

Environmental Technology Verification Report

Climate Energy freewatt™ Micro-Combined Heat and Power System

Prepared by:



Greenhouse Gas Technology Center



Operated by
Southern Research Institute



Under a Cooperative Agreement With
U.S. Environmental Protection Agency

and



Under Agreement With
New York State Energy Research and Development Authority

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THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM



ETV Joint Verification Statement

TECHNOLOGY TYPE:	Gas-Fired Internal Combustion Engine Combined With Heat Recovery System
APPLICATION:	Distributed Electrical Power and Heat Generation Using Climate Energy freewatt™ Micro-Combined Heat and Power System
TECHNOLOGY NAME:	Climate Energy freewatt™ Micro-Combined Heat and Power System
COMPANY:	Climate Energy, LLC.
ADDRESS:	Utica, New York
WEB ADDRESS:	www.freewatt.com

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the purchase, design, distribution, financing, permitting, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, stakeholder groups that consist of buyers, vendor organizations, and permittees, and with the full participation of individual technology developers. The program evaluates the performance of technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests, collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Greenhouse Gas Technology Center (GHG Center), one of six verification organizations under the ETV program, is operated by Southern Research Institute in cooperation with EPA's National Risk Management Research Laboratory. A technology of interest to GHG Center stakeholders is distributed

generation (DG) sources, especially when they include combined heat and power (CHP) capabilities. The improved efficiency of DG/CHP systems makes them a viable complement to traditional power generation technologies.

The GHG Center collaborated with the New York State Energy Research and Development Authority (NYSERDA) to evaluate the performance of the Climate Energy freewatt Micro-Combined Heat and Power System. The system is a reciprocating internal combustion (IC) engine distributed electrical generation and combined heat and power (DG / CHP) installation designed and commissioned by Climate Energy. Heat is captured from the generator engine and passed to domestic heat loads via a closed heat transfer loop. Climate Energy has installed a hydronic version of the freewatt system at a private residence in Lake Ronkonkoma, Long Island, New York.

TECHNOLOGY DESCRIPTION

The following technology description is based on information provided by Climate Energy and does not represent verified information. The freewatt micro combined heat and power (MCHP) system is a nominal 1.2 kW natural gas-fueled engine driven generator from which excess heat is recovered for use on-site. This technology provides 240v single phase electrical power in parallel with the utility supply. The engine is a liquid-cooled 4-cycle unit that drives a permanent magnet generator and inverter. Waste heat produced by the engine is recovered in engine coolant, from the engine block, the oil sump, and the exhaust gases and supplies first stage space and water heating for the host site's hydronic space and water system.

With the freewatt system, heat is captured from the generator engine and passed to domestic heat loads via a closed heat transfer loop. In this installation, the CHP system provides domestic hot water via an indirectly-heated hot water heater to the residence via a hydronic heating system. Included in the package is a high efficiency boiler that provides backup/peak heating and a "hybrid" hydronic system controller that manages the hot water temperatures delivered to the hydronic system from the boiler/CHP system. The system is connected in parallel to the electric utility grid, which provides standby and peak power as required.

The system operates on a thermal-load-following mode, in which power is generated only when heat is called for from the system. The system is configured to enable export of excess power generation to the grid. Manufacturer specifications indicate that the recovered energy will supply up to about 12 thousand British thermal units per hour (MBtu/h) to the local heating loads while producing 1.2 kW of electric power. The supplementary boiler can provide up to an additional 190 MBtu/h.

VERIFICATION DESCRIPTION

Field testing was conducted on September 9 and 10, 2009. The defined system under test (SUT) was tested to determine performance for the following verification parameters:

- Electrical performance and power quality
- Electrical efficiency
- CHP thermal performance
- Atmospheric emissions performance
- Nitrogen oxides (NO_x) and carbon dioxide (CO₂) emission offsets.

The verification included a series of controlled test periods in which the GHG Center maintained steady system operations for 3 thirty-minute test periods to evaluate electrical and CHP efficiency and emissions performance, heat and power output, power quality, and efficiency.

Rationale for the experimental design, determination of verification parameters, detailed testing procedures, test log forms, and QA/QC procedures can be found in the ETV Generic Verification Protocol (GVP) for DG/CHP verifications developed by the GHG Center. Site specific information and details regarding instrumentation, procedures, and measurements specific to this verification were detailed in the Test and Quality Assurance Plan titled *Test and Quality Assurance Plan – Climate Energy freewatt™ Micro-Combined Heat and Power System*.

VERIFICATION OF PERFORMANCE

Results of the verification represent the freewatt system’s performance as installed at the host residence in Lake Ronkonkoma, NY on the two days tested. Quality Assurance (QA) oversight of the verification testing was provided following specifications in the ETV Quality Management Plan (QMP). The GHG Center’s QA manager conducted an audit of data quality on at least 10 percent of the data generated during this verification and a review of this report. Data review and validation was conducted at three levels including the field team leader (for data generated by subcontractors), the project manager, and the QA manager. Through these activities, the QA manager has concluded that the data meet the data quality objectives that are specified in the Test and Quality Assurance Plan.

Electrical and Thermal Performance

Table S-1. freewatt MCHP Electrical and Thermal Performance

Test ID	Fuel Input (MBtu/h)	Electrical Power Generation Performance		Heat Recovery Performance		Total CHP System Efficiency ^a (%)
		Power Delivered (kW)	Efficiency ^a (%)	Heat Recovered (MBtu/h)	Thermal Efficiency ^a (%)	
Run 1	15.8	1.00	21.6	9.17	58.3	79.8
Run 2	15.7	1.00	21.6	8.93	56.7	78.3
Run 3	15.7	1.00	21.6	7.58	48.2	69.7
Avg.	15.7	1.00	21.6	8.56	54.4	76.0

^a Based on actual power available for consumption at the test site (power generated less parasitic losses). LHV Based.

Key findings for freewatt MCHP electrical and thermal performance were:

- After parasitic losses, electrical efficiency averaged approximately 22 percent at this site.
- The amount of heat recovered from the MCHP and used for water heating at the residence averaged 8.56 MBtu/hr. Corresponding thermal efficiency was 54.4 percent and combined heat and power efficiency averaged 76.0 percent.

- Boiler heat production, tested separately, averaged 43.7 MBtu/h, or 12.8 kW_e. Boiler fuel utilization efficiency (AFUE) during these forced control test conditions averaged 96 percent.

Emissions Performance

Test ID	CO2 Emissions			THC Emissions			NOx Emissions		
	ppm	lb/hr	lb/MWh	ppm	lb/hr	lb/MWh	ppm	lb/hr	lb/MWh
Run 1	99343	1.35	1358	177	2.42E-03	2.43	5.90	8.04E-05	0.081
Run 2	100741	1.35	1356	183	2.45E-03	2.46	5.47	7.33E-05	0.074
Run 3	98242	1.35	1352	175	2.40E-03	2.41	6.54	8.96E-05	0.090
Avg.	99442	1.35	1355	179	2.42E-03	2.43	5.97	8.11E-05	0.081

(Consistent with the GVP, results are based on electrical output only).

Test ID	CO2 Emissions			THC Emissions			NOx Emissions		
	ppm	lb/hr	lb/MMBtu	ppm	lb/hr	lb/MMBtu	ppm	lb/hr	lb/MMBtu
Run 1	87470	6.36	153	8.08	5.88E-04	0.014	20.1	0.001	0.035
Run 2	88755	7.07	139	4.23	3.37E-04	0.007	25.2	0.002	0.040
Run 3	89793	8.38	216	3.41	3.18E-04	0.008	28.0	0.003	0.067
Avg.	88673	7.27	170	5.24	4.14E-04	0.010	24.4	0.002	0.047

Key findings for freewatt MCHP emissions and power quality performance were:

- For the MCHP, NO_x emissions averaged 0.081 lb/MWh. CO₂ and THC emissions averaged 1,355 and 2.43 lb/MWh.
- Boiler NO_x emissions averaged 0.047 pounds per million Btu (lb/MMBtu) heat delivered to the residence. CO₂ and THC emissions averaged 170 and 0.01 lb/MMBtu.
- Test results for CO emissions were invalidated after completion of testing and data analysis. The data were invalidated due to excessive variability in analytical results caused by the use of an inappropriate analyzer range. An identical freewatt unit was tested for CO emissions in a laboratory setting by the Gas Technology Institute (GTI) in early 2010 [6]. Results from the GTI testing indicate average CO emissions of 0.23 lb/MWh for the MCHP and 0.07 lb/MWh for the MCHP and boiler combined. These CO emissions data are not independently verified ETV results but are indicative of freewatt CO emissions performance under controlled operating conditions.
- Average electrical frequency was 60.00 Hz and average power factor was 99.2 percent.

