the unit and may accumulate rapidly leading to plugging. Problematic deposits and scaling are usually caused by the presence of calcium and magnesium carbonates in the water supply. General Hardness (GH) is the measure of calcium and magnesium ions in the water. GH is commonly expressed in parts per million (ppm) of calcium carbonate ($CaCO_3$) or degrees hardness (dH). See Table below.

Table 8 - Water Hardness Guidelines

mg/L of $CaCO_3$	dH	Description
0 - 50	0 - 3	Soft
50 - 100	3 - 6	Fairly Soft
100 - 200	6 - 12	Slightly Hard
200 - 300	12 - 18	Moderately Hard
300 - 540	18 - 30	Hard
540+	30+	Very Hard

Heating of hard water may cause the precipitation of limestone ($CaCO_3$) which will appear as a layer of scale on the plate surface. Carbonate scaling and other solids (except silica) can be removed by back flushing the heat exchanger with a mild acid, however frequent acid flushing can also cause corrosion.

Maintain the recommended water quality levels and periodically check heat exchanger pressure drops for optimum efficiency and system life. Always obtain expert advice for geothermal applications.

Balance and Expansion Tanks

Balance tanks should be used to compensate for the increase in volume as the water heats up. General practice is to have compensation equal to 10-15% of the water volume in that system.

Environmental Limits and Concerns

Temperature:

Operating: 0 to 48C (32-120F)

Storage: -20 to 50C (-4-122F) **The working fluid must be removed prior to storage.*

Relative Humidity:

Operating: 10-85%

Storage: 10-95%

Altitude:

Operating: 1500 m (5000’) maximum

Storage: 5000 m (16,000’) maximum

Shipping G forces:

Not to exceed 3.5 g vertical, 1.5 g longitudinal or lateral

Site Leveling:

Slope of installation surface not to exceed 2 cm in 3 m (1” in 10’)

Corrosive or Dirty Environment:

Please contact ElectraTherm for design considerations if the Power+ may be exposed to:

- Explosive Gases
- Caustic gases or solutions
- Extreme or harsh environment
- Marine/Coastal environments
- Other- If you are unsure about the intended environment conditions consult with ElectraTherm's engineering department. Often equipment can be changed or protected to meet special needs.

Vermin:
Machine to be installed in an area generally free from vermin. Machine interior, and particularly the electrical cabinet, to be inspected and maintained free of biological activity such as nesting termites, ants, mice, or molds/fungi.

Plant Layout and Site Preparation

During the planning phase of the project the location of the ORC and other equipment should be carefully considered in order to prevent problems with installation, maintenance, and performance. The ORC has been designed so that it can be setup and run outside without being placed in a container or building. If the machine is to be placed inside a building or container, ensure that there is an opening large enough to bring the ORC into and out of.

The ORC requires 4 feet (1219 mm) of clearance around all four sides in order to allow adequate room for installation and maintenance. It is also necessary to have forklift access to the front of the ORC for internal component maintenance (the generator and expander primarily).

**If the access to the ORC is restricted and does not meet the requirements above; additional costs may be claimed in order to perform maintenance and repair work that otherwise would be covered in the general warranty of the ORC.*

The foundation where the ORC will sit must be such that it can support 8000 lbs. (3629 kg). The ORC contains reciprocating components that will transmit vibration and noise. Elevating the unit can augment noise levels. There are four anchor-hole locations that should be used to secure the ORC to the foundation. Figure 11 illustrates these clearance requirements.

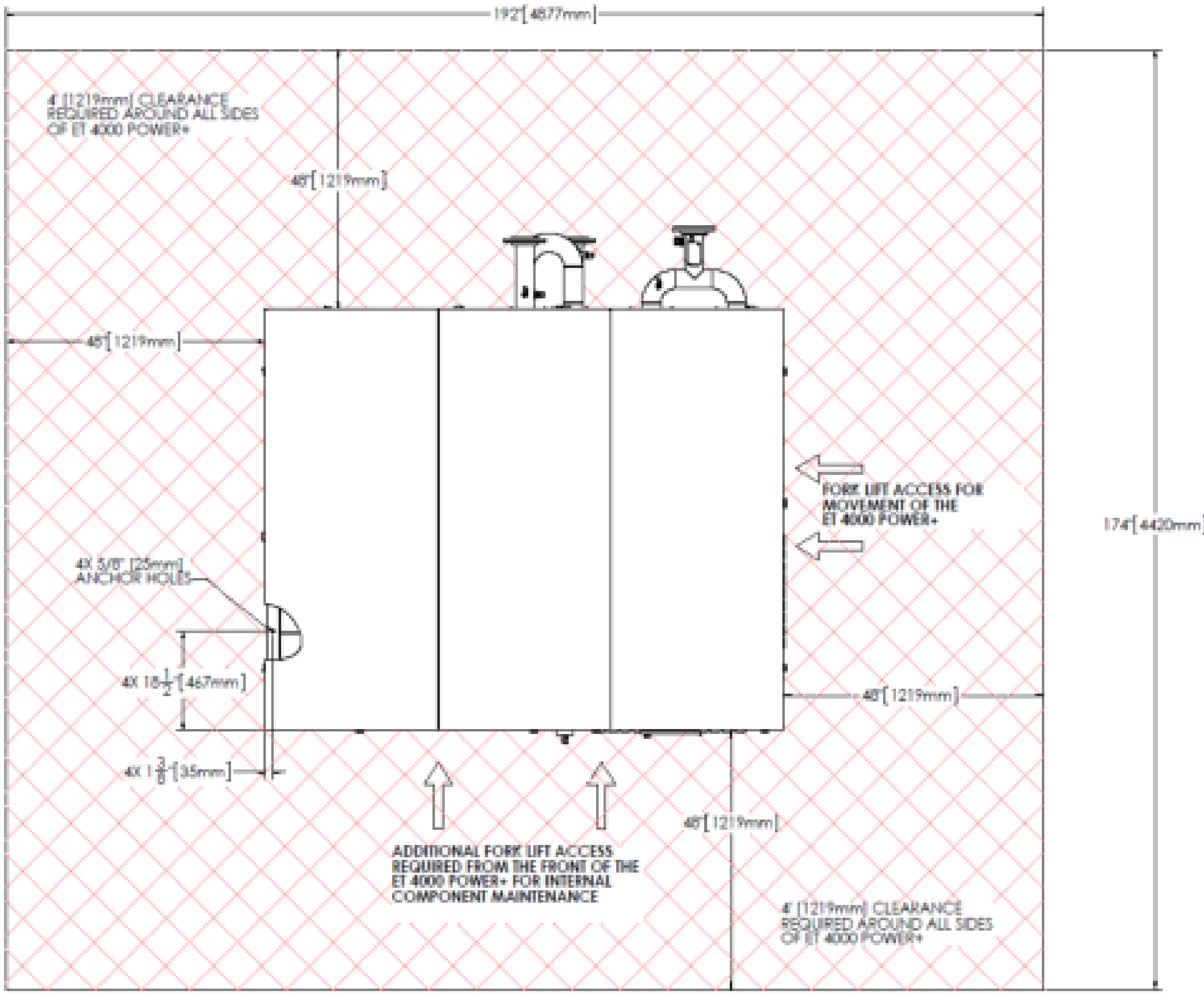


Figure 11: Power+ Clearance Requirements

Electrical Requirements

Connection of Generator to Utility Grid:

