BSR/ASHRAE Standard SPC204P

Public Review Draft

Method of Test for Rating Micro Combined Heat and Power Devices

First Public Review (November 2019)
(Draft Shows Complete Proposed New Standard)

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FOREWORD

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1. PURPOSE

The purpose of this standard is to provide a uniform laboratory test method for determining the net electrical power generating performance and thermal power recovery performance of micro combined heat and power devices, referred to as micro-cogeneration devices. The standard specifies the equipment and instrumentation required, test methods, and calculation procedures.

2. SCOPE

This standard provides a comprehensive set of procedures for micro combined heat and power devices whose maximum net electrical power output is less than 50kW and whose maximum useful thermal power output is less than 300kW. The maximum allowable ratio of thermal power output (exclusive of any auxiliary heating equipment) to net electrical power output is 15.

This standard applies to the following stationary micro combined heat and power devices that use, but are not limited to, an internal combustion engine, a turbine, a Stirling engine, or a fuel cell as the heat and power generating source. Only appliances that utilize natural gas, propane, or diesel as the fuel source are covered. Appliances that utilize biofuels or biogases as the fuel source are not covered, but the procedures and methods in this standard are applicable to the evaluation of those appliances. Separate tests are defined for stand-alone devices and devices that are part of a packaged system that includes ancillary heating equipment. These tests cover single stand-alone devices or single devices that are part of a package system. Groups of devices operating in parallel are not covered by this standard.

This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices to determine the applicability of regulatory limitations prior to use.

3. Definitions, Abbreviation, Symbols, and Prefixes

3.1 Definitions

Auxiliary electrical energy: external electrical power required to operate the device at design conditions.

Combined heat and power (CHP): the simultaneous generation of electrical and useful thermal power from a single fuel source.

Combustion air: air required to provide for the complete combustion of fuel and usually consisting of primary air, secondary air, and excess air.

Condensing micro heat and power device: a micro heat and power device, which condenses the flue gas and claims the latent heat of vapor as useful heat.

Device: piece of equipment or a mechanism designed to serve a special purpose or to perform a special function.

Duct: a conduit that contains a static and moving fluid. Duct could be used instead of pipe and tubing in this standard.

Electric current: movement or flow of charge in an electrical circuit, measured in amperes.

Electrical efficiency: the indication of fuel-to-electricity conversion efficiency of the micro combined heat and power system measured at the test boundary.

Energy: the total energy in watt-hours is the integration of power utilized over the time period of interest.

Flow rate: the mass or volumetric flow of a fluid per unit of time that moves in a duct or conduit.

Gross electrical efficiency: the indication of fuel-to-electricity conversion efficiency of the device that includes internal parasitic losses only.

Heat recovery fluid: the fluid used to transfer thermal energy from the device for useful application to a specific load or system.

Mass flow rate: mass of a gas or liquid fluid moving per unit of time.

Micro-CHP (µCHP): a micro-cogeneration device whose maximum net electrical power output is less than 50kW and whose maximum useful thermal power output is less than 300kW. The maximum allowable ratio of thermal power output (exclusive of any auxiliary heating equipment) to net electrical power output is 15.

Net electrical efficiency: the indication of fuel-to-electricity conversion efficiency of the device defined at the test boundary and accounting for the actual energy required to operate the micro combined heat and power device.

Net thermal efficiency: the indication of fuel-to-heat conversion efficiency of the device defined at the test boundary.

Non-condensing micro heat and power device: a micro heat and power device, which does not condense the flue gas and does not claim the latent heat of vapor as useful heat.

Pressure: reference terminology to both absolute and static pressure.

Relative humidity (rh, RH): (1) ratio of the mole fraction of water vapor to the mole fraction of water vapor saturated at the same temperature and barometric pressure. (2) Ratio of the partial pressure or density of water vapor to the saturation pressure or density, respectively, at the same dry-bulb temperature and barometric pressure of the ambient air.

Resistance temperature detector (RTD)*:* a sensor used to measure temperature. Many RTD elements consist of a length of fine wire wrapped around a ceramic or glass core.

Standard conditions: reference conditions of a fluid at 20°C (68°F) and 101.325 kPa (14.696 psia), also called normal temperature and pressure (abbreviated as NTP) as established by NIST.

Static pressure: the pressure of the fluid at zero velocity.

Temperature: reference terminology to either absolute or total temperature.

Test boundary: encompasses the micro combined heat and power device. Energy performance attributes and calculations require measurements of all energy streams entering and leaving the device test boundary and that all measurements are made at the test boundary.

Thermal efficiency: thermal efficiency is the indication of fuel-to-heat conversion efficiency of the micro combined heat and power system measured at the test boundary.

Thermocouple grid: an array of thermocouples used in in-plane average temperature measurement in duct systems.

Voltage (V): a measurement of the electromotive force or potential developed between separated positive and negative electric charges.

Volumetric flow rate: volume of a gas or liquid fluid moving per unit of time.

3.2 Abbreviations

Table 1. Abbreviations

Abbreviation	Name
AHRI	Air-conditioning, Heating, and Refrigeration Institute
ASTM	American Society for Testing Materials
CHP	Combined heat and power
EPA	Environmental Protection Agency
NIST	National Institute of Standards and Technology

3.3 Symbols

Table 2. Symbols

Symbol	Name	Quantity
A	ampere	electric current
BTU	British thermal unit	heat
C	Celsius	Celsius temperature
c_p	heat recovery fluid specific heat	heat capacity
cfm	cubic feet per minute	volumetric flow
dBA	Decibel	power, acoustic intensity
E_{in}	total electrical energy input	electrical energy
$E_{out - gross}$	gross electrical energy output	electrical energy
$E_{out - net}$	net electrical energy output	electrical energy
F	Fahrenheit	Fahrenheit temperature
ft	feet	length
gpm	gallons per minute	volumetric flow
fpm	feet per minute	volumetric flow
g	gram	mass
h	hour	time
h_{in}	enthalpy of the heat recovery fluid entering the device test boundary	enthalpy
h_{out}	enthalpy of the heat recovery fluid leaving the device test boundary	enthalpy
HHV	higher heating value	heat of combustion
Hz	hertz	periodic frequency
in H_2O	inches of water column	pressure
J	Joule	energy, work, heat
K	Kelvin	thermodynamic temperature
l	Liter	volume
LHV	lower heating value	heat of combustion

m	meter	length
m_{fuel}	mass of fuel	mass
M_w	mass of heat recovery fluid	mass
min	minute	time
mol	mole	amount of substance
Pa	pascal	pressure, stress
P_{in}	electrical power input	power
P_{out}	electrical power output	power
ppm	parts per million	quantity
psia	pound per square inch absolute	pressure
psig	pound per square inch gauge	pressure
q	fuel heating value (mass basis)	heat of combustion
q_v	fuel heating value (volume basis)	heat of combustion
Q_{fuel}	fuel energy input	energy
Q_{out}	total heat recovery output	energy
R	Rankine	Rankine temperature
s	second	time
scfm	standard cubic feet per minute	volume flow
sfpm	standard feet per minute	volume flow
t	time	time
V	volt	potential, electric
$V_{g, std}$	volume of fuel at standard conditions	volume
VAC	volt alternating current	potential, electric
W	watt	power, radiant flux
ΔT	temperature difference	temperature
$\eta_{net\ electrical}$	net electrical efficiency	efficiency (%)
$\eta_{thermal}$	thermal efficiency	efficiency (%)
η_{total}	total efficiency	efficiency (%)