Details on the verification test design, measurement test procedures, and Quality Assurance/Quality Control (QA/QC) procedures can be found in the Test Plan titled *Test and Quality Assurance Plan – Climate Energy freewatt™ Micro-Combined Heat and Power System* (SRI 2009). Detailed results of the verification are presented in the Final Report titled *Environmental Technology Verification Report for Climate Energy freewatt™ Micro-Combined Heat and Power System* (SRI 2010). Both can be downloaded from the GHG Center’s web-site (www.sri-rtp.com) or the ETV Program web-site (www.epa.gov/etv).

Signed by Cynthia Sonich-Mullin
(3/7/2013)

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Greenhouse Gas Technology Center
A U.S. EPA Sponsored Environmental Technology Verification (ETV) Organization



Environmental Technology Verification Report

**Climate Energy freewatt™
Micro-Combined Heat and Power System**

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ACRONYMS AND ABBREVIATIONS

ADQ	Audit of Data Quality
Btu	British thermal units
Btu/scf	British thermal units per standard cubic feet
CHP	combined heat and power
CO	carbon monoxide
CO ₂	carbon dioxide
CT	current transformer
DG	distributed generation
DQO	data quality objective
DUT	device under test
EGRID	Emissions and generation resource integrated database
EPA	Environmental Protection Agency
ETV	Environmental Technology Verification
GHG Center	Greenhouse Gas Technology Center
GVP	generic verification protocol
gpm	gallons per minute
Hz	hertz
IC	internal combustion
IEEE	Institute of Electrical and Electronics Engineers
kVA	kilovolt-amperes
kVA _r	kilovolt-amperes reactive
kW	kilowatts
kW _e	kilowatts electric
kW _t	kilowatts thermal
kWh	kilowatt hours
lb/hr	pounds per hour
lb/kWh	pounds per kilowatt-hour
lb/MWh	pounds per megawatt-hour
LHV	lower heating value
MBtu/h	thousand British thermal units per hour
MMBtu/hr	million British thermal units per hour
MQO	Measurement quality objective
NIST	National Institute of Standards and Technology
NO _x	nitrogen oxides
NYSERDA	New York State Energy Research and Development Authority
NY LI	New York State Long Island
O ₂	oxygen
ORD	Office of Research and Development
ppm	parts per million volume, dry
psia	pounds per square inch, absolute
QA/QC	Quality Assurance/Quality Control
QMP	Quality Management Plan
RTD	resistance temperature detector
scf	standard cubic feet
scfh	standard cubic feet per hour
SUT	system under test
TQAP	Test and Quality Assurance Plan
THC	total hydrocarbons

1.0 INTRODUCTION

1.1. BACKGROUND

The U.S. Environmental Protection Agency's Office of Research and Development (EPA-ORD) operates the Environmental Technology Verification (ETV) program to facilitate the deployment of innovative technologies through performance verification and information dissemination. The goal of ETV is to further environmental protection by accelerating the acceptance and use of improved and innovative environmental technologies. ETV was implemented in response to the belief that there are many viable environmental technologies that are not being used for the lack of credible third-party performance data. With performance data developed under this program, technology buyers, financiers, and permittees in the United States and abroad will be better equipped to make informed decisions regarding environmental technology purchase and use.

The Greenhouse Gas Technology Center (GHG Center) is one of six verification organizations operating under the ETV program. The GHG Center is managed by EPA's partner verification organization, Southern Research Institute (Southern), which conducts verification testing of promising greenhouse gas mitigation and monitoring technologies. The GHG Center's verification process consists of developing verification protocols, conducting field tests, collecting and interpreting field and other data, obtaining independent stakeholder input, and reporting findings. Performance evaluations are conducted according to externally reviewed verification Test and Quality Assurance Plans and established protocols for quality assurance.

The GHG Center is guided by volunteer groups of stakeholders, who direct the GHG Center regarding which technologies are most appropriate for testing, help disseminate results, and review Test Plans and Technology Verification Reports. A technology area of interest to some GHG Center stakeholders is distributed electrical power generation (DG), particularly with combined heat and power (CHP) capability. DG refers to electricity generation equipment, typically under 1,000 kilowatts (kW), that provides electric power at a customer's site (as opposed to central station generation). A DG unit can be connected directly to the customer or to a utility's transmission and distribution (T&D) system. Examples of technologies available for DG include gas turbine generators, internal combustion engine generators (gas, diesel, other), photovoltaics, wind turbines, fuel cells, and microturbines. DG technologies provide customers one or more of the following main services: standby generation (i.e., emergency backup power), peak shaving generation (during high-demand periods), base-load generation (constant generation), and CHP generation.

The GHG Center and the New York State Energy Research and Development Authority (NYSERDA) have agreed to collaborate and share the cost of verifying several new DG technologies located throughout the State of New York. The verification described in this document evaluated the performance of one such DG system - Climate Energy's freewatt Micro-Combined Heat and Power System. The system is a reciprocating internal combustion (IC) engine distributed electrical generation and combined heat and power (DG / CHP) installation designed and commissioned by Climate Energy. Heat is captured from the generator engine and passed to domestic heat loads via a closed heat transfer loop. Climate Energy has installed a hydronic version of the freewatt system at a private residence in Lake Ronkonkoma, Long Island, New York.

The GHG Center evaluated the performance of the freewatt by conducting field tests over an 18-hour verification period (September 9 and 10, 2009). These tests were planned and executed by the GHG Center to independently verify the electricity generation rate, thermal energy recovery rate, electrical

power quality, energy efficiency, emissions, and greenhouse gas emission reductions for the unit as operated at the residence. Details on the verification test design, measurement test procedures, and Quality Assurance/Quality Control (QA/QC) procedures are contained in two related documents:

Technology and site specific information can be found in the document titled *Test and Quality Assurance Plan – Climate Energy freewatt™ Micro-Combined Heat and Power System* [1]. It can be downloaded from the GHG Center's web-site (www.sri-rtp.com) or the ETV Program web-site (www.epa.gov/etv). This Test and Quality Assurance Plan (TQAP) describes the system under test (SUT), project participants, site specific instrumentation and measurements, and verification specific QA/QC goals. The TQAP was reviewed and revised based on comments received from NYSERDA, Climate Energy, and the EPA Quality Assurance Team. The TQAP meets the requirements of the GHG Center's Quality Management Plan (QMP) and satisfies the ETV QMP requirements.

Rationale for the experimental design, determination of verification parameters, detailed testing procedures, test log forms, and QA/QC procedures can be found in the Association of State Energy Research and Technology Transfer Institutions (ASERTTI) DG/CHP Distributed Generation and Combined Heat and Power Performance Protocol for Field Testing [2]. It can be downloaded from the web location www.dgdata.org/pdfs/field_protocol.pdf. The ETV GHG Center has adopted portions of this protocol as a draft generic verification protocol (GVP) for DG/CHP verifications [3]. This ETV performance verification of the freewatt system was based on the GVP.

The remainder of Section 1.0 describes the freewatt system technology and test facility and outlines the performance verification procedures that were followed. Section 2.0 presents test results, and Section 3.0 assesses the quality of the data obtained. Section 4.0, submitted by Climate Energy, presents additional information regarding the CHP system. Information provided in Section 4.0 has not been independently verified by the GHG Center.

1.2. FREEWATT COGENERATION UNIT TECHNOLOGY AND VERIFICATION DESCRIPTION

The freewatt system is a reciprocating IC engine based DG / CHP installation designed and commissioned by Climate Energy. The system under test (SUT) for this verification was a hydronic version of the freewatt system installed by Climate Energy at a private residence in Lake Ronkonkoma, Long Island, New York. Figure 1-1 shows the residential installation tested during this verification. Detailed system specifications are provided in Appendix A.



Figure 1-1. Freewatt Hydronic System Tested in Lake Rononkoma, NY

With the freewatt system, heat is captured from the generator engine and passed to domestic heat loads via a closed heat transfer loop. In this installation, the CHP system provides domestic hot water via an indirectly-heated hot water heater and comfort heat to the residence via a hydronic heating system. Included in the package is a high efficiency boiler that provides backup/peak heating and a “hybrid” hydronic system controller that manages the hot water temperatures delivered to the hydronic system from the boiler/CHP system. The system is connected in parallel to the electric utility grid, which provides standby and peak power as required.

The system operates on a thermal-load-following mode, in which power is generated only when heat is called for from the system. The system is configured to enable export of excess power generation to the grid.

Manufacturer specifications indicate that the recovered energy will supply up to 12 thousand British thermal units per hour (MBtu/h) to the local heating loads while producing 1.2 kilo Watt (kW) of electric power. The supplementary boiler can provide up to an additional 190 MBtu/h.