The ElectraTherm Power+ uses an asynchronous induction generator to connect to the electrical grid. The Generator is brought up to Synchronous speed (1500 RPM for 50 Hz, or 1800 RPM for 60 Hz) mechanically via the expander and is connected to the grid at near synchronous speed. There is typically a small inrush current spike at connection that lasts for less than 100 ms at grid connection.

Size of Utility Grid Required for Connection:

The Power+ Generator requires an active grid of at least 300 kWe capacity, with a continuous base load power being supplied to the grid of at least 100 kWe.

Voltage of Utility Grid:
The induction generator supplied with the Power+ is rated for 400 V/50 Hz/3 phase or 480 V/60 Hz/3 phase. Different voltage connections to the Power+ can be achieved through the use of transformers.

Grid Interconnection Requirements:
By nature of the induction generator design, and internal controls built into the Power+, the generator is unable to “island” for any extended period of time. The Power+ control system monitors phase imbalance, loss of phase, and over-voltage during normal operation, and will shut down during faults as related to those monitored items. Safe connection to and disconnection from the grid is inherent in the normal mode of operation of the Power+.

While the Power+ inherently has its own grid interconnect controls, IEEE 1547 specifications for interconnection of an induction generator device require very time specific, *settable* thresholds for disconnection of the power generating device, and monitoring of a few different settings that the Power+ doesn’t monitor. If the local authority having jurisdiction (utility, inspector, county, state, etc.…) requires that IEEE 1547 interconnection specifications or similar are met, a separate Grid Protection relay will be required in order to meet the specifications. Standard IEEE 1547 threshold specifications and settings for the grid protection relay can be provided by ElectraTherm, although the local jurisdiction or authorities requirements will likely supersede the IEEE 1547 specifications. The physical grid protection relay is not provided by ElectraTherm.

Electrical Specification Tables:

Table 7

Gross power production from the Power+**		
line frequency	50hz	60hz
rated output	75kWe	75kWe
phase	3 phase	3 phase
voltage	380-420 VAC	460-500 VAC
connection	3 wire delta	3 wire delta
typical generator speed	1520RPM	1820RPM
in-rush current at grid tie	<500A	<500A
in-rush current duration	<100ms	<100ms

** outputs exclude auxiliary power consumption of P+ or peripheral components outside of Power+

Table 8

Auxiliary power consumption of the P+*				
kWe min	kWe max	voltage	frequency	electrical connection
0.5kWe	9kWe	380-420 VAC	50 Hz	3-wire delta
0.5kWe	9kWe	460-500 VAC	60 Hz	3-wire delta

* Auxiliary power consumption can be connected directly to the generator output, or wired separately from the power production.

Customer Electrical Connections:
The Power+ comes configured standard for a single point of power connection. In this configuration, the internal Power+ parasitic is removed from the generator gross power produced inside the Power+. The Power+ may be field configured to separate the Power+ auxiliary loads from the Power+ Generator. This will allow the parasitic loads to be powered from a separate circuit as shown in Figure 12.

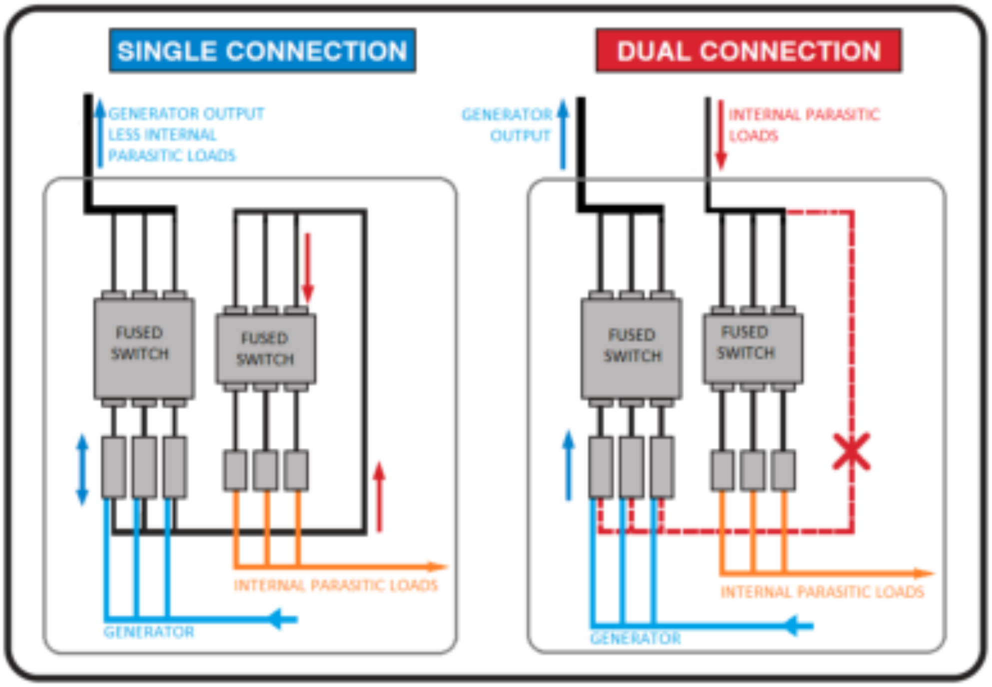


Figure 12: Power Connections

Customer Controls and Connections:
The Power+ is set up with relays and contacts that allow for remote control and external component management. The majority of these connections are dry contacts, meaning the Power+ is only opening and closing the relays. The operating signal/power to the various components must be supplied. The only output given by the Power+ is a 4-20mA signal used to control cooling fan speeds. The machine is programmed so that it can open and close the hot water and cold water valves, start and stop circulating pumps, receive remote start and stop signals, and be shut down by a grid protection opened circuit.