3.4 Prefixes

Table 3. Prefixes

Symbol	Name	Quantity
h	hecto	10^2
k	kilo	10^3
M	mega	10^6
m	milli	10^{-3}
µ	micro	10^{-6}
n	Nano	10^{-9}

4. TEST BOUNDARY

The purpose of the test boundary diagram, shown in **Figure 1**, is to define a consistent basis for calculating micro combined heat and power device performance attributes, such as electrical power generation efficiency and useful thermal power output from recovered heat. Additional test boundary diagrams are in **Informative Appendix C**.

Device. The device is a micro combined heat and power piece of equipment or a mechanism offered by the manufacturer, designed to serve a special purpose or to perform a special function. Two categories of stationary micro combined heat and power devices are covered: unitary and non-unitary.

Unitary - combines the prime mover and auxiliary components (pumps, fans, storage) all in one or a few assemblies for simplified application and installation.

Non-Unitary - The prime mover is a single assembly with auxiliary components (pumps, fans, storage) provided by the site.

Test Boundary. The test boundary encompasses the micro combined heat and power device. Energy performance attributes and calculations require the measurement of all energy streams entering and leaving the test boundary. All measurements are measured at the test boundary.

Common energy streams include:

- Incoming electricity from the electric grid or customer grid
- Outgoing electricity to the electric grid or customer grid
- Incoming fuel connection
- Incoming thermal load
- Outgoing thermal load.

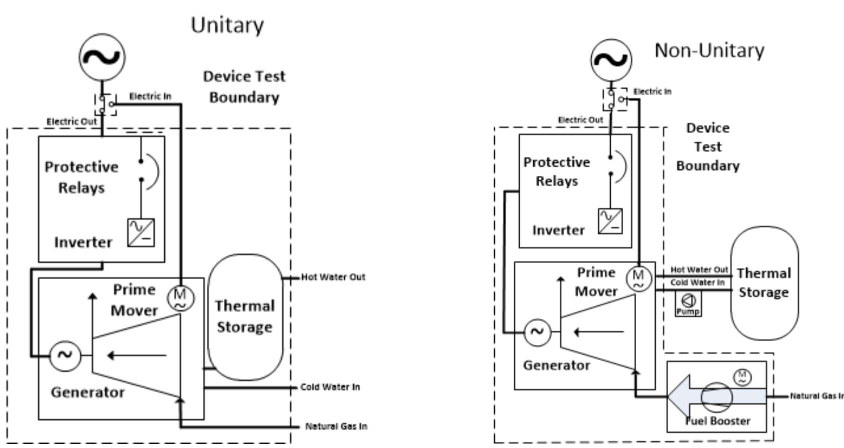

Figure 1. Generic (a) Unitary and (b) Non-Unitary micro-CHP devices with defined test boundaries.

5. DATA COLLECTION

5.1 Instrumentation

The instruments used for testing the micro-CHP device shall comply with the minimum requirements as shown in **Table 4**. These instruments shall be used for referencing standard test conditions, steady state verification, and test calculations.

5.1.1 Calibration

Instruments shall be calibrated to a recognized standard or manufacturer's specifications at regular intervals.

Table 4. Instrumentation

Property Measured	Item Measured	Informative Note: Example of Instrument Type	Minimum Resolution	Minimum Accuracy	Informative Note: Approximate Range of Readings
Pressure	Combustion Air	Barometer	±0.17kPa (±0.05 in. Hg)	±0.34kPa (±0.1in. Hg)	98.2 to 101.2kPa (29 to 30 in. Hg)
	Exhaust gas back pressure	Differential pressure transducer	±0.12kPa (±0.05 in. H_2O)	±0.025kPa (±0.1 inch of water column)	As needed 0 to 2.5kPa (0 to 10 inch of water column)
	Fuel*	Pressure Gauge	±3.45 kPa (±0.5 psig)	±6.9kPa (±1.0 psig)	0 to 482.6kPa (0 to 70 psig)
	Heat recovery fluid (liquid)*	Pressure Gauge	±3.45 kPa (±0.5 psig)	±6.9kPa (±1.0 psig)	0 to 482.6kPa (0 to 70 psig)
Temperature	Exhaust Gas	Thermocouple or RTD	±1 °C (±1.8°F)	±2 °C (±4°F)	-17.9°C to 315.46°C (0 to 600°F)
	Fuel*				-17.8°C to 51.52°C (0 to 125°F)
	Combustion air	Thermocouple grid			-18°C to 52°C (0 to 125°F)
	Heat recovery fluid (liquid)				-18°C to 100°C (0 to 212°F)
Relative Humidity	Combustion air	Hygrometer	±0.10%	±2% of reading	20 to 95%
Flow	Fuel	Positive displacement	Greater of 2 (1 scfm) or ±0.25% of hourly rate	±2% of reading	Sized for Rated Flow
	Heat recovery fluid (liquid)	Insertion turbine	$\pm 0.4 \frac{L}{m}$ (±0.01 gpm)	±2% of reading	Sized for Rated Flow
Heating Values	Fuel	Gas Chromatograph	$5 \frac{KJ}{kg}$ $(2 \frac{BTU}{lbm})$	±2% of reading	$0 \text{ to } 116 \frac{MJ}{kg}$ $(0 \text{ to } 50 \frac{kBTU}{lbm})$

Voltage	Electrical output	Spectrum analyzer and multi-meter	0.1VAC	± 0.5 % of nominal voltage	0 to 480V
Frequency	Electrical output	Spectrum analyzer and multi-meter	0.1Hz	± 0.1 Hz	60Hz
Current	Electrical output	Spectrum analyzer and multi-meter	0.1A	± 0.5 %	0 to 150A
Gross electrical power	Electrical output	Spectrum analyzer and multi-meter	0.1 W to 1 kW	± 1 % of reading	0 to 50 kW
Auxiliary electrical power	Electrical input	Spectrum analyzer and multi-meter	0.1 W to 1 kW	± 1 % of reading	0 to 20 kW

5.2 Measurement

Measurements shall be taken and determined at a maximum interval of five (5) seconds and a minimum data collection period of fifteen (15) minutes at the test boundary.