On-site loads include:

- year-round domestic hot water (DHW)
- hydronic space heating during cold weather

The test campaign determined the emissions performance, electrical performance, thermal recovery and electrical efficiency of the CHP module during a “controlled test period”.

1.3. PERFORMANCE VERIFICATION OVERVIEW

Following the GVP, the verification included evaluation of the freewatt system performance over a series of controlled test periods. Because this unit is designed to operate at full load only, tests were only conducted while the unit operated at nominal 1.2 kW. The freewatt verification was limited to the performance of the system under test (SUT) within a defined system boundary. Figure 1-2 illustrates the SUT boundary for this verification. The figure indicates two distinct boundaries. The device under test (DUT) or product boundary includes the freewatt system selected for this test including all of its internal components. The SUT includes the DUT as well as the heat transfer fluid circulation pump. Following the GVP, this verification incorporated the system boundary into the performance evaluation.

The ETV program test of the freewatt combined heat and power (CHP) system will require the temporary installation of various sensors and instruments. The schematics presented in Figures 1-2 and 1-3 show the mechanical and electrical layouts for metering. This monitoring scheme was designed to allow separate quantification of MCHP and total heat production. Hydronic boiler heat production was determined as the difference between the two. However, during the controlled test periods insufficient hot water demand precluded a test configuration whereas both the MCHP and the boiler had sufficient load to operate concurrently. Therefore, each unit was tested separately to determine thermal efficiency.

The defined SUT was tested to determine performance for the following verification parameters:

- Electrical Performance
- Electrical Efficiency
- CHP Thermal Performance
- Emissions Performance

Each of the verification parameters listed were evaluated during the controlled test periods as summarized in Table 1-1. This table also specifies the dates and time periods during which the testing was conducted. Simultaneous monitoring for power output, heat recovery rate, heat input, ambient meteorological conditions, and exhaust emissions was performed during each of the controlled test periods. Fuel gas samples were collected to determine fuel lower heating value and other gas properties. Average electrical power output, heat recovery rate, energy conversion efficiency (electrical, thermal, and total), and exhaust stack emission rates are reported for each test period.

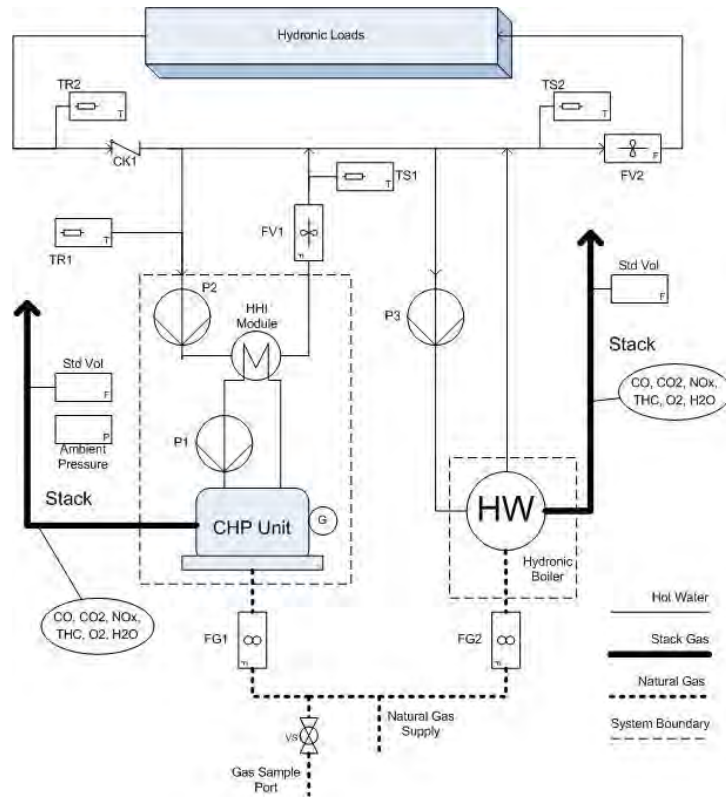


Figure 1-2: Mechanical Instrumentation Schematic

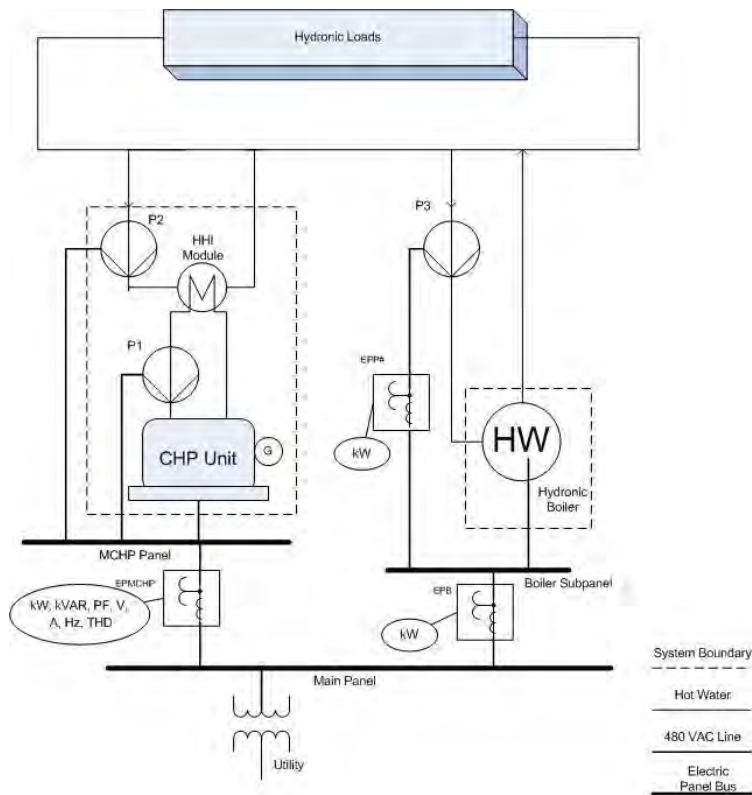


Figure 1-3: Electrical One-Line Drawing with Instrumentation

Table 1-1. Controlled Test Periods

Controlled Test Periods			
Start Date	End Date	Test Condition	Verification Parameters Evaluated
09/09/2009	09/10/2009	Power command 1 kW, three 30-minute test runs for the MCHP and boiler separately	NO _x , CO, CH ₄ , CO ₂ emissions, and electrical (MCHP only), thermal, and CHP efficiency, power quality

The following sections identify the sections of the GVP that were followed during this verification, identify site specific instrumentation for each, and specify any exceptions or deviations.

1.3.1. Electrical Performance (GVP §2.0)

Determination of electrical performance was conducted following §2.0 and Appendix D1.0 of the GVP. The following parameters were measured:

- Real power, kW
- Apparent power, kVA
- Reactive power, kVAR
- Power factor, %
- Frequency, Hz
- Voltage, V
- Current, A

The verification parameters were measured with a digital power meter manufactured by Power Measurements Ltd. (Model 7600 ION). The meter operated continuously, unattended, scanning all power parameters once per second and computing and recording one-minute averages. The rated accuracy of the power meter is ± 0.1 percent, and the rated accuracy of the current transformers (CTs) needed to employ the meter at this site is ± 1.0 percent. Overall power measurement error was ± 1.0 percent.

1.3.2. Electrical Efficiency (GVP §3.0)

Determination of electrical efficiency was conducted following §3.0 and Appendix D2.0 of the GVP. The following parameters were measured:

- Real power production, kW
- External parasitic load power consumption, kW
- Ambient temperature, °F
- Ambient barometric pressure, psia
- Fuel LHV, Btu/scf
- Fuel consumption, scfh

Real power production net of transformer losses was measured by the Power Measurements Ltd. Digital power meter. Ambient temperature was recorded on the datalogger from a single Class A 4-wire RTD. The specified accuracy of the RTD was ± 0.6 °F. Ambient barometric pressure was measured by a Setra Model 280E ambient pressure sensor with a full scale (FS) of 0 – 25 psia and an accuracy of ± 1% FS.

Gas flow was measured by a Model 8C175 Series B3 Roots Meter manufactured by Dresser Measurement with a specified accuracy of $\pm 1\%$. Gas temperature was measured by a Class A 4-wire platinum resistance temperature detector (RTD). The specified accuracy of the RTD is ± 0.6 °F. Gas pressure was measured by an Omega Model PX205 Pressure Transducer. The specified accuracy of the pressure transducer is $\pm 0.25\%$ of reading over a range of 0 – 30 psia. Three gas samples were collected and shipped to Empact Analytical of Brighton, Colorado for lower heating value (LHV) analysis. Results of the gas samples collected during the controlled tests were invalidated due to the indication of a small amount of air in the sample canisters. Three additional samples were collected on July 29 and submitted to Empact. Results of these samples show that air was not present in the canisters and results of these samples were therefore used for the efficiency calculations.