Contact ElectraTherm for a complete drawing of the customers interface connections.

The machine may be monitored and controlled remotely from a PC with an internet connection or via an App on iPhones and iPads using a wireless connection.
The machine stores its running data and uploads it to a server at ElectraTherm headquarters. This data is used to monitor performance and troubleshoot any issue that may arise. It is possible to output the data to a SCADA system using a KEPDirect OPC Server. KEPDirect OPC Server is a third-party software that provides means of communication between the Power+ and other software such as a database or SCADA (Supervisory Control and Data Acquisition) system.

STANDARD SCOPE OF SUPPLY

The Power+ cannot function as a standalone power generator. Its ability to produce power requires that it serve as one piece of a larger heat-to-power system. Since the potential applications for a Power+ range from internal combustion engines to biomass boilers, solar thermal collectors and more, the auxiliary equipment that makes up the Balance of Plant (BOP) can vary greatly from site to site. Figure 13 illustrates the scope of supply compared to the BOP.

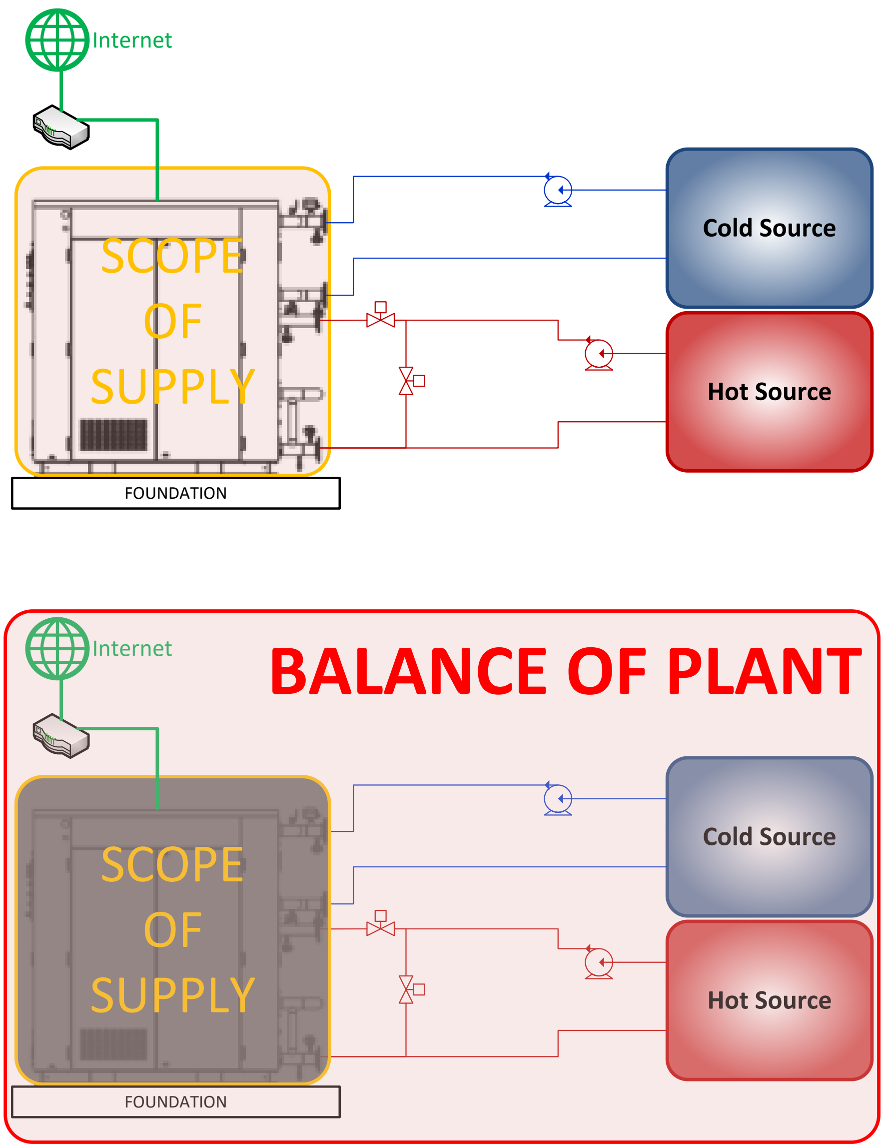


Figure 13: Scope of Supply vs. Balance of Plant

The next section will discuss the specific items that need to be considered in order to design and develop a successful waste heat to power system.

Items Supplied by ElectraTherm

The items and equipment supplied by ElectraTherm are as follows:

The Power+ Water-Cooled ORC System

The Power+ is supplied with all the necessary equipment to take in both hot & cold water and utilize the thermal energy to generate electrical power. This includes:

- Internal Heat Exchangers
  - Hot-Water Supply to Working Fluid
  - Working Fluid to Cold-Water Supply
- Working Fluid Pump
- Expander
- Induction Generator
- Power Factor Correction Equipment
- Control System & HMI
- ORC Required Sensors & Instrumentation
- System lubrication oil (POE oil)

Required Items Not Supplied by ElectraTherm

The additional items which need to be supplied by the ElectraTherm Distributor, End-User, Third-Party Contractor, or a combination thereof are as follows:

Hot-Water Supply

- Heat Source & Heat Collection/Exchange Equipment
- Hot-Water Circulating Pump
- Interconnection Piping, Expansion Joints, & Associated Support Structures
- Hot-Water Bypass Piping, Valve(s) & Actuator(s)
- Flange Connection Gaskets & Hardware

Cold-Water Supply

- Heat-Sink (Cooling Tower, Radiator, Site Process Water, Cooling Pond, etc.)
- Cold-Water Circulating Pump
- Interconnection Piping, Expansion Joints & Associated Support Structures
- Flange Connection Gaskets & Hardware

Electrical Equipment

- Power Wires to Power+ Terminals
- Grid Protection Device (Depending on Local Codes)
- Instrumentation Wiring to External Equipment (Actuators, Relays, etc.)

Working Fluid

- Refrigerant (Honeywell Genetron® R-245fa or other approved manufacturers)

Other Requirements

- Motive force for bypass valve actuation
    - Dry contacts are provided for the hot water bypass valves, but the motive force must be provided by the customer.
- Internet connection
    - A 24/7 internet connection with upload/download speeds of at least 0.5 Mbps must be available at the Power+ location.
    - Each Power+ requires at least two static IP addresses on the customer's LAN for devices that send email alerts and upload log files to the internet.
    - The same two devices must be reachable via port forwarding through a fixed public IP (internet) address for the purposes of monitoring or software updates.