5.2.1 Pressure

Combustion air. Barometric pressure measurement instruments shall comply with the specifications shown in **Table 4** and be located at the test boundary in a stable environment away from external influences, such as a fan discharge and human activity that effect measurements.

Exhaust Gas Back Pressure. Exhaust backpressure measuring instruments shall comply with the specifications shown in **Table 4**. The instrument shall be installed on exhaust pipe and follow methods described in the **Normative Appendix D**.

Fuel. Maintain the fuel supply pressure in accordance with the manufacturer's specifications. Fuel pressure shall be measured with pressure gauges that comply with the specification shown in **Table 4**. The pressure gauge shall be installed on the fuel line, in line with the flowmeter at the test boundary.

5.2.2 Temperature

Exhaust Gas. Temperature-measuring instruments shall comply with the specifications shown in **Table 4**. The instrument shall be installed on exhaust pipe and follow methods described in the **Normative Appendix D**. The temperature measuring instrument shall be installed at the test boundary.

Combustion Air (Ambient Air). Combustion Air shall be measured at the test boundary and shall be within ±2 °C (±4°F) of the test temperature when recorded over the test period interval.

Fuel. Temperature-measuring instruments shall comply with the specifications shown in **Table 4**. The instrument shall be installed on the fuel line, in-line with the flowmeter at the test boundary.

Heat Recovery Fluid (Liquid). Temperature-measuring instruments shall comply with the specifications shown in **Table 4**. All inlet and outlet fluid temperature measurements shall be made under well-mixed flow conditions. The instruments shall be installed at the test boundary. The inlet temperature instrument shall be installed in line next to the flowmeter.

5.2.3 Relative Humidity

The relative humidity measurement shall be in a stable environment away from external influences, such as a fan discharge and human activity that effect measurements, and at the test boundary. If a relative humidity (RH) transducer is used to measure the relative humidity of the surrounding air, the relative humidity shall be measured with an accuracy of ±2% of the reading.

5.2.4 Flow

Fuel. Either mass or volumetric flow rate method shall be used to determine the fuel flow rate input into the device. The flowmeter shall comply with the specifications shown in **Table 4**, and shall be installed at the test boundary.

Heat Recovery Fluid (Liquid). Either mass or volumetric flow rate method shall be used to determine the fuel flow rate input into the device. The flowmeter shall comply with the specifications shown in **Table 4** and shall be installed and measured at the test boundary.

5.2.5 Heating Value

Gaseous Fuel. Higher heating values for gaseous fuel shall be measured by in-line/at-line periodic sampling using a chromatograph or calorimeter and analyzing each sample individually for heating value. The analysis of gaseous fuels, either by in-line or at-line sampling, shall be done in accordance with one or more of the following methods: ASTM D 1826-94 (1998), Standard Test Method for Calorific (Heating) Value of Gases in Natural Gas Range by Continuous Recording Calorimeter; ASTM D3588-98, Standard Practice for Calculating Heat Value, Compressibility Factor, and Relative Density of Gaseous Fuels; ASTM D 7314-10, Standard Practice for Determination of the Heating Value of Gaseous Fuels using Calorimetry and On-line/At-line Sampling; ASTM D7164 – 10, Standard Practice for On-line/At-line Heating Value Determination of Gaseous Fuels by Gas Chromatography; or ASTM D1945 - 03(2010), Standard Test Method for Analysis of Natural Gas by Gas Chromatography. A method for calculating and presenting heating values of a fuel mixture is presented in Appendix C. The heating value of a fuel shall comply with the specifications shown in **Table 4**.

Liquid Fuel. Higher heating values for liquid fuels shall be determined by calorimeter in accordance with *ASTM D240 – 09, Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter* and shall comply with the specifications shown in **Table 4**.

5.2.6 Electrical Measurements

Testing will determine electrical parameters (frequency, voltage, and current) of the micro-CHP device. The electrical measurement device shall be located at the device test boundary. When multiple meters are used to measure the total external product parasitic load, the calculated combined accuracy and resolution must remain within limits stated in **Table 4**.

6. TEST PROCEDURES

6.1 Installation

The device shall be installed and operated in accordance with the manufacturer's instructions unless specifically required otherwise by the test method. The device shall be equipped with the instrumentation and measurement methods described in **Chapter 5**.

6.2 Test Setup Requirements

Pre-Test Verification of Steady State Conditions. Prior to data sampling, it shall be verified that device is at steady state operation for test conditions and variables. Steady-state operation is established and verified by three (3) successive readings at the beginning, midpoint, and end of a fifteen (15) minute period where the exhaust gas temperature does not deviate by more than 2.7°C (5°F) and heat recovery fluid outlet temperature does not deviate by more than 2.7°C (5°F).

Data Sampling Rate and Test Run Data Collection Duration. A data acquisition system shall be used to record all data continuously throughout the data collection period. A maximum data sample interval of five (5) seconds and minimum data collection period of fifteen (15) minutes shall be used for each test run. Fuel heating value measurements shall be made per day of testing. As a minimum, the data acquisition system shall allow for determination of the maximum, minimum, and average values during the data collection period.

Measurements. After steady state is achieved and the data acquisition system has been engaged, measure the device's operating parameters and performance. Each parameter recorded during a test run shall not vary from the computed average for that operating condition during the entire run by more than the maximum permissible deviations shown in **Table 5**. If any specified measured value exceeds the maximum permissible deviation from the computed average during a test run, that test run shall be repeated.

Table 5. Required Measurements for Testing

Item Measured	Property Measured	Units	Maximum Permissible Deviation During Steady State Test Period
Combustion Air	Barometric pressure,	kPa (in. Hg)	±10%
	Relative Humidity	%	±10%
	Temperature	°C (°F)	±2.7°C (±5°F)
Fuel	Pressure	kPa (psig)	±0.025 kPa (±0.036 psig)
	Temperature	°C (°F)	±2.7°C (±5°F)
	Higher heating value	$\frac{MJ}{kg}\left(\frac{kBTU}{lbm}\right)$	$\pm 1\ \frac{MJ}{kg}\left(\pm 0.4\ \frac{kBTU}{lbm}\right)$
	Flow rate *	Nm³/h (scfm)	±0.2% of nominal value
Exhaust Gas	Backpressure	kPa (psig)	±2.5kPa (±0.36 psig)
	Temperature	°C (°F)	±2.7°C (±5°F)
Heat Recovery Fluid (Liquid)	Temperature	°C (°F)	±2.7°C (±5°F)
	Volumetric flow rate	$\frac{L}{m}\ (gpm)$	±0.2% of nominal value
Electrical Output	Voltage	V	±0.5% of reading
	Frequency	Hz	±0.5% of reading
	Current	A	±0.5% of reading
	Auxiliary electrical power	kW	±0.4% of reading
	Gross electrical power	kW	±0.4% of reading

Electrical Output Production and Power Quality Determination. Testing will determine the quantity of electrical output voltage. Testing will verify that the output voltage shall be within 0.5% of the nominal output voltage rating and that the frequency shall be within 0.5% of nominal output frequency rating when the device has resistive loads of 50%, 75%, and 100%.