The external parasitic load introduced by the heat transfer fluid circulation pump was monitored using a second digital power meter manufactured by Power Measurements Ltd. (Model 7500 ION). Meter specifications and accuracy was the same as those for the power meter.

1.3.3. CHP Thermal Performance (GVP §4.0)

Determination of CHP thermal performance was conducted following §4.0 and Appendix D3.0 of the GVP. The following parameters were quantified:

- Thermal performance in heating service, Btu/h
- Thermal efficiency in heating service, %
- Actual SUT efficiency in heating service as the sum of electrical and thermal efficiencies, %

To quantify these parameters, heat recovery rate was measured throughout the verification. This verification used an Omega Model FTB-905 flow meter with a nominal linear range of 2.5 – 29 gpm. An Omega Model FSLC-64 transmitter amplified the flow meter's pulse output. An Agilent / HP Model 34970A totalized and logged the pulse output. Accuracy of this system was $\pm 1.0\%$ of reading. Class A 4-wire platinum resistance temperature detectors (RTD) were used to determine the transfer fluid supply and return temperatures. The specified accuracy of the RTDs, including an Agilent / HP Model 34970A datalogger, is ± 0.6 °F. Pretest calibrations documented the RTD performance. The density and specific heat of the fluid (water) was obtained from standard tables [4].

The GVP followed for this verification represents the standard verification protocol for all DG/CHP verifications conducted under the ETV program. It should be noted however that for this verification, an additional thermal performance analysis was conducted. Specifically, collected field testing data was also used to estimate boiler performance following ASHRAE Standard 103-2007 [5]. This standard, commonly used in the residential heating and cooling industry to determine annual fuel utilization efficiency (AFUE), was added to the analysis due to its applicability to a water heating system of this size (residential). The standard was used to determine simple boiler steady state efficiency as a function of heat input (fuel consumption) and heat losses (via the exhaust duct), thereby including the system's ventilation heat supply to the conditioned space, which is not accounted for using the standard GVP methodology.

1.3.4. Emissions Performance (GVP §5.0)

Determination of emissions performance was conducted following §5.0 and Appendix D4.0 of the GVP and included emissions of NO_x, CO, CO₂, CH₄, and THC. Emissions testing was performed by Southern using a Horiba OBS-2200 portable emissions monitoring system (PEMS). The PEMS also measures

exhaust gas flow with a stack flow tube. The field team temporarily installed the PEMS and flow tube on the exhaust stack. The mean concentration for each gas during each individual test run, integrated with the mean exhaust gas volumetric flow rate observed during that test run, yielded the run's gaseous emission rate in pounds per hour.

1.3.5. Field Test Procedures and Site Specific Instrumentation

Field test procedures followed the guidelines and procedures detailed in the following sections of the GVP:

- Electrical performance - §7.1
- Electrical efficiency - §7.2
- CHP thermal performance - §7.3
- Emissions performance - §7.4

Controlled tests were conducted as three one-hour test replicates at a system power command of approximately 1.0 kW. Hot water was dumped as needed to maintain demand and allow the freewatt unit to operate over the entire test period. A planned long-term monitoring period was not conducted due to field testing problems (Section 3.1). Measurements recorded during the test periods included:

- Power output,
- Fuel consumption (gas flow, pressure, and temperature),
- Heat recovery rate (transfer fluid flow, supply temperature, and return temperature),
- Heat transfer fluid circulation pump power consumption, and
- Ambient conditions (temperature and pressure).

Site specific measurement instrumentation is summarized in Table 1-2. The location of the instrumentation relative to the SUT is illustrated in Figures 1-2 and 1-3. All measurement instrumentation met the GVP specifications.

Table 1-2: Instrument Descriptions and Locations

Index	Ch_ID (channel)	Parm_ID (parameter)	Description	Nominal rating / expected value	Location	Sensor manufacturer, model number
1	1	F _{V1}	Heat transfer fluid (water) flow rate	5 gallon per minute (gpm)	Outlet of CHP circulation pump and standby pump	Hedland model HTTF1-BA-NN ultrasonic flow meter (3/4" copper pipe)
3	02	T _{S1}	Supply temperature	80 - 140 °F	Outlet of CHP circulation pump	Omega SA-RTD-80-MTP 3-wire surface mount resistance temperature device (RTD)
4	03	T _{R1}	Return temperature	70 - 100 °F	Heat transfer fluid return line	Omega SA-RTD-80-MTP 3-wire surface mount RTD
6	04	F _{G1}	MCHP Natural gas consumption, 100 pulse per acf	31 pulse/min at 18,500 Btu/h	Revenue gas meter	Invensys R200 with IMAC pulse converter
7	05	F _{G2}	Boiler Natural gas consumption	144 pulse/min at 80,000 Btu/h	Revenue gas meter	Dresser Roots 8C175
8	06	F _{V2}	Main hydronic heating loop flow rate	10 gpm	Main hydronic loop	Hedland model HTTF1-BA-NN ultrasonic flow meter (3/4" copper pipe)
9	07	T _{S2}	Main hydronic heating loop supply temperature	80 - 140 °F	Main loop downstream of last heat source outlet (supply)	Omega SA-RTD-80-MTP 3-wire surface mount RTD
10	08	T _{R2}	Main hydronic heating loop return temperature	70 - 100 °F	Main hydronic loop upstream of first heat source inlet (return)	Omega SA-RTD-80-MTP 3-wire surface mount RTD
11	Lab Analysi s	Fuel_LHV	Natural gas lower heating value	910 British thermal units per standard cubic foot (Btu/scf)	Gas Sample Port	Empact Analytical sampling bottles
12	Power Meter/ Logger	EP _{MCHP}	Generated real power, reactive power, power factor, voltage, current, frequency, total harmonic distortion	1.2 kW	Generator output	Power Logic ION 7500 with (2) Flex- core CTY-050A-1 CTs
13	09	EP _B	Parasitic load (boiler controls and boiler circulating pump) real power consumption including boiler	0.2 kW, 8.9 pulse/min	Boiler subpanel	WattNode WNB-37-208P with (2) WattNode CTS-0750-015 split-core CTs
14	010	EP _{MCHP_in}	Consumed real power	0.1 kW, 4.4 pulse/min	MCHP subpanel	WattNode WNB-37-208P with (3) WattNode CTS-0750-015 split-core CTs (P1 output)
15	011	EP _{MCHP_out}	Generated real power	1.2 kW, 53 pulse/min	P2 output, same instrument as Index (14) above.	P2 output, same instrument as Index (14) above.

In addition to the above verification parameters, the TQAP provided a detailed procedure for estimating NO_x and CO₂ emission reductions resulting from electrical generation. The procedure correlates the estimated annual electricity savings in MWh with New York and nationwide electric power system emission rates in lb/MWh. The planned approach for this verification assumed that the freewatt system generates power at a rate similar to that recorded during the verification monitoring period throughout the entire year. However, due to the limited amount of data that was collected during the verification, a valid extrapolation of results to generating rates and subsequent annual emission offsets was not possible, and this parameter was therefore not verified.

The ETV program has published the Distributed Generation and Combined Heat and Power Field Testing Protocol [1] (generic protocol). The generic protocol contains detailed test procedures, instrument specifications, analytical methods, and QA / QC procedures. This test campaign conformed to the generic protocol specifications, with modifications or special considerations as listed in the following subsections. Appendix A provides field data forms as derived from the generic protocol.

2.0 VERIFICATION RESULTS

2.1. OVERVIEW

The verification was conducted on September 9 and 10, 2009. Testing was conducted to verify power and heat production, and CHP efficiency. The controlled test periods in September also included determination of system emissions and power quality.

The GHG Center acquired several types of data that represent the basis of verification results presented here. The following types of data were collected and analyzed during the verification:

- Continuous measurements (fuel gas pressure, temperature, and flow rate, power output and quality, heat recovery rate, parasitic load, and ambient conditions)
- Fuel gas heating value data
- Emissions testing data

The field team leader reviewed, verified, and validated some data, such as DAS file data and reasonableness checks while on site. The team leader reviewed collected data for reasonableness and completeness in the field. The data from each of the controlled test periods was reviewed on site to verify that variability criteria specified below in Section 2.2 were met. The emissions testing data was validated by reviewing instrument and system calibration data and ensuring that those and other reference method criteria were met. Calibrations for fuel flow, pressure, temperature, electrical and thermal power output, and ambient monitoring instrumentation were reviewed on site to validate instrument functionality. Other data such as fuel LHV analysis results were reviewed, verified, and validated after testing had ended. All collected data was classified as either valid, suspect, or invalid upon review, using the QA/QC criteria specified in the TQAP. Review criteria are in the form of factory and on-site calibrations, maximum calibration and other errors, audit gas analyses, and lab repeatability. Results presented here are based on measurements which met the specified Data Quality Objectives (DQOs) and QC checks and were validated by the GHG Center.