System Package Options

In addition to offering the Power+ generator as a standalone unit, ElectraTherm offers a full turnkey system package including a liquid loop radiator (LLR), cold water pump, integrated controls, and the associated connections; all of which require minimum engineering on the customer's side.

Standalone 4400 B Series

4400 B Series System Package

FACTORY TESTS AND INSPECTIONS

Each Power+ undergoes a quality assurance process throughout the entire machine build and test process. The factory acceptance process is documented and tracked through final shipment of machines. Certification is provided for a summary of the overall process, as well as for a series of electrical tests required to meet EN/ISO 60204-1.

Factory Acceptance Certification List

Certification of Power+ factory acceptance process is provided with all machines. Table 9 shows the list summarizing the process protocols. A results column indicating that each requirement has been met is included in the certificate.

Table 9 - Factory Acceptance Certification List

Item	Description
Piping hydrostatic test	Pressurize to 1.5x maximum allowable working pressure
Mechanical integrity check	Verify all components assembled to specifications

System pressure test	Pressurize to 250 psig for 30 minutes
System vacuum test	Vacuum pull to < 500 microns for 30 minutes
Electrical connection check	Complete Factory checklist and verify customer interconnect signals
Horn and light panel validation	Perform audible and visual inspection of functionality
System cleanliness validation	Acceptable system flush through filter examination
Electrical tests	Verify electrical integrity
Operational control check	Perform standard start-up / operation / shut-down
Sensor verification test	Verify all sensor readings
Performance validation	Verify power output meets or exceeds specification
Safety interlocks test	Confirm machine response
Final visual inspection	Verify condition of all surfaces and components prior to shipment

Factory Acceptance Electrical Testing

Several electrical tests are required for conformance with 2006/95/EC (known as the "Low Voltage Directive"). These are found in BS EN 60204-1:2006.

Insulation Resistance (HiPot) Test

A voltage of 500 VDC is applied between the power circuit conductors and the protective bonding circuit, as specified in paragraph 18.3 of EN 60204-1:2006. A minimum insulation resistance of 100 MΩ is required of 4400 B-Series machines. The minimum insulation resistance specified by the standard itself is 1 MΩ.

Withstand Voltage (Dielectric Strength) Test

A voltage of 1000 VAC is applied between the power circuit conductors and the protective bonding circuit at a frequency of 60 Hz for two seconds. Paragraph 18.4 of EN 60204-1:2006 states that requirements are satisfied if "no disruptive discharge occurs," however ElectraTherm limits the leakage current to 7 mA.

Continuity of the Protective Bonding Circuit

A current of 2.4 A is passed through each leg of the protective bonding circuit, and the voltage drop is measured. The machine is accepted if the voltage drop through each conductor is within the range specified by Table G.1 of EN 60204-1:2006.

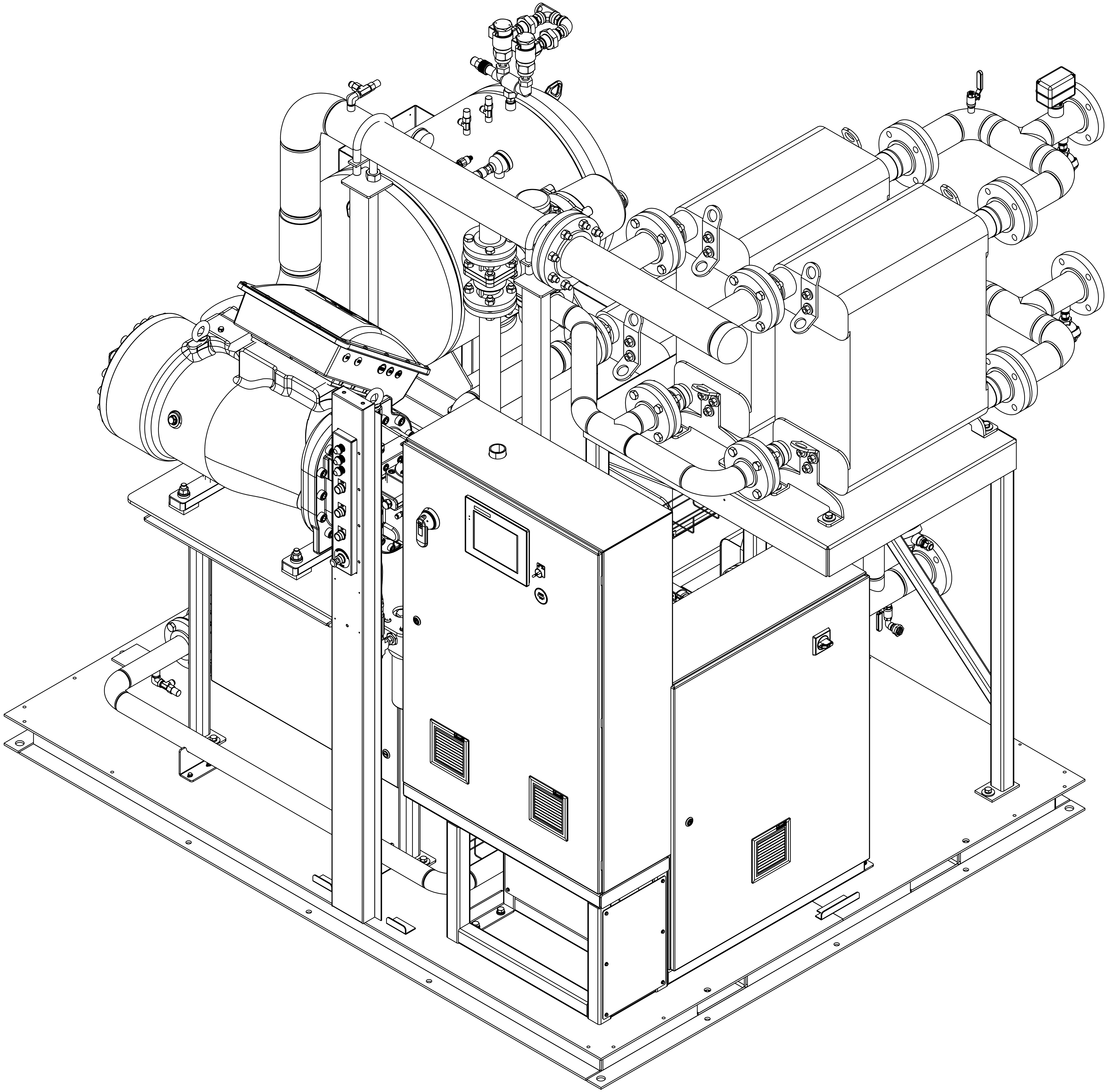
REFERENCES

BSi. (2006). *BS EN 60204-1:2006 Safety of machinery - Electrical equipment of machines - Part 1: General requirements.* UK: BSi British Standards.