Thermal Energy Production Determination. Testing shall verify thermal energy output by varying heat recovery fluid inlet temperature at maximum, mid-range, and minimum of the manufacturer's specified range at test conditions and 100% electric resistive loading.

Post-Test Verification of Steady State Conditions. At completion of each test run, it shall be verified that steady-state operations was maintained throughout the test. If the stability criteria were not satisfied throughout the entire test run, the test shall be repeated. The instrument calibrations shall be verified. If the instrument has failed to its calibration cycle, the test shall be repeated with a calibrated instrument.

6.3 Tests

Tests shall be conducted under the fixed conditions specified in **Table 6** and variable conditions specified in **Table 7**. Deviations from the specified testing conditions, such as operating at electrical output of 74% rather than a specified nominal 75% rated output, or combustion air temperature of 15°C (59°F) rather than a specified nominal 15°C (59°F), shall be documented in the test report.

Table 6. Fixed Parameters During Testing

Parameter	Setting
Fuel supply pressure	Within the manufacturer specified range
Exhaust duct backpressure	Within the manufacturer specified range
Combustion air relative humidity	Within manufacturer specified range
Heat recovery fluid flow rate	Manufacturer specified or controlled

Table 7. Variable Test Conditions

Tests Number	Combustion Air Temperature	Electric Load Output	Heat Recovery Fluid Inlet Temperature
1	15°C (59°F)	100 %	Manufacturer Specified Minimum
2	15°C (59°F)	100%	Manufacturer Specified Mid-Range
3	15°C (59°F)	100%	Manufacturer Specified Maximum
4	15°C (59°F)	75 %	Manufacturer Specified Maximum
5	15°C (59°F)	50 %	Manufacturer Specified Maximum
6	35°C (95°F)	100 %	Manufacturer Specified Maximum
7	35°C (95°F)	75 %	Manufacturer Specified Maximum
8	35°C (95°F)	50 %	Manufacturer Specified Maximum
9	35°C (95°F)	100 %	Manufacturer Specified Mid-Range
10	35°C (95°F)	100 %	Manufacturer Specified Minimum
11	4.4°C (40°F)	100 %	Manufacturer Specified Minimum
12	4.4°C (40°F)	100 %	Manufacturer Specified Mid-Range
13	4.4°C (40°F)	100 %	Manufacturer Specified Maximum
14	4.4°C (40°F)	75 %	Manufacturer Specified Maximum
15	4.4°C (40°F)	50 %	Manufacturer Specified Maximum

7. CALCULATIONS

This section provides a consistent means of calculating the device's performance attributes based on laboratory testing and data collection methods. The methods used in calculating certain parameters, such as electrical efficiency and thermal output, will depend on the type of measurement equipment used during testing.

All results shall be calculated based on the higher heating value (HHV) of the fuel. All mandatory results shall be calculated with measurements made at the Test Boundary. Lower heating value (LHV) may be used to calculate additional informative results, if desired.

7.1. Efficiency

7.1.1. Total Efficiency

According to the first law of thermodynamics, the total efficiency is the sum of the ratios of the net electrical efficiency and the net heat recovery efficiency. Total efficiency is calculated by the following equation:

Equation 1. Total Efficiency

$$\eta_{\text{total}} = \eta_{\text{net electrical}} + \eta_{\text{net thermal}} \qquad (1)$$

Where:

η_{total} = total efficiency, (%)
$\eta_{\text{net electrical}}$ = net electrical efficiency, (%)
$\eta_{\text{net thermal}}$ = thermal efficiency, (%)

7.1.2. Net Electrical Efficiency

Net electrical efficiency is calculated by the following equation:

Equation 2a. Net Electrical Efficiency (SI units)

$$\eta_{\text{net electrical}} = \left(\frac{E_{net}}{Q_{fuel}}\right) * 100 \qquad (2a)$$

Where:

$\eta_{\text{net electrical}}$ = net electrical efficiency, (%)
E_{net} = net electrical energy output for the test duration, (kW·h)
Q_{fuel} = total fuel energy into the system for the test duration, (kW·h)

Equation 2b. Net Electrical Efficiency (imperial units)

$$\eta_{\text{net electrical}} = \left(\frac{E_{net} * 3412.14}{Q_{fuel}}\right) * 100 \qquad (2b)$$

Where:

$\eta_{\text{net electrical}}$ = net electrical efficiency, (%)
E_{net} = net electrical energy output for the test duration, (kW·h)
Q_{fuel} = total fuel energy into the system for the test duration, (BTU)
3412.14 = conversion factor (kW·h to BTU)

7.1.3. Heat Recovery Efficiency

Useful heat recovery efficiency is the ratio of the total usable energy in the form of heat to the total energy input.

Equation 3a. Heat Recovery Efficiency (SI units)

$$\eta_{\boldsymbol{net}\ \boldsymbol{t}\text{hermal}} = \left(\frac{Q_{out}}{Q_{fuel}}\right) * 100 \qquad (3a)$$

Where:

$\eta_{\text{net thermal}}$ = thermal efficiency, (%)
Q_{out} = total heat recovery output, (kW·h)

Q_{fuel} = total fuel energy into the system, (kW·h)

Equation 3b. Heat Recovery Efficiency (imperial units)

$$\eta_{\text{net thermal}} = \left(\frac{Q_{out}}{Q_{fuel}}\right) * 100 \quad (3b)$$

Where:

$\eta_{\text{net thermal}}$ = thermal efficiency, (%)
Q_{out} = total usable heat recovery output, (BTU)
Q_{fuel} = total fuel energy into the system, (BTU)

7.2. Fuel Energy Input

7.2.1 Fuel Chemical Energy Input

Fuel chemical energy input shall be calculated based on HHVs. The LHV may be used to calculate additional informative results.