The GHG Center attempted to obtain a reasonable set of short-term data to examine daily trends in electricity and heat production, and power quality. It should be noted that these results may not represent performance over longer operating periods or at significantly different operating conditions.

Test results are presented in the following subsections:

- Section 2.1 – Electrical and Thermal Performance and Efficiency
- Section 2.2 – Power Quality Performance
- Section 2.3 – Emissions Performance and Reductions

The results show that the freewatt unit produces high quality power and is capable of operating in parallel with the utility grid. At this residential installation, the MCHP unit can produce a steady 1 kW of net electrical power after associated parasitic losses, and net electrical efficiency at full load averaged 21.6 percent. The average MCHP heat recovery rate measured during the controlled test periods was 8.56 MBtu/h and thermal efficiency averaged 54.4 percent.

NO_x emissions averaged 0.08 lb/MWh, and emissions of CO and THC averaged 81 and 2.4 lb/MWh, respectively. CO₂ emissions for this residence through use of the freewatt are estimated at approximately

38 percent higher than the average grid emission factor. Detailed analyses are presented in the following sections.

During controlled test periods where the boiler demand was maximized, the boiler delivered 43.7 MBtu/h at an average efficiency of 56.3 percent (determined using GVP procedures). Boiler fuel utilization efficiency averaged 96 percent (determined using ASHRAE AFUE procedures). Normalized to heat production, boiler emissions of NOx and THC during this testing averaged 0.05 and 0.01 pounds per million Btu produced (lb/MMBtu), respectively.

In support of the data analyses, the GHG Center conducted an audit of data quality (ADQ) following procedures specified in the QMP. A full assessment of the quality of data collected throughout the verification period is provided in Section 3.0.

2.2. ELECTRICAL AND THERMAL PERFORMANCE AND EFFICIENCY

The heat and power production performance evaluation included electrical power output, heat recovery, and CHP efficiency determinations during controlled test periods. After each test run, analysts reviewed the data and determined that all test runs were valid by meeting the following criteria:

- at least 90 percent of the one-minute average power meter data were logged
- data and log forms that show SUT operations conformed to the permissible variations throughout the run (Table 2-1)
- ambient temperature and pressure readings were recorded at the beginning and end of the run
- at least 3 complete kW or kVA readings from the external parasitic load were recorded
- field data log forms were completed and signed
- records demonstrate that all equipment met the allowable QA/QC criteria

Based on American Society of Mechanical Engineers (ASME), Performance Test Code 17 (PTC-17), the GVP specified guidelines state that efficiency determinations were to be performed within 30 minute test periods in which maximum variability in key operational parameters did not exceed specified levels. Table 2-1 summarizes the maximum permissible variations observed in power output, ambient temperature, ambient pressure, gas pressure, and gas temperature at the meter for each test run. The table shows that the PTC-17 requirements for all parameters were met for all test runs.

Table 2-1. Variability in Operating Conditions

	Maximum Observed Variation in Measured Parameters		
	Power Output ^a	Ambient Temp. (°F)	Ambient Pressure ^a
Maximum Allowable Variation	± 5 %	± 5 °F	± 1 %
Run 1	0.50	0.8	0.01
Run 2	0.32	0.3	0.01
Run 3	0.32	0.2	0.03

^a Maximum (Average of Test Run – Observed Value) / Average of Test Run · 100

2.2.1. Electrical Power Output, Heat Production, and Efficiency During Controlled Tests

Table 2-2 summarizes the power output, heat production, and efficiency performance of the SUT. The heat recovery and fuel input determinations corresponding to the test results are summarized in Tables 2-3 and 2-4. A total of 3 fuel samples were collected for compositional analysis and calculation of LHV for heat input determinations. There was very little variability in any of the measurements associated with the efficiency determinations.

The average net electrical power delivered to the residence was 1.0 kW during operation. The average electrical efficiency at this power output was 21.6 percent. Electric power generation heat rate, which is an industry-accepted term to characterize the ratio of heat input to electrical power output, averaged 15,700 Btu/kWh.

MCHP heat recovery and use during the controlled test periods averaged 8.56 MBtu/h, or 2.51 kW_t. Thermal efficiency at this site averaged 54.4 percent and total CHP efficiency (electrical and thermal combined) averaged 76.0 percent under these conditions.

Table 2-2. Freewatt MCHP Electrical and Thermal Performance – Controlled Test Periods

Test ID	Fuel Input (MBtu/h)	Electrical Power Generation Performance		Heat Recovery Performance		Total CHP System Efficiency (%)	Ambient Conditions	
		Power Delivered (kW)	Efficiency ^a (%)	Heat Recovered (MBtu/h)	Thermal Efficiency ^a (%)		Temp (°F)	Pbar (psia)
Run 1	15.8	1.00	21.6	9.17	58.3	79.8	84.7	14.80
Run 2	15.7	1.00	21.6	8.93	56.7	78.3	85.0	14.80
Run 3	15.7	1.00	21.6	7.58	48.2	69.7	85.1	14.80
Avg.	15.7	1.00	21.6	8.56	54.4	76.0	84.9	14.80

^a Based on actual power available for consumption at the test site (power generated less parasitic losses). LHV Based.

Boiler heat recovery, tested separately, averaged 43.7 MBtu/h, or 12.8 kW_t. Thermal efficiency for the boiler during these forced control test conditions averaged 56.3 percent using the approach and methodologies outlined the DG/CHP GVP [1] and as specified in the test plan. Boiler efficiency averaged 96 percent when calculated using the ASHRAE AFUE method [6], which is a standard industry measure of efficiency for residential type units.

Table 2-3. Freewatt Boiler Thermal Performance – Controlled Test Periods

Test ID	Fuel Input (MBtu/h)	Heat Recovery Performance		Ambient Conditions	
		Heat Recovered (MBtu/h)	Thermal Efficiency (%)	Temp (°F)	Pbar (psia)
Run 1	77.5	41.5	53.6	86.2	14.80
Run 2	77.5	50.8	65.5	88.1	14.80
Run 3	77.5	38.7	49.9	89.7	14.80
Avg.	77.5	43.7	56.3	88.0	14.80

2.3. POWER QUALITY PERFORMANCE

Table 2-4 summarizes the power quality statistics for voltage, power factor, and frequency. The data show that the unit produced power at quality levels well within the IEEE recommendations for all parameters.

Table 2-4. Summary of freewatt MCHP Power Quality

Parameter	Average	Maximum Recorded	Minimum Recorded	Standard Deviation
Voltage (v)	121.76	122.68	120.49	0.58
Frequency (Hz)	60.00	60.04	59.97	0.01
Power Factor (%)	99.23	99.29	99.12	0.02

2.4. EMISSIONS PERFORMANCE

2.4.1. Freewatt MCHP and Boiler Exhaust Emissions

Stack emission measurements were conducted during each of the controlled test periods in accordance with the EPA reference methods listed in the GVP. Following the GVP, the SUT was maintained in a stable mode of operation during each test run based on PTC-17 variability criteria. Results are summarized separately for the MCHP and boiler exhaust ducts in Tables 2-5 and 2-6.

Test ID	CO2 Emissions			THC Emissions			NOx Emissions		
	ppm	lb/hr	lb/MWh	ppm	lb/hr	lb/MWh	ppm	lb/hr	lb/MWh
Run 1	99343	1.35	1358	177	2.42E-03	2.43	5.90	8.04E-05	0.081
Run 2	100741	1.35	1356	183	2.45E-03	2.46	5.47	7.33E-05	0.074
Run 3	98242	1.35	1352	175	2.40E-03	2.41	6.54	8.96E-05	0.090
Avg.	99442	1.35	1355	179	2.42E-03	2.43	5.97	8.11E-05	0.081

Test ID	CO2 Emissions			THC Emissions			NOx Emissions		
	ppm	lb/hr	lb/MMBtu	ppm	lb/hr	lb/MMBtu	ppm	lb/hr	lb/MMBtu
Run 1	87470	6.36	153	8.08	5.88E-04	0.014	20.1	0.001	0.035
Run 2	88755	7.07	139	4.23	3.37E-04	0.007	25.2	0.002	0.040
Run 3	89793	8.38	216	3.41	3.18E-04	0.008	28.0	0.003	0.067
Avg.	88673	7.27	170	5.24	4.14E-04	0.010	24.4	0.002	0.047

Emissions results for NO_x, THC, and CO₂ concentrations are reported in units of parts per million by volume dry (ppmvd). Measured pollutant concentration data were converted to mass emission rates using EPA Method 2 and are reported in units of pounds per hour (lb/hr). The MCHP emission rates are also reported in units of pounds per megawatt hour electrical output (lb/kMWh). They were computed by dividing the mass emission rate by the net electrical power generated during each test run. Boiler emission rates are also reported in units of lb/MMBtu normalized to the amount of heat produced during the tests.