ISO. (2010). *ISO 3744:2010(E) Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering methods for an essentially free field over a reflecting plane.* Switzerland: International Standards Organization.

Petersen, B. (2009). *Guideline of Water Quality for Copper Brazed Plate Heat Exchangers.* Nordborg: Danfoss District Heating.

Polaris. (n.d.). *Brazed Plate Heat Exchanger Operations Manual.* Edison.



SERIES 4000B POWER+ OVERALL

HEIGHT = 7'3" [2221 mm]
LENGTH = 7'11" [2419 mm]
WIDTH = 7'7" [2316 mm]
WEIGHT = TBD

GENERAL NOTES:

1. FLANGES ON ELECTRATHERM POWER+ HEAT EXCHANGERS CANNOT TAKE ANY FLANGE LOADS. PIPE SUPPORTS AND THERMAL EXPANSION MUST BE DESIGNED IN BY DEALER OR CUSTOMER, FLEXIBLE PIPE OR HORIZONTAL "U" SECTIONS MAY BE USED AS APPROPRIATE, IN ACCORDANCE WITH LOCAL ZONING CODES AND REQUIREMENTS.

2. SERIES 4000B POWER+ EQUIPMENT TO BE SHIPPED BY TRUCK, AIR OR BARGE ONLY. EXCESSIVE SHOCK LOADS DURING TRANSIT SHOULD BE AVOIDED. TRANSPORTING EQUIPMENT VIA RAILWAY WILL VOID FACTORY WARRANTY.

Revision	Rev. No. A	Revision Issued	Revision Checked	Revision Approved	Revision Date
Prepared PAr	Checked BMu	Approved TBr	Scale 1:6	Weight N/ALBS	Compare

Series4000B, Generic Build

ElectraTherm
BY BITZER GROUP

Date: 08 JAN 20

Drawing No.: ETS-90171

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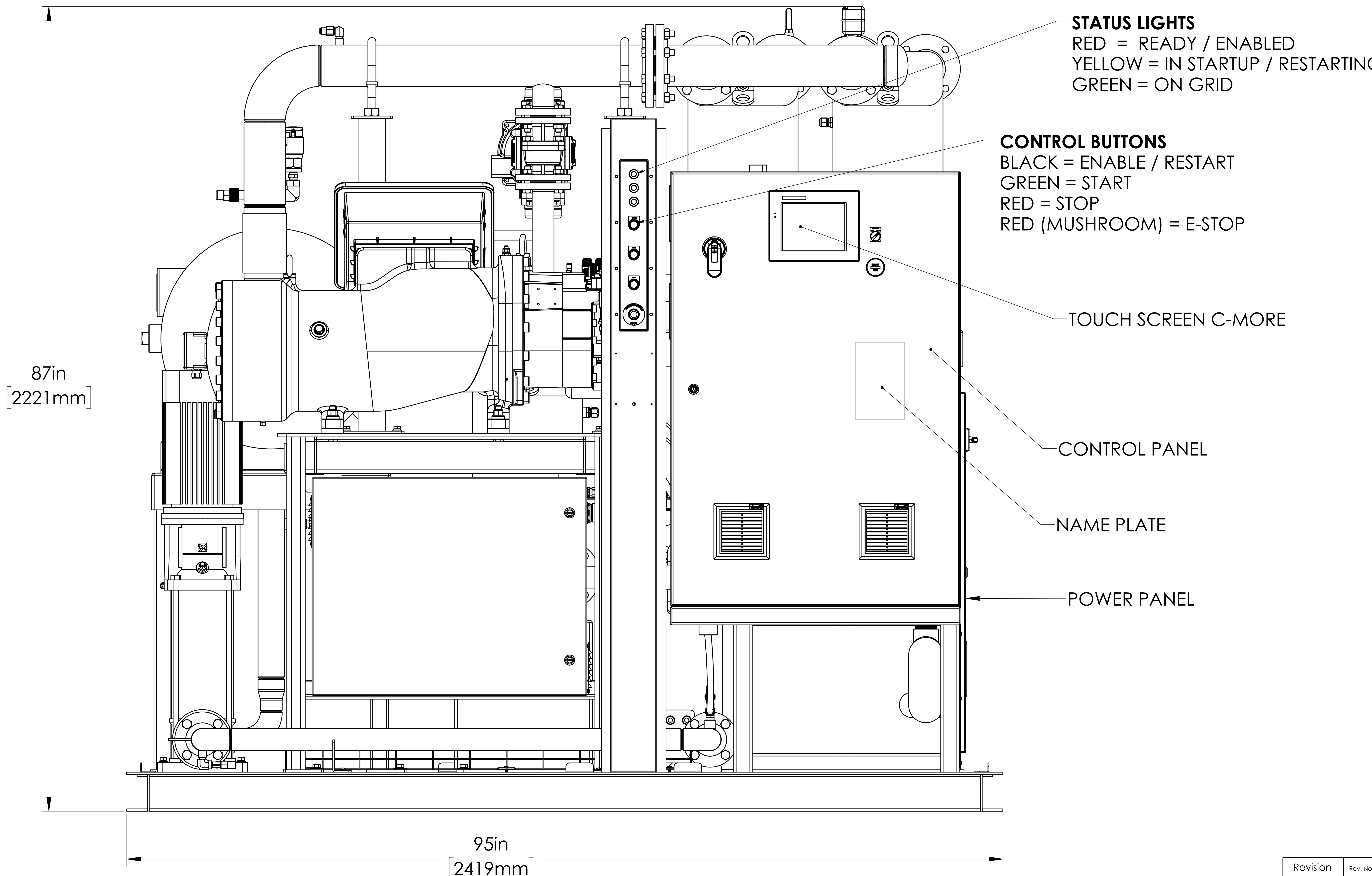
Size D



SERIES 4000B FRONT VIEW

Revision	Rev. No. A	Revision Issued	Revision Checked	Revision Approved	Revision Date
Prepared PAr	Checked BMu	Approved TBr	Scale 1:6	Weight N/ALBS	Compare