The following basic equations are used to calculate the energy input utilizing the appropriate calculation methods depending on the fuel type and measurement equipment:

Equation 4a. Fuel Chemical Energy Input, Mass Basis (SI units)

$$Q_{fuel} = \frac{q * m_{fuel}}{3.6} \quad (4a)$$

Where:

Q_{fuel} = fuel energy input, (kW·h)
q = fuel heating value (HHV or LHV if additional informative results are calculated), $\left(\frac{MJ}{kg}\right)$
m_{fuel}= mass of fuel, (kg)
3.6 = conversion factor (MJ to kW·h)

Equation 4b. Fuel Chemical Energy Input, Mass Basis (imperial units)

$$Q_{fuel} = q \cdot m_{fuel} \quad (4b)$$

Where:

Q_{fuel} = fuel energy input, (Btu)
q = fuel heating value (HHV or LHV if additional informative results are calculated), $\left(\frac{BTU}{lb}\right)$
m_{fuel} = mass of fuel, (lb)

Equation 5a. Fuel Chemical Energy Input, Volume Basis (SI units)

$$Q_{fuel} = \frac{q_v \cdot V_{g,std}}{3.6} \quad (5a)$$

Where:

Q_{fuel} = fuel energy input, (kW·h)
q_v = fuel heating value (HHV or LHV if additional informative results are calculated), $\left(\frac{MJ}{m^3}\right)$ or $\left(\frac{MJ}{L}\text{ for liquid fuel}\right)$

$V_{g,std}$ = volume of fuel at standard conditions[1], (m^3) or (l for liquid fuel)
3.6 = conversion factor (MJ to kW·h)

Equation 5b. Fuel Chemical Energy Input, Volume Basis (imperial units)

$$Q_{fuel} = q_v \cdot V_{g,std} \qquad (5b)$$

Where:

Q_{fuel} = fuel energy input, (BTU)
q_v = fuel heating value (HHV or LHV if additional informative results are calculated) $\left(\frac{BTU}{ft^3}\right)$ or $\left(\frac{BTU}{\text{gal}}\text{for liquid fuel}\right)$
$V_{g,std}$ = volume of fuel at standard conditions[2], (ft^3) or (gal for liquid fuel)

7.3. Fuel Heating Value

7.3.1. Gaseous Fuels

See Section 5.2.5 for Gaseous fuel - Heating Value measurement requirements.

7.3.2. Liquid Fuels

See Section 5.2.5 for Liquid fuel - Heating Value measurement requirements.

7.4. Electrical Energy Output

Electrical energy output shall be calculated and reported based on the real power indication (electrical energy output) as measured at the device test boundary.

7.4.1. Gross Electrical Energy Output

Gross electrical energy output shall be based on direct measurement taken during testing at the device test boundary.

The gross electrical energy output measured over the test duration shall be obtained by integrating the electrical power output measurements over the test run period:

Equation 6. Gross Electrical Energy Output

$$E_{gross} = \int_{t_1}^{t_2} P_{out}(t)d(t) \qquad (6)$$

Where:

E_{gross} = gross electrical energy output: integral sum of all electrical energy outputs from the Device for the duration of the test period, (kW·h)
$P_{out}(t)$ = electrical power output at time t_i (kW)
$d(t)$ = time interval, $t_n - t_0$

7.4.2. Net Electrical Energy Output

The net electrical energy output shall be calculated based on the gross electrical energy output of the system, less the total electric energy input measured at the device test boundary over the test duration. The net electrical energy produced is given by:

[1] See Section 3.1 for an explanation of standard conditions
[2] See Section 3.1 for an explanation of standard conditions

Equation 7. Net Electrical Energy Output

$$E_{net} = E_{gross} - E_{in} \quad (7)$$

Where:

E_{net} = net electrical energy output for the test duration, (kW·h)
E_{gross} = gross electrical energy output measured over the test duration, (kW·h)
E_{in}= total electrical energy input over the test duration, (kW·h)

7.4.3. Total Electrical Energy Input

Total electrical energy input shall be based on direct measurement taken during testing at the device test boundary.

The total electrical energy input measured over the test duration shall be obtained by integrating the electrical power input measurements over the test run period:

Equation 8. Total Electrical Energy Input

$$E_{in} = \int_{t_0}^{t_n} P_{in}(t)d(t) \quad (8)$$

Where:

E_{in} = total electrical energy input: integral sum of all electrical energy inputs supplied to the device for the duration of the test period, (kW·h)
$P_{in}(t)$ = electrical power input at time t_i (kW)
d(t) = time interval, t_n - t_o

7.5. Heat Recovery Output

Heat recovery output shall be calculated using either specific heat or specific enthalpy values and measuring heat transfer fluid or mass flow rate(s) and the heat recovery fluid inlet and outlet temperatures or enthalpies at the device test boundary.

7.5.1. Heat Recovery Output from Specific Heat

Heat recovery output (Q_{out}) shall be calculated by applying appropriate specific heat values and densities in the following basic heat transfer equation:

Equation 9. Heat recovery output from Specific Heat (SI units)

$$Q_{out} = \frac{\sum M_w \bullet c_p \bullet \Delta T}{3600} \quad (9)$$

Where:

Q_{out} = total heat recovery output summed over all heat recovery fluid streams, (kW·h)
M_w = total mass of heat transfer fluid circulating through the device test boundary during the test period, (kg)
c_p = heat recovery fluid specific heat at the average operating temperature, $\left(\frac{kJ}{\text{kg} \cdot °\text{C}} \text{for liquid fuel}\right)$
ΔT = difference between outlet and inlet temperatures of the heat transfer fluid , (°C)
3600 = conversion factor (kJ to kW·h)

Equation 10. Heat recovery output from Specific Heat (imperial units)

$$Q_{out} = \sum M_w \bullet c_p \bullet \Delta T \quad (10)$$

Where:

Q_{out} = total heat recovery output summed over all heat recovery fluid streams, (BTU)
M_w = total mass of heat transfer fluid circulating through the device test boundary during the test period, (lb)
c_p = heat recovery fluid specific heat at the average operating temperature , $\left(\frac{BTU}{lb \cdot °F}\right)$
ΔT = difference between outlet and inlet temperatures of the heat transfer fluid, (°F)

7.5.2. Heat Recovery Output from Specific Enthalpy

Equation 11a. Heat recovery Output using Specific Enthalpy (SI units)

$$Q_{out} = \frac{\sum(h_{out} - h_{in}) \cdot M_w}{3600} \quad (11a)$$

Where:

Q_{out} = total heat recovery output summed over all heat recovery fluid streams, (kW·h)
h_{in} = average enthalpy heat transfer fluid entering the device test boundary during the test period, $\left(\frac{kJ}{kg}\right)$
h_{out} = average enthalpy of heat transfer fluid leaving the device test boundary during the test period, $\left(\frac{kJ}{kg}\right)$
M_w = total mass of heat transfer fluid circulating through the device test boundary during the test period, (kg)
3600 = conversion factor (kJ to kW·h)

Equation 11b. Heat recovery Output from Specific Enthalpy (imperial units)

$$Q_{out} = \sum(h_{out} - h_{in}) \cdot M_w \quad (11b)$$

Where:

Q_{out} = total heat recovery output summed over all heat recovery fluid streams, (BTU)
h_{in} = average enthalpy heat transfer fluid entering the device test boundary during the test period, $\left(\frac{BTU}{lb}\right)$
h_{out} = average enthalpy of heat transfer fluid leaving the device test boundary during the test period, $\left(\frac{BTU}{lb}\right)$
M_w = total mass of heat transfer fluid circulating through the device test boundary during the test period, (lb)

8. REPORTING

Scope. The detailed format of the test report is left to the discretion of the testing organization and the organization sponsoring the testing.