NO_x emissions averaged 0.08 lb/MWh and emissions of THC averaged 2.4 lb/MWh. During controlled test periods where the boiler demand was maximized, the boiler delivered 43.7 MBtu/h at an average efficiency of 56.3 percent. Normalized to heat production, boiler emissions of NO_x THC during this testing averaged 0.05 and 0.01 pounds per million Btu produced (lb/MMBtu), respectively.

Concentrations of CO₂ in the MCHP exhaust gas averaged 9.9% with a corresponding average CO₂ emission rate of 1,355 lb/MWh.

Test results for CO emissions were invalidated after completion of testing and data analysis. The data were invalidated due to excessive variability in analytical results caused by the use of an inappropriate analyzer range. An identical freewatt unit was tested for CO emissions in a laboratory setting by the Gas Technology Institute (GTI) in early 2010 [6]. The GTI testing was conducted under controlled and steady operating conditions following EPA reference methods for emissions testing. Results from the GTI testing indicate average CO emissions of 0.23 lb/MWh for the MCHP and 0.07 lb/MWh for the MCHP and boiler combined. These CO emissions data are not independently verified ETV results but are indicative of freewatt CO emissions performance under controlled operating conditions.

3.0 DATA QUALITY ASSESSMENT

3.1. DATA QUALITY OBJECTIVES

Under the ETV program, the GHG Center specifies data quality objectives (DQOs) for each verification parameter before testing commences as a statement of data quality. The DQOs for this verification were developed based on past DG/CHP verifications conducted by the GHG Center, input from EPA’s ETV QA reviewers, and input from both the GHG Centers’ executive stakeholders groups and industry advisory committees. As such, test results meeting the DQOs will provide an acceptable level of data quality for technology users and decision makers. The DQOs for electrical and CHP performances are quantitative, as determined using a series of measurement quality objectives (MQOs) for each of the measurements that contribute to the parameter determination:

<u>Verification Parameter</u>	<u>DQO (relative uncertainty)</u>
Electrical Performance	±2.0 %
Electrical Efficiency	±2.5 %
CHP Thermal Efficiency	±3.5 %

Each test measurement that contributes to the determination of a verification parameter has stated MQOs, which, if met, demonstrate achievement of that parameter’s DQO. This verification is based on the GVP which contains MQOs including instrument calibrations, QA/QC specifications, and QC checks for each measurement used to support the verification parameters being evaluated. Details regarding the measurement MQOs are provided in the following sections of the GVP:

- § 8.1 Electrical Performance Data Validation
- § 8.2 Electrical Efficiency Data Validation
- § 8.3 CHP Performance Data Validation

The DQO for emissions is qualitative in that the verification will produce emission rate data that satisfies the QC requirements contained in the EPA Reference Methods specified for each pollutant. Details regarding the measurement MQOs for emissions are provided in the following section of the GVP:

- § 8.4 Emissions Data Validation

Completeness goals for this verification were to obtain valid data for 90 percent of the test periods. With the exception of CO emissions testing, these goals were met as all of the planned controlled tests were conducted and validated, and 99 percent of valid one-minute average data were collected during the monitoring period (although the monitoring period was severely shortened to only 18 hours). As stated earlier, the CO emissions testing conducted by the GHG Center during this verification has been invalidated due to the use of an inappropriate analyzer operating range. The instrument used for this testing (Horiba OBS 2000) has an analytical range for CO of 0 to 10 percent. After testing and during data review it was determined that actual stack concentrations of CO were less than 10000 ppm on the MCHP and less than 500 ppm on the boiler (or less than 10% of the operating range). Manufacturer expected CO concentrations, as validated by the GTI laboratory testing, are on the order of less than 100 ppm. Considering the analytical limitations of the instrument used for testing, the CO data for this verification are considered invalid.

Regarding the extended monitoring period, a series of issues and problems encountered during testing precluded the verification from including a valid continuous data. Therefore, this verification does not include results of verification parameters requiring long term analytical data including availability, reliability, and GHG and other emissions offsets.

The following sections document the MQOs for this verification, followed by a reconciliation of the DQOs stated above based on the MQO findings.

3.2. DOCUMENTATION OF MEASUREMENT QUALITY OBJECTIVES

3.2.1. Electrical Generation Performance

Table 3-1 summarizes the MQOs for electrical generation performance.

Table 3-1. Electrical Generation Performance MQOs

Measurement	QA/QC Check	When Performed	Allowable Result	Result Achieved
kW, kVA, kVAR, PF, I, V, f(Hz)	Power meter NIST-traceable calibration	18-month period	± 2.0%	ION 7600: calibration is within spec. ION 7500: calibration is within spec.,
	CT documentation	At purchase	ANSI Metering Class 0.3%; ± 1.0% to 360 Hz (6 th harmonic)	Meets spec.
V, I	Sensor function checks	Beginning of load tests	V: ± 2.01% I: ± 3.01%	V (7500, 7600): 0.5%, 1.02% I (7500, 7600): 2.06%, 0.5%
	Power meter crosschecks	Before field testing	± 0.1% differential between meters	V: 0.07% I: 0.03%
Ambient temperature	NIST-traceable calibration	18-month period	± 1 °F	Meets spec.
	Ice and hot water bath crosschecks	Before and after field testing	Ice water: ± 0.6 °F Hot water: ± 1.2 °F	Before (ice, hot): 0.01 °F, 0.1 °F After (ice, hot): 0.1 °F, 0 °F
Barometric pressure	NIST-traceable calibration	18-month period	± 0.1 "Hg or ± 0.05 psia	Meets spec.
	Crosscheck with gas pressure sensor	Before and after field testing	± 0.08 psia differential between sensors	Before: 0.3 psia After: 0.19 psia

All of the MQOs met the performance criteria. Following the GVP, the MQO criteria demonstrate that the DQO of ±2 % relative uncertainty for electrical performance was met.

3.2.2. Electrical Efficiency Performance

Table 3-2 summarizes the MQOs for electrical efficiency performance.

Table 3-2. Electrical Efficiency MQOs

Measurement	QA/QC Check	When Performed	Allowable Result	Result Achieved
Gas meter	NIST-traceable calibration	18-month period	± 1.0% of reading	Meets spec.
	Differential pressure check	At installation	< 0.1 in.	0.025 in.
Gas pressure	NIST-traceable calibration	18-month period	± 0.5% of FS	Meets spec.
	Crosscheck with ambient pressure sensor	Before and after field testing	± 0.08 psia differential between sensors	Before: 0.3 psia After: 0.19 psia
Gas temperature	NIST-traceable calibration	18-month period	± 1.0% of FS	Meets spec.
	Ice and hot water bath crosschecks	Before and after field testing	Ice water: ± 0.6 °F Hot water: ± 1.2 °F	Before (ice, hot): 0.01 °F, 0.1 °F After (ice, hot): 0.1 °F, 0 °F
Fuel Gas LHV	NIST-traceable standard gas calibration	Weekly	± 1.0% of reading	Meets spec.
	ASTM D1945 duplicate sample analysis and repeatability	Each sample	Within D1945 repeatability limits for each gas component	Meets spec.

All of the MQOs met the performance criteria with the exception of the pressure sensor cross checks. Error in the barometric pressure sensor was discussed in the Section 3.2.1. Following the GVP, the MQO criteria in Tables 3-1 and 3-2 demonstrate that the DQO of ± 2.5% relative uncertainty for electrical efficiency was met.

3.2.3. CHP Thermal Efficiency Performance

Table 3-3 summarizes the MQOs for CHP thermal efficiency performance.