Series4000B, Generic Build

ElectraTherm BY BITZER GROUP

Date: 08 JAN 20

Drawing No.: ETS-90171

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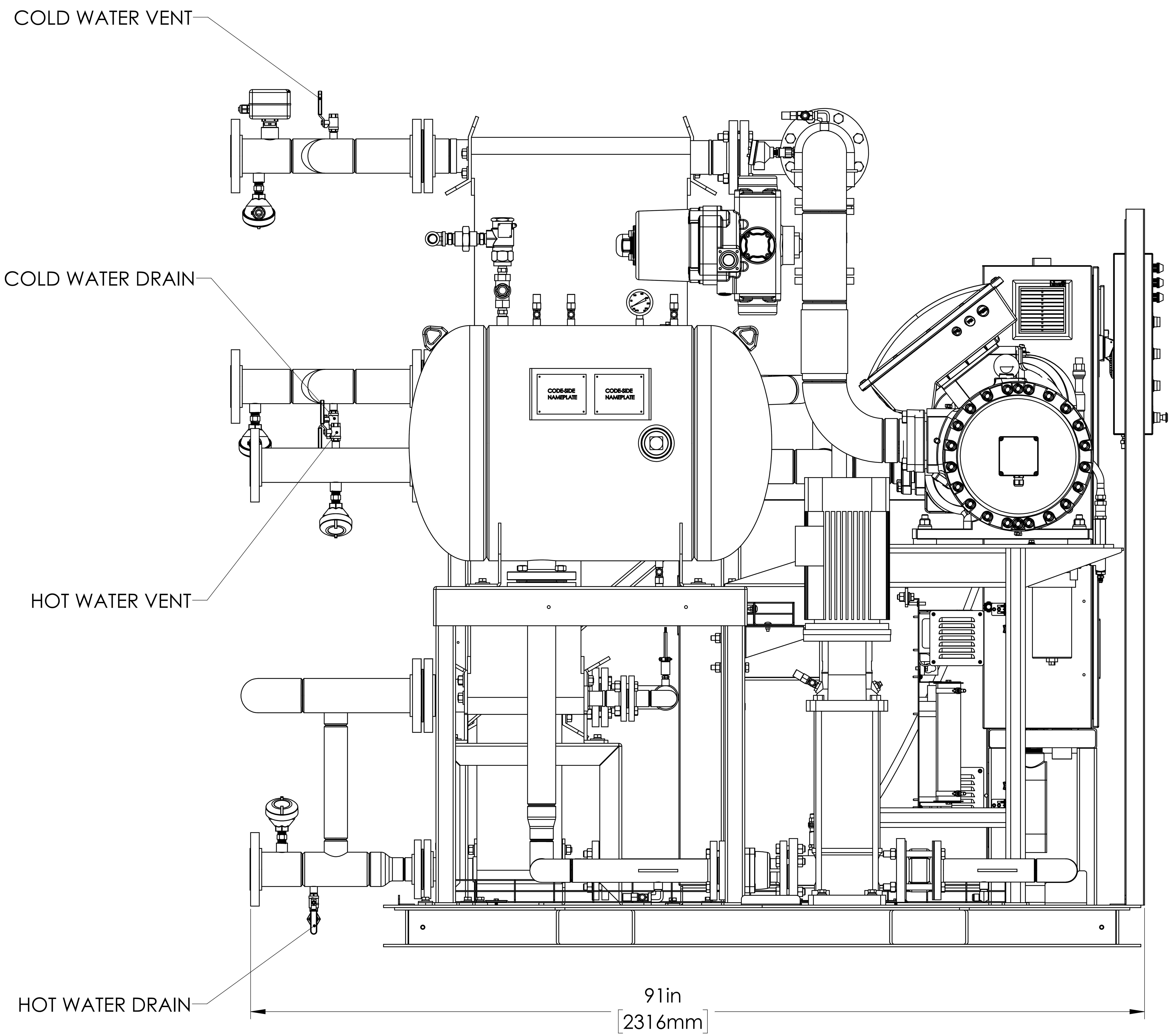

SERIES 4000B SIDE VIEW

Revision	Rev. No. A	Revision Issued	Revision Checked	Revision Approved	Revision Date
Prepared PAr	Checked BMu	Approved TBr	Scale 1:6	Weight N/ALBS	Compare