The test report shall include a minimum level of information such that third parties not involved in testing the device will be able to make a fair assessment of the device's performance characteristics. The stability criteria (both parameters and allowable deviation) utilized during testing shall be included as an appendix to the report. The following subsections enumerate the reported parameters.

8.1. Overall Test Information

The test report shall include a description of the test site location and configuration and the detailed boundary document prepared for the specific tests, including all instrument locations. The dates of testing are to be included in the report. The following sections and information shall be included in the report:

1) Name of tester, address, contact information
2) Date of tests
3) Description of testing facility and testing equipment
4) Location of test site (address)
5) City, State
6) Site elevation
7) Type of fuel utilized during testing
8) Manufacturer's published data sheet
9) Equipment tested
    a) Manufacturer name
    b) Prime mover information
        i) Type (reciprocating engine, microturbine, Stirling, etc...)
        ii) Model number
        iii) Serial number
        iv) Rated output
        v) Maximum output
        vi) Operating speed
        vii) Heat recovery energy
            (1) Type (hot water/glycol, steam, other)
            (2) Maximum outlet (supply) temperature
            (3) Nominal output
    c) Heat recovery fluid type (water, glycol, air, other)
10) Electric generator information (if applicable)
    a) Model number
    b) Serial number
    c) Rated output
    d) Maximum output
    e) Nominal voltage
11) Thermal energy recovery/production equipment (if applicable)
    a) Manufacturer
    b) Model number
    c) Serial number
    d) Nameplate rating conditions
    e) Nameplate rated output
12) Controls and protection information (if applicable)
    a) Manufacturer
    b) Model number
    c) Serial number

13) System testing description, including:
    a) Written description of device tested
    b) Detailed drawing(s) of laboratory and test configuration indicating:
        i) Test boundary
        ii) Incoming electricity from the electric grid or customer grid
        iii) Outgoing electricity to the electric grid or customer grid
        iv) Incoming fuel connection
        v) Incoming thermal load
        vi) Outgoing thermal load
        vii) Instrumentation locations for measurements
14) Parasitic loads list indicating all internal and external loads used in calculating and reporting of electrical output and efficiency.

9. REFERENCES

1. *ASTM D 1826-94 (1998), Standard Test Method for Calorific (Heating) Value of Gases in Natural Gas Range by Continuous Recording Calorimeter.*
2. *ASTM D 1945 gives the results in the type and amount of gaseous constituents to calculate heating value.*
3. *ASTM D 3588-98, Standard Practice for Calculating Heat Value, Compressibility Factor, and Relative Density of Gaseous Fuels.*
4. *ASTM D 7314-10 Standard Practice for Determination of the Heating Value of Gaseous Fuels using Calorimetry and On-line/At-line Sampling.*
5. *ASHRAE Standard 41.1-2013* -- *Standard Method for Temperature Measurement.*
6. *2013 ASHRAE Handbook—Fundamentals*, Chapter 6, Table 3-2.

INFORMATIVE ANNEX A – BIBLIOGRAPHY

ASERTTI. 2008. *Distributed Generation and Combined Heat and Power Laboratory Testing Protocol,* Association of State Energy Research and Technology Transfer Institutions.

ASHRAE. 2013. *SI Guide for HVAC*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 1791 Tullie Circle, NE, Atlanta, GA 30329.

ASHRAE. 2016. *CHAPTER 7 COMBINED HEAT AND POWER SYSTEM*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 1791 Tullie Circle, NE, Atlanta, GA 30329.

NORMATIVE APPENDIX B – HEAT OF COMBUSTION, THE HIGHER AND LOWER HEATING VALUE OF FUELS

Lower Heating Value (LHV) is the heat of combustion of the fuel. Energy in the latent heat of vaporization of water in the combustion products is not released as heat. LHV is useful in calculating and comparing heating values for fuels where condensation of the reaction products is impractical and not used.

Higher Heating Value (HHV) is the heat of combustion of the fuel and the latent heat of vaporization of water in the combustion products. HHV is useful in calculating and comparing heating values for fuels where condensation of the reaction products is practical and used.

Calculations used HHV in the ASHRAE SPC 204, Method of Test for Rating Micro Combined Heat and Power Devices Standard for the following considerations:

- Competing Product Standards Use HHV: In the United States and Canada, the standards for products against which micro-CHP devices will compete (residential and commercial space and water heating appliances) use HHV as a basis for calculating efficiency.
- HHV Provides a Better Comparison: The purpose of this standard is to enable an equitable comparison between various micro-CHP devices. While the efficiency of a non-condensing micro-CHP device may be based upon LHV or HHV, it is improper to base a condensing micro-CHP device's efficiency on the LHV (resulting in efficiencies greater than 100%).
- Market is Largely for Condensing Units: Very few micro-CHP devices provide cooling, and therefore, the primary market for micro-CHP devices is colder climates with larger heating demands. In these regions, the marketplace is rapidly moving toward a condensing-furnace only standard.
- Most Applications Support Condensing Units: With dew point temperatures of typical combustion by-products between 49 °C (120 °F) and 54 °C (130 °F), the heat sink for most applications can support condensation.
- Condensing Micro-CHP Devices Will Be Common: At the time of the draft standard, the majority of micro-CHP devices under development or near commercialization for the North American residential and commercial market were condensing units.

Relating LHV to HHV. **Equation B.1** defines the relationship between LHV and HHV.

$$LHV = HHV - H_v\left(\frac{n_{H_2O,out}}{n_{fuel,in}}\right) \quad \text{(B.1)}$$

Where:

LHV = lower heating value of the fuel, $\frac{kJ}{kg}\left(\frac{BTU}{lbm}\right)$

HHV = higher heating value of the fuel, $\frac{kJ}{kg}\left(\frac{BTU}{lbm}\right)$

H_v = the heat of vaporization of water, $\frac{kJ}{kg}\left(\frac{BTU}{lbm}\right)$

$n_{H_20,out}$ = number moles of water vaporized

$n_{fuel,in}$ = number of moles of water combusted

The analysis of gaseous fuels, either by in-line or at-line sampling, shall be done in accordance with one or more of the following methods: *ASTM D 1826-94 (1998), Standard Test Method for Calorific (Heating) Value of Gases in Natural Gas Range by Continuous Recording Calorimeter; ASTM D3588-98, Standard Practice for Calculating Heat Value, Compressibility Factor, and Relative Density of Gaseous Fuels; ASTM D 7314-10, Standard Practice for Determination of the Heating Value of Gaseous Fuels using Calorimetry and On-line/At-line Sampling; ASTM D7164 – 10, Standard Practice for On-line/At-line Heating Value Determination of Gaseous Fuels by Gas Chromatography; or ASTM D1945 - 03(2010), Standard Test Method for Analysis of Natural Gas by Gas Chromatography*.