Table 3-3. CHP Thermal Efficiency Performance MQOs

Description	QA/QC Check	When Performed	Allowable Result	Result Achieved
Heat transfer fluid flow meter	NIST-traceable calibration	18-month period	± 1.0% of reading	Meets spec.
	Sensor function checks	At installation	See Appendix B8 of TQAP	Zero flow: 0 gpm Normal flow: 8 gpm
	Zero flow response check	At installation; Immediately prior to first test run	Less than 0.3 gpm	Installation: 0 gpm Prior to testing: 0 gpm
T _{supply} and T _{return} sensors	NIST-traceable calibration	18-month period	± 0.6 °F between 100 and 210 °F	Meets spec.
	Sensor function checks	At installation	Ice water: ± 0.6 °F Hot water: ± 1.2 °F	Ice water: 0.2 °F Hot water: 0.1 °F
	Ice and hot water bath crosschecks	Before and after field testing	Ice water: ± 0.6 °F Hot water: ± 1.2 °F	Before (ice, hot): 0.08 °F, 0.13 °F After (ice, hot): 0 °F, 0 °F

All of the MQOs met the performance criteria. Following the GVP, the MQO criteria in Tables 3-1, 3-2, and 3-3 demonstrate that the DQO of ± 3.5% relative uncertainty for CHP thermal efficiency was met.

3.2.4. Emissions Measurement MQOs

Sampling system QA/QC checks were conducted in accordance with GVP and TQAP specifications to ensure the collection of adequate and accurate emissions data. The reference methods specify detailed sampling methods, apparatus, calibrations, and data quality checks. The procedures ensure the quantification of run-specific instrument and sampling errors and that runs are repeated if the specific performance goals are not met. Table 3-4 summarizes relevant QA/QC procedures.

Table 3-4. Summary of Emissions Testing Calibrations and QA/QC Checks

Description	QA/QC Check	When Performed	Allowable Result	Result Achieved
CO ₂ , O ₂	Analyzer calibration error test	Daily before testing	± 2% of analyzer span	All calibrations, system bias checks, and drift tests were within the allowable criteria.
	System bias checks	Before each test run	± 5% of analyzer span	
	System calibration drift test	After each test run	± 3% of analyzer span	
NO _x	Analyzer interference check	Once before testing begins	± 2% of analyzer span	All criteria were met for the NO _x measurement system.
	Sampling system calibration error and drift checks	Before and after each test run	± 2% of analyzer span	
THC	System calibration error test	Daily before testing	± 5% of analyzer span	All criteria were met for the THC measurement system.
	System calibration drift test	After each test run	± 3% of analyzer span	

Satisfaction and documentation of each of the calibrations and QC checks verified the accuracy and integrity of the measurements and that reference method criteria were met for each of the parameters with the exception of CH₄. Reported CH₄ concentrations are considered suspect because they were higher than the measured THC values. In addition, the duplicate analysis conducted on the sample from run 3 exceeded the ± 5% MQO.

3.3. AUDITS

This verification was supported by ADQ conducted by the GHG Center QA manager. During the ADQ, the QA manager randomly selected data supporting each of the primary verification parameters and followed the data through the analysis and data processing system. The ADQ confirmed that no systematic errors were introduced during data handling and processing.

Also, a readiness/planning review was conducted by the QA manager. During the readiness/planning review, the QA Manager confirmed that the pre-test preparations, calibrations, and activities conformed to the approved TQAP.

4.0 TECHNICAL AND PERFORMANCE DATA SUPPLIED BY CLIMATE ENERGY

Note: This section provides an opportunity for Climate Energy to provide additional comments concerning the freewatt System and its features not addressed elsewhere in the Report. The GHG Center has not independently verified the statements made in this section.

The basic findings of this evaluation result in reported levels of performance, in terms of overall electric and heating efficiency, below those determined by Climate Energy and several national test laboratories. Mainly, this is due to differences in accounting for the useful application of the generated heat and electricity. We believe the ETV characterization that has been applied is more appropriate for industrial CHP systems and not the self-contained home heating appliances and systems the freewatt is intended to replace. A particular point of fact in this regard is that national standards for home heating appliances do not penalize the overall efficiency of the heating appliance for the electric power consumption of the whole heating system, as has been done in this study. Even though the freewatt system has very low parasitic power consumption per unit of heat generated and delivered to the building compared to conventional heating systems, the mere accounting of it in the methods applied under the protocol followed here lowers freewatt apparent overall efficiency in comparison. Another significant difference is that this verification does not account for all of the useful heat provided by the system directly into thermally conditioned space in which it is installed, in that the protocol used here disregards the available cabinet heat from the MCHP appliance. This heating contribution is normally recognized in national standards for the performance of hydronic (boiler) heating appliances.

Also, we do wish to point out the discrepancy in this report between the statements that the measured Annual Fuel Utilization Efficiency (AFUE) of the freewatt boiler was found to be 96% (section 2.2.1 text) and that the measured thermal efficiency of the freewatt boiler averaged 56.% (Table 2-3). Although this verification was conducted following approved DG/CHP performance verification protocols, several independent test laboratories have confirmed the freewatt boiler AFUE at the levels stated here using the AFUE test procedure accepted by the industry and adopted by the Department of Energy for residential heating boilers. Complications and uncertainties in the direct measurement of thermal output of small boilers is a primary reason the AFUE method, based on stack gas analysis and flue losses, has been used by industry and government for determining the practical operating efficiency of residential boilers which are normally installed in the thermally conditioned space of a building.

5.0 REFERENCES

- [1] Southern Research Institute, *Test and Quality Assurance Plan - Test and Quality Assurance Plan – Climate Energy freewatt™ Micro-Combined Heat and Power System*, SRI/USEPA-GHG-QAP-46, www.sri-rtp.com, Greenhouse Gas Technology Center, Southern Research Institute, Research Triangle Park, NC. August 2009.
- [2] Association of State Energy Research and Technology Transfer Institutions, *Distributed Generation and Combined Heat and Power Field Testing Protocol, DG/CHP Version*, ASERTTI, Madison, WI, October 2004.
- [3] Southern Research Institute, *Generic Verification Protocol – Distributed Generation and Combined Heat and Power Field Testing Protocol*, SRI/USEPA-GHG-GVP-04, www.sri-rtp.com, Greenhouse Gas Technology Center, Southern Research Institute, Research Triangle Park, NC. July 2005.
- [4] *CRC Handbook of Chemistry and Physics*. Robert C. Weast, Ph.D., editor, CRC Press, Inc., Boca Raton, FL. 1980.
- [5] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., *Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers*, ANSI/ASHRAE Standard 103-2007, www.ashrae.org, Atlanta, GA, 2007.
- [6] Gas Technology Institute, *Freewatt – Plus Performance Test Results*, GTI-208081.05-15625, www.gastechnology.org, Des Plaines, Illinois, 2010. 1980.

APPENDIX A

Hydronic Freewatt System Model 1.2 HDZFN



TECHNICAL SPECIFICATION

**Hydronic Freewatt System
Model freewatt-1.2HDZF**

MICRO-COMBINED HEAT AND POWER SYSTEMS

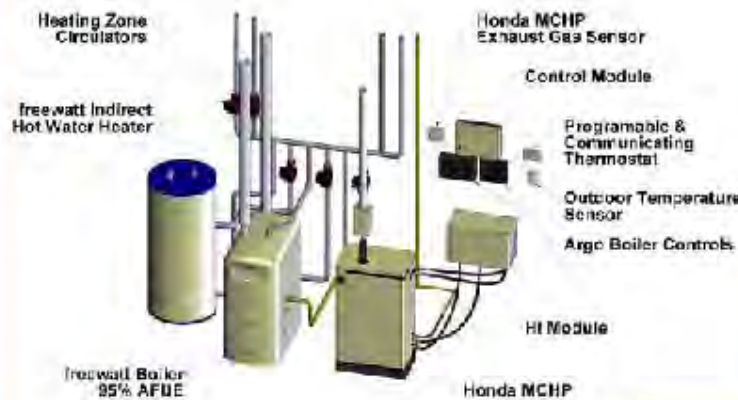
Climate Energy's freewatt™ System combines two technologies, an advanced boiler and a natural gas-fired engine generator. This hybrid heat and power generation package provides unrivaled total energy efficiency in combined heat and power delivery to the home. The freewatt™ System is designed to be installed in the place of a typical boiler and uses the same ductwork system to deliver the heat to the home.