Series4000B, Generic Build

ElectraTherm BY BITZER GROUP

Date 08 JAN 20

Drawing No. ETS-90171

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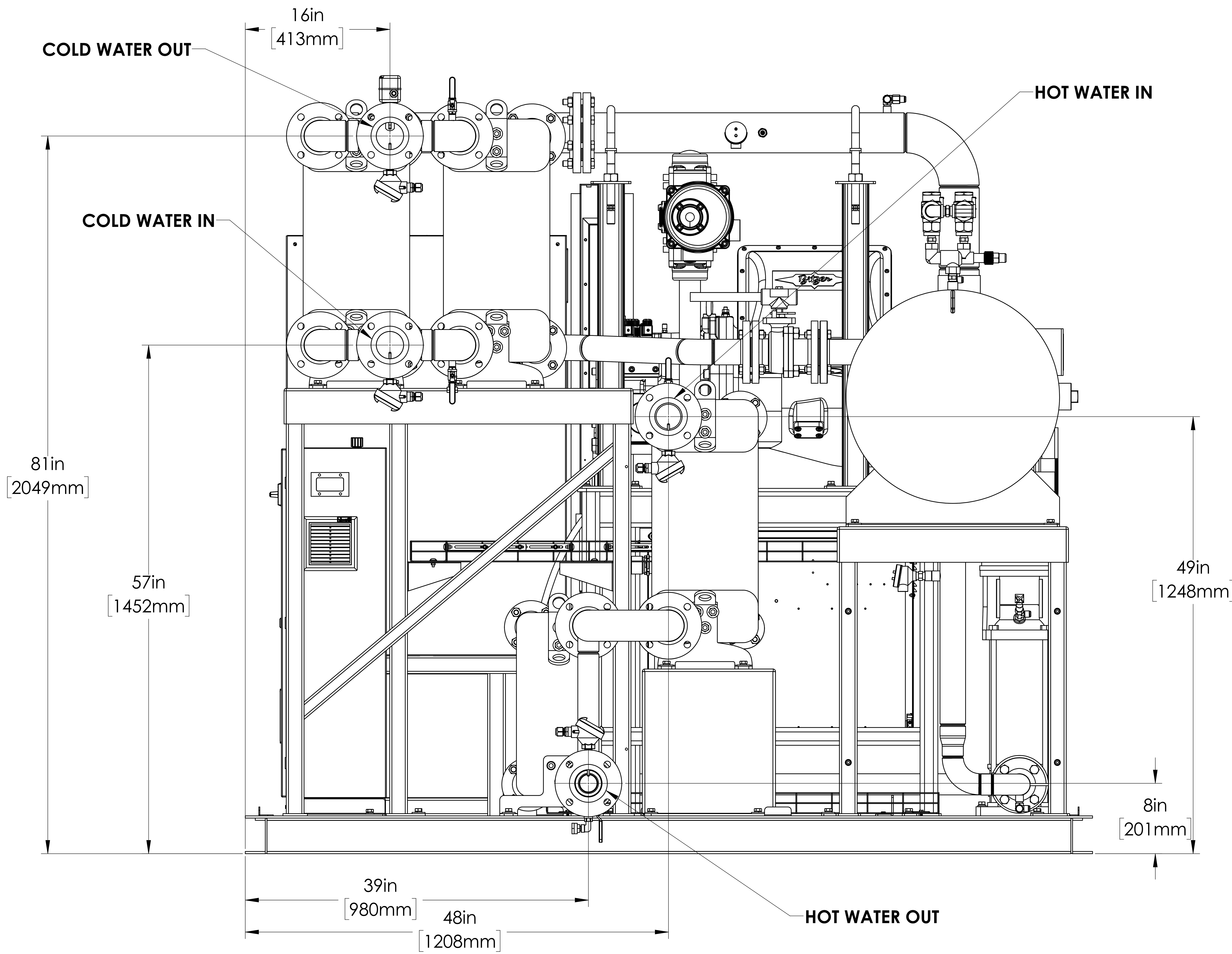
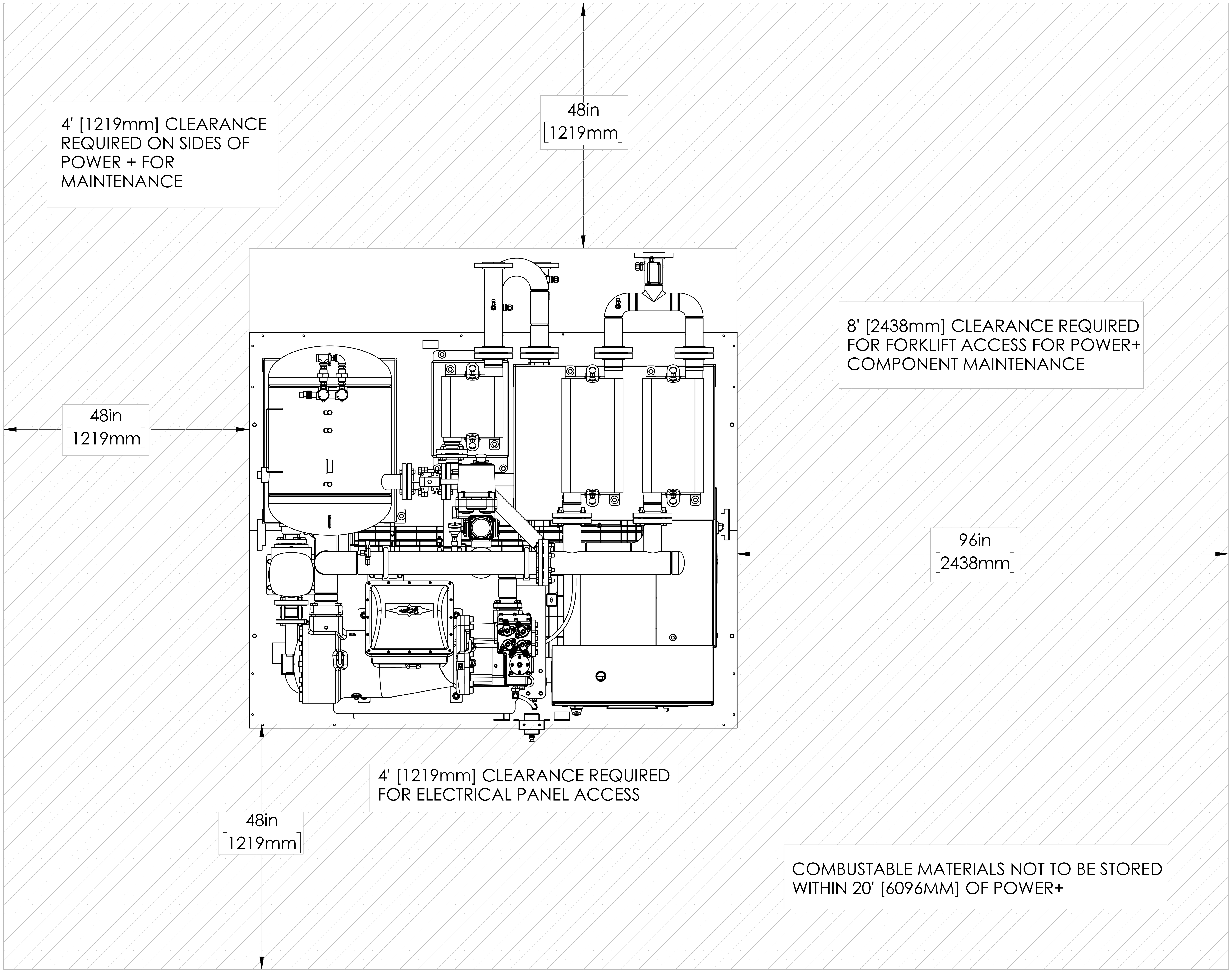


SERIES 4000B BACK VIEW

CUSTOMER CONNECTIONS	
COLD WATER IN	3" #150
COLD WATER OUT	3" #150
HOT WATER IN	3" #150
HOT WATER OUT	3" #150

CUSTOMER CONNECTION MATING FLANGES, GASKETS, AND HARDWARE PROVIDED.

Revision	Rev. No. A	Revision Issued	Revision Checked	Revision Approved	Revision Date
Prepared PAr	Checked BMu	Approved TBr	Scale 1:6	Weight N/ALBS	Compare
Series4000B, Generic Build		Date 08 JAN 20	Drawing No. ETS-90171	ElectraTherm BY BITZER GROUP	
				Page 4 : 5	Size D



SERIES 4000B TOP VIEW

Revision	Rev. No. A	Revision Issued	Revision Checked	Revision Approved	Revision Date
Prepared PAr	Checked BMu	Approved TBr	Scale 1:10	Weight N/ALBS	Compare