Heating Values of Fuel Mixture Species. Examples of HHV and LHV of species in fuel mixtures are shown in **Table B.1**. The fuel mixture HHV and LHV shall be calculated using **Equations B.2a** and **B.2b,** respectively:

$$LHV_f = \sum_{i=1}^{N} LHV_i \cdot x_i \quad \text{(B.2a)}$$

$$HHV_f = \sum_{i=1}^{N} HHV_i \cdot x_i \quad \text{(B.2b)}$$

Where:

x_i = mole fraction of fuel component *i*

N = number of components in the sample size

LHV_i = lower heating value of the fuel of component *y*, $\frac{kJ}{kg}\left(\frac{BTU}{lbm}\right)$

LHV_f = lower heating value of the fuel mixture, $\frac{kJ}{kg}\left(\frac{BTU}{lbm}\right)$

HHV_i = higher heating value of the fuel of component *y*, $\frac{kJ}{kg}\left(\frac{BTU}{lbm}\right)$

HHV_f = higher heating value of the fuel mixture, $\frac{kJ}{kg}\left(\frac{BTU}{lbm}\right)$

Table B.1 Properties of Natural Gas Components

Species	Molecular Weight	Higher Heating Value**		Lower Heating Value**	
		$\frac{BTU}{lbm}$	$\frac{kJ}{kg}$	$\frac{BTU}{lbm}$	$\frac{kJ}{kg}$
Methane	16.043	23,891	(55,568)	21,511	(50,032)
Ethane	30.07	22,333	(51,944)	20,429	(47,516)
Propane	44.097	21,653	(50,362)	19,992	(46,499)
Isobutane	58.123	21,232	(49,383)	19,590	(45,564)
n-Butane	58.123	21,300	(49,541)	19,658	(45,722)
Isopentane	72.15	21,085	(49,041)	19,456	(45,252)
n-Pentane	72.15	21,043	(48,944)	19,481	(45,311)
Neopentane	72.15	20,958	(48,746)	19,371	(45,055)
C6+*	86.177	20,943	(48,711)	19,393	(45,106)
Nitrogen	28.013	0	(0)	0	(0)
Carbon Dioxide	44.01	0	(0)	0	(0)

* C6+ is a grouping for hexanes, heptanes, octanes, and heavier compounds that are present in trace amounts. For purposes of calculating the heating value of the fuel, the C6+ values are based on the properties of 100% Hexane.

** Values are specified at Standard Temperature and Pressure defined in Imperial Units of 60°F (15.5°C) and 14.696psia (1,013.25hPa).

NORMATIVE APPENDIX C - EXAMPLES OF TEST BOUNDARY CONFIGURATION DIAGRAMS

C.1 Unitary Boundary Configurations. Examples of a unitary micro-CHP hot water device (**Figure C.1**) and unitary micro-CHP forced air device test boundaries (**Figure C.2**).

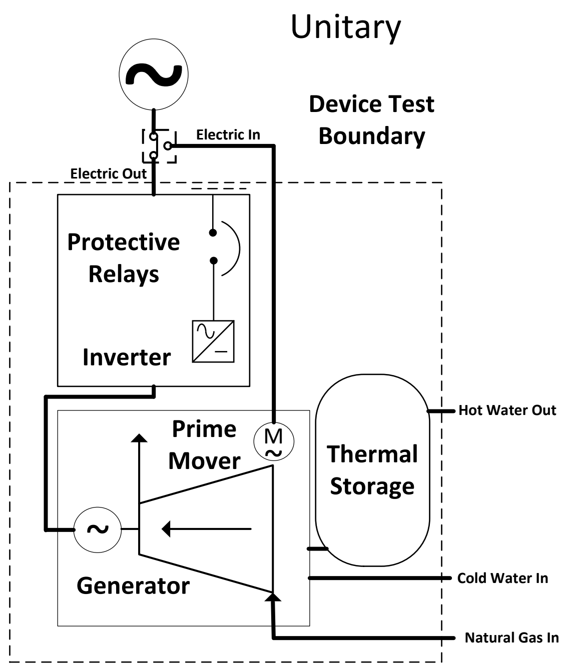

Figure C.1. Generic Unitary micro-CHP hot water device test boundary

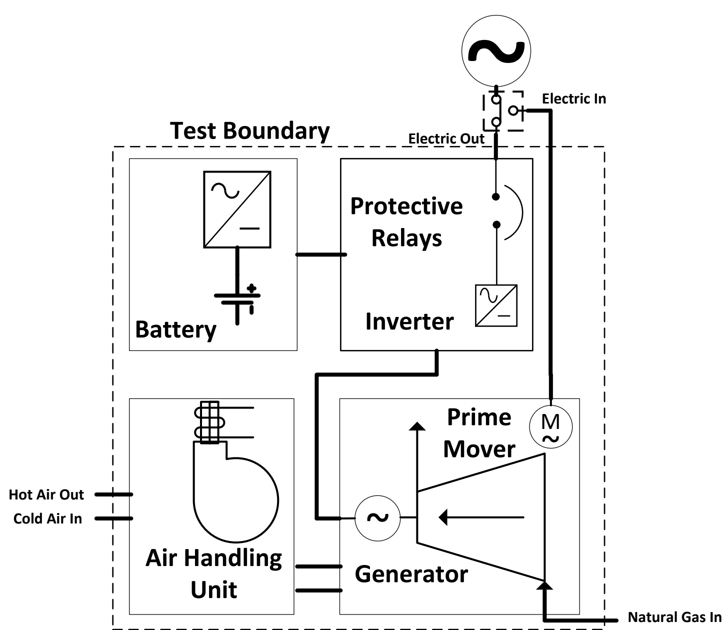

Figure C.2. Generic Unitary micro-CHP forced air device test boundary

C.2 Non-Unitary Boundary Configurations. Examples of non-unitary micro-CHP device test boundaries: Turbine (**Figure C.3**), Fuel Cell (**Figure C.4**), IC Engine (**Figure C.5**), and IC Engine with Batteries for Blackstart (**Figure C.6**).