FREEWATT™ SYSTEM FEATURES

- **Honda MCHP Power Generation Technology**
 - o Honda Reliable
 - o Quiet (47 dBA)
 - o Efficient (85%+ Heat And Power)
 - o 1.2 kW of Electric Power Production
 - o UL 1741 Certified for Grid Interconnection
 - o Proven Technology
 - o PVC Exhaust Venting
- **Advanced Boiler**
 - o Energy-Star Qualified
 - o High Efficiency (95% AFUE)
 - o Condensing Appliance
- **Hybrid Integration Module**
 - o Permanent Magnet Pump
 - o Compact Brazed Plate Heat Exchanger
- **Control Module**
 - o freewatt™ System Controller
 - o Advanced Heat And Power Algorithm
 - o Communicating Thermostat
 - o Internet Connection
- **Simple Installation**
- **Compatible with Conventional Baseboard and Radiant Heat Emitters**

FREEWATT™ SYSTEM BENEFITS

- **Reliable Power Generation, Powered by Honda™**
- **Significantly Reduced:**
 - o Home's Carbon Footprint Using Energy Conservation
 - o Monthly Electric Bill by Net-Metering Power Generation & Use
- **Enhanced Comfort**
 - o Low Level of Continuous Heat Delivery
- **Increases house value by \$6,000 to \$20,000 (National Appraiser's Institute)**
- **Reduces environmental (CO2) footprint 23% annually**
- **System Monitoring through the Internet Connection**
- **Breakthrough Home Energy Technology**
- **Simplified Grid Interconnection**



The Boiler and HI Module assembly is design certified in the US and Canada by the Canadian Standards Association.



As an Energy Star partner, Climate Energy has determined that the boiler included as part of the Freewatt system meets Energy Star guidelines for energy efficiency.



The Honda MCHP is an Underwriters Laboratory (UL) Listed, Utility Interactive, Cogeneration, Stationary Engine-Generator Assembly, File Number ITSLAU2004 (U.S.) and E-1887/187004 (Canada).



Hydronic freewatt System
Model freewatt-L2HD2FN

Engineered for High Efficiency

1. Honda MCHP Unit
 - Delivers a steady-state efficiency of 86% while producing power and heat, thereby reducing the amount of energy consumed to generate your power.
 - Delivers exhaust through PVC Venting.
2. Advanced Hot Water Boiler
 - Delivers 95% AFUE with a corrosion resistant aluminum block heat exchanger.
 - Outdoor reset increases efficiency and indoor comfort.
3. Hybrid Integration Module
 - Consumes under 80 watts to deliver heat from Honda MCHP unit to air coil heat exchanger.
4. Control Module
 - Advanced heat and power algorithm optimizes power production of Honda MCHP unit.



Hydronic freewatt System

Advanced Technology

5. Onboard Inverter
 - Integrated inverter delivers high quality power to the home's main circuit panel.
 - UL 1741 Certified for Grid Interconnection.
6. Exhaust Heat Exchanger
 - High efficiency heat exchanger reduces exhaust products to 140° F, allowing use of PVC venting.
 - Three-way catalytic converter significantly reduces emissions.
7. Combustion Control System
 - Oxygen sensor feedback allows for excellent emissions control.
 - Stopping gas valve offers almost unlimited control of gas/air mixture.



Honda MCHP Unit

Quiet Operation & Comfort

- Honda MCHP Unit
- Generates heat & power at a noise level of only 47 dBA.

- Advanced Hot Water Boiler
- Ultra quiet operation while delivering heat in Low Heat mode.
 - Low Heat mode drastically reduces temperature swings and increases overall comfort.

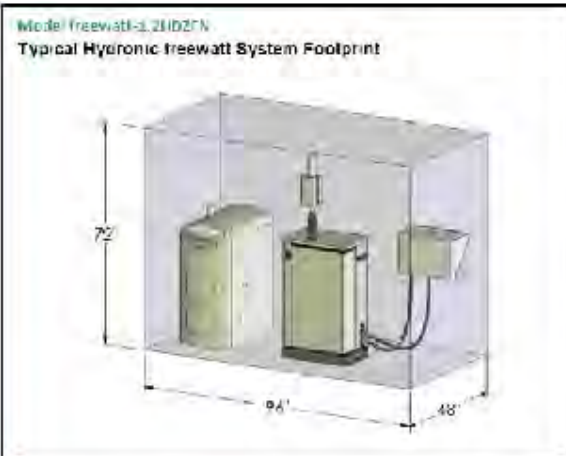
- freewatt System
- Low Heat mode – MCHP operates.
 - High Heat mode – MCHP and furnace operate.

Reliability

Honda's commitment to bringing products to market that improve the quality of people's life goes well beyond cars and motorcycles. Since 1953, Honda has manufactured over 40 million power products worldwide and continues as a leader in the development of low-emission, fuel efficient, environmentally friendly 4-stroke engines for use several power equipment applications. Now Honda's unwavering reliability, quality, durability and environmentally conscious efficiency combines with Climate Energy's Freewatt System to bring more combined heat and power to the home.



**Hydronic Freewatt System
Model freewatt-1.2HDZFN**



**Model freewatt-1.2HDZFN
Connections**

Boiler

Electrical: 120 Volts AC, 60 Hz, 1 phase, Less than 12 amps
Air Intake/Vent: 3" Sch 40 PVC
Natural Gas: 1/2" NPT
Condensate Drain: 1/2" PVC
Internet Connection: RJ45

Honda MCHP

Electrical: 240 Volts AC, 60 Hz, 1 phase, Less than 8 amps
Vent: 2" Sch 40 PVC
Natural Gas: 1/2" NPT w/ flexible connector
Condensate Drain: 1/2" tube

Consult Installation Manuals for more details.

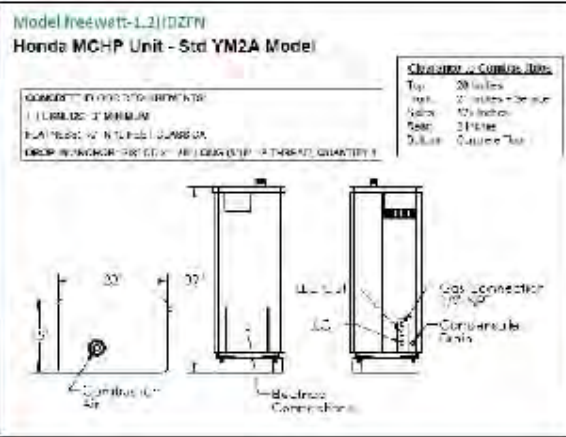
**Model freewatt-1.2HDZFN
System Clearances**

Dimensions	Boiler	Honda MCHP	Service
Top	1"	20"	8"
Left Side	1"	12"	14"
Right Side	1"	12"	-
Base	0 - Note 1	0 - Note 2	-
Front	0"	21"	54"
Back	6"	2"	-
Intake/Vent Piping	0"	0"	-
Near Boiler HW Piping	1"	0"	-

Note: 1. Combustible floor covering, if at all, is req'd.
 2. MCHP is attached to base that is anchored to concrete floor.

**Model freewatt-1.2HDZFN
Boiler Dimensions & Locations**

Dimensions	Boiler
Height	30 3/8"
Width	16"
Depth	30 7/8"
Return Connection	Back/Right/Top
Supply Connection	Top
Exhaust Vent	Top
Air Intake	Back/Top
Fuel Gas	Back/Right/Top



HEATING CAPACITIES – NATURAL GAS	
Model	CP95M 300
Efficiency (AFUE)	95%
Stage 1 – Micro-CHP Mode (Low)	
Input (MBH) @ 2,000°	18.5
Output (MBH) @ 2,000°	12.0
Stage 2 – Min Heat Mode (High)	
Input (MBH) @ 2,000°	80
Output (MBH) @ 2,000°	75
Stage 2 – Max Heat Mode (High)	
Input (MBH) @ 2,000°	200
Output (MBH) @ 2,000°	190
BOILER CONNECTION DIMENSIONS	
Supply	1 1/2"
Return	1 1/2"
MAXIMUM VENTING LENGTHS (per applicable codes for all Q)	
Venting Length (ft.) – Boiler (3")	100 ft.
Venting Length (ft.) – Honda MCHP (2")	90 ft.

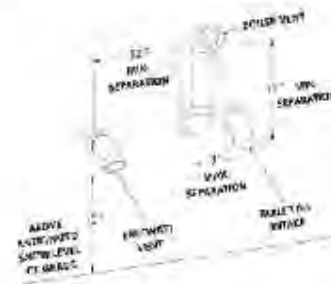
Model Freewall-1.21021N
Control Module Details



Model Freewall-1.21021N
Typical Roof Vent/intake Terminations

Consult Installation Manuals for more details.

Model Freewall-1.21021N
Typical Sidewall Vent/intake Terminations



Consult Installation Manuals for more details.

Model Freewall-1.21021N
Grid Interconnection

The grid interconnection of the Honda MCHP unit is required to operate the system. Depending on the state's regulations and the electric utility, different grid interconnection application processes are required. Climate Energy is actively educating state governments and electric utilities about the benefits of Micro-CHP and how the Freewall System can be a critical component in their energy conservation portfolio. If any questions surface during the grid interconnection process, please contact your Climate Energy product technician or Climate Energy at 508-350-4500.



For More Information:
1.508.350.4500

www.climate-energy.com