Series4000B, Generic Build

ElectraTherm BY BITZER GROUP

Date: 08 JAN 20

Drawing No.: ETS-90171

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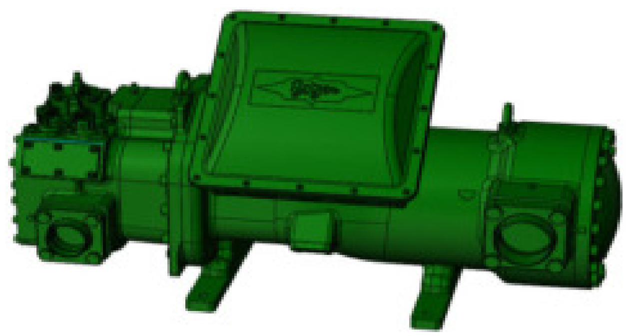
ELECTRICAL SPECIFICATION DRAWING
FOR HSE85 SERIES SEMI-HERMETIC EXPANDER / INDUCTION GENERATOR
100HP / 75KW / 400V / 50Hz

ELECTRICAL SPECIFICATIONS

Nominal Output Power (HP)	100
Nominal Output Power (Kw)	75
Nominal Voltage (VAC)	400
Electrical Phases	3
Electrical Connection Type	3 wire delta
Nominal AC Frequency (Hz)	60
Nominal Speed (RPM)	3000
Operating voltage Range (VAC)	385-420
Operating Frequency range (Hz)	47-53
Operating power factor	0.95
Generator Type	Asynchronous



OUTPUT PERFORMANCE AT 400V/50Hz

OPERATION POINT	OUTPUT	ACTIVE POWER	APPARENT POWER	REACTIVE POWER	CURRENT (uncorrected)	POWER FACTOR	CURRENT (corrected)	POWER FACTOR
[%]	[hp]	[kw]	[kva]	[kvar]	[amps]	[uncorrected]	[amps]	[corrected]
12.50%	12.6	9.4	23.4	21.5	33.8	0.40	14.2	>.95
25%	25.1	18.8	32.3	26.3	46.7	0.58	28.5	>.95
50%	50.3	37.5	48.1	30.1	69.4	0.78	57.0	>.95
75%	75.4	56.3	65.4	33.4	94.4	0.86	85.5	>.95
100%	**100.6**	**75.0**	**84.8**	**39.7**	122.5	**0.88**	114.0	**>.95**

ASYNCHRONOUS GENERATOR PARAMETERS

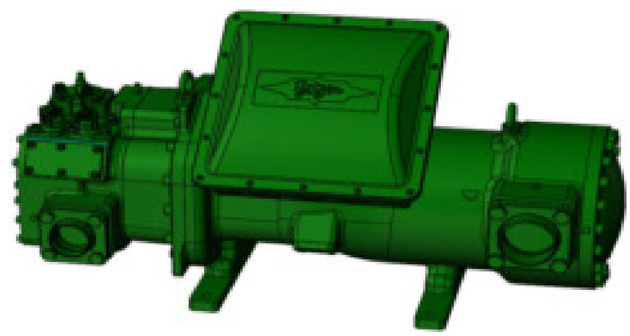
Parameter	value	units/notes
Winding Resistance AT 25°C, FWS	0.1089	ohm, +/- 7%
Rm Resistance (IEC 61363-1)	0.1008	ohm
X"m Sub Transient Reactance of motor (IEC 61363-1)	0.342	ohm
Xd Synchronous reactance	N/A	not applicable for asynchronous generators
Xd' Transient Reactance	N/A	not applicable for asynchronous generators
Xd" Sub Transient Reactance	N/A	not applicable for asynchronous generators
Short Circuit Ratio	N/A	not applicable for asynchronous generators
Output regulation (electrical output in generation)	N/A	output varies based on input conditions to expander
Maximum short circuit current (IEC 61363-1)	1054	Amps (Star convention, L-N voltages and currents)
Initial symmetrical short circuit current(IEC 61363-1)	593	Amps
Maximum current during connection (in-rush current)	690	Amps
Locked Rotor Amps, FWS	690	Amps at 400V/50Hz
Break Down Torque	563	NM at 400V/50Hz
Apparent power regulation from 0-100% load	N/A	not applicable for asynchronous generators

Document Revision: 05292020-R5

ELECTRICAL SPECIFICATION DRAWING
FOR HSE85 SERIES SEMI-HERMETIC EXPANDER / INDUCTION GENERATOR
100HP / 75KW / 480V / 60Hz

ELECTRICAL SPECIFICATIONS

Nominal Output Power (HP)	100
Nominal Output Power (Kw)	75
Nominal Voltage (VAC)	480
Electrical Phases	3
Electrical Connection Type	3 wire delta
Nominal AC Frequency (Hz)	60
Nominal Speed (RPM)	3600
Operating voltage Range (VAC)	440-506
Operating Frequency range (Hz)	57-63
Operating power factor	0.95
Generator Type	Asynchronous



OUTPUT PERFORMANCE AT 480V/60Hz

OPERATION POINT	OUTPUT	ACTIVE POWER	APPARENT POWER	REACTIVE POWER	CURRENT (uncorrected)	POWER FACTOR	CURRENT (corrected)	POWER FACTOR
[%]	[hp]	[kw]	[kva]	[kvar]	[amps]	[uncorrected]	[amps]	[corrected]
12.50%	12.6	9.4	24.4	22.5	29.3	0.39	11.9	>.95
25%	25.1	18.8	37.5	32.5	45.1	0.50	23.7	>.95
50%	50.3	37.5	50.7	34.1	60.9	0.74	47.5	>.95
75%	75.4	56.3	66.9	36.2	80.4	0.84	71.2	>.95
100%	**100.6**	**75.0**	**84.8**	**39.7**	**102.0**	**0.88**	**94.9**	**>.95**

ASYNCHRONOUS GENERATOR PARAMETERS

Parameter	value	units/notes
Winding Resistance AT 25°C, FWS	0.1069	ohm, +/- 7%
Rm Resistance (IEC 61363-1)	0.1008	ohm
X"m Sub Transient Reactance of motor (IEC 61363-1)	0.41	ohm
Xd Synchronous reactance	N/A	not applicable for asynchronous generators
Xd' Transient Reactance	N/A	not applicable for asynchronous generators
Xd" Sub Transient Reactance	N/A	not applicable for asynchronous generators
Short Circuit Ratio	N/A	not applicable for asynchronous generators
Output regulation (electrical output in generation)	N/A	output varies based on input conditions to expander
Maximum short circuit current (IEC 61363-1)	1164	Amps (Star convention, L-N voltages and currents)
Initial symmetrical short circuit current(IEC 61363-1)	606	Amps
Maximum current during connection (in-rush current)	690	Amps
Locked Rotor Amps, FWS	743	Amps at 480V/60Hz
Break Down Torque	544	NM at 480V/60Hz
Apparent power regulation from 0-100% load	N/A	not applicable for asynchronous generators

Document Revision: 05292020-R5