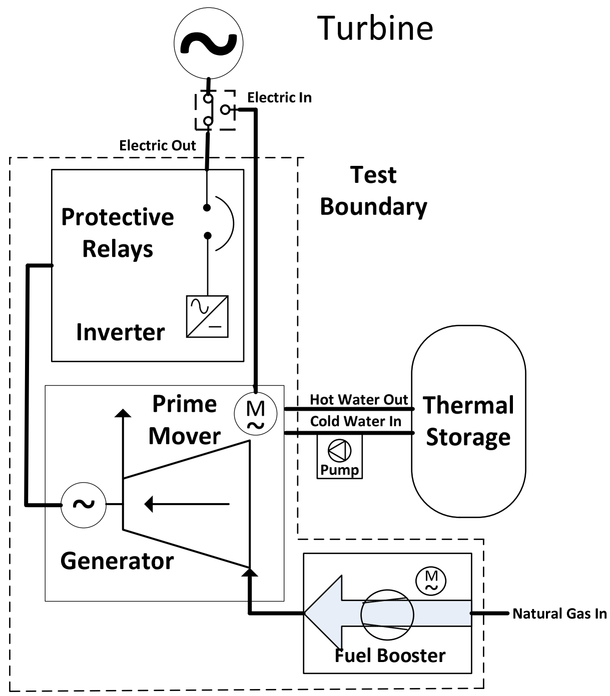

Figure C.3. Turbine Non-Unitary micro-CHP device test boundary

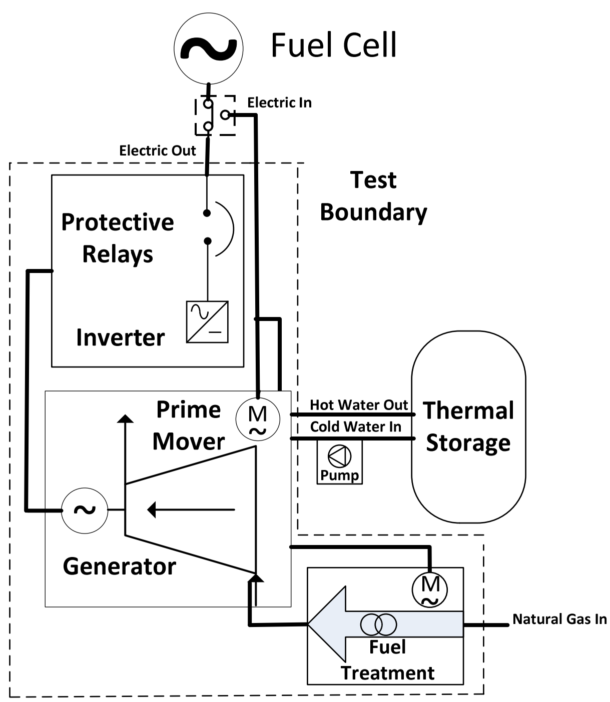

Figure C.4. Fuel Cell Non-Unitary micro-CHP device test boundary

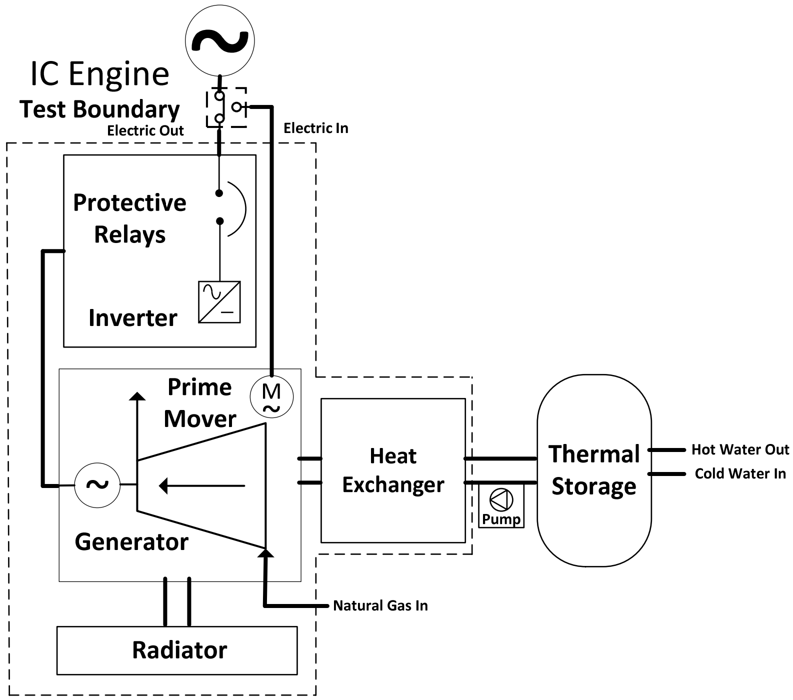

Figure C.5. IC Engine Non-Unitary micro-CHP device test boundary

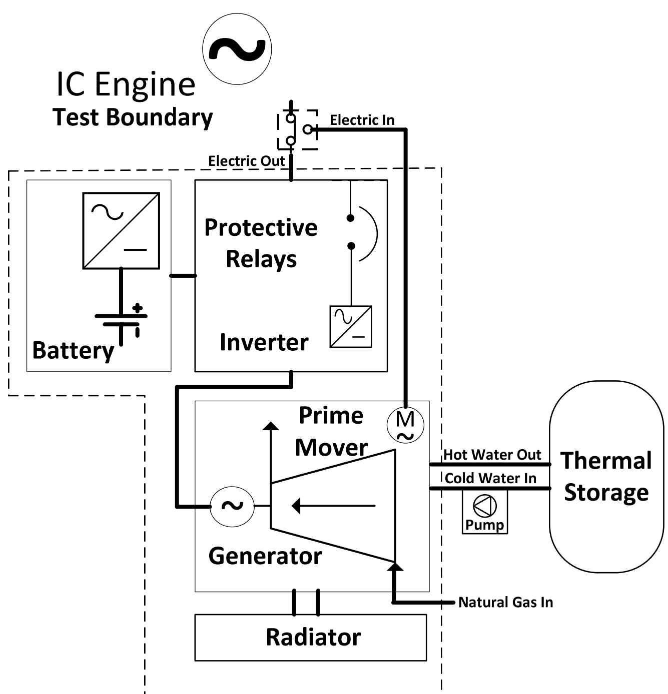

Figure C.6. IC Engine with Blackstart Non-Unitary micro-CHP device test boundary

NORMATIVE APPENDIX D - FLUID MEASUREMENTS AND CALCULATIONS

D.1 Scope. This appendix provides a comprehensive set of measurement methods and calculations for fluid mass, mass flow rate, volumetric flow rate, velocity, density, temperature, and pressure that shall be used in this standard

D.2 Flowmeter. An instrument that measures flow rate of a fluid in a duct.

D.2.1 General. The general terms related to flowmeters implemented in this document are described in the following sections.
D.2.2 Range. The flowmeter range shall be within range of flow rates used in the test procedures.
D.2.3 Pressure Drop. The flowmeter pressure drop shall not exceed the allowable pressure drop defined in the test procedure.

D.2.3.1 Flow Conditioning. Flow conditioners are recommended to reduce the number of straight duct diameters when measuring flow rates. AMCA flow straightener, shown in **Figure D.1**, are commonly used in the industry for airflow measurements.

D.2.3.2 Well-mixed Flow Conditions. Well-mixed flow conditions are ideal for temperature and flow rate measurements. **Figure D.2** shows examples of velocity pressure distribution in a duct and the criteria for acceptable well-mixed conditions.

D.2.3.3 Liquid Mass Flow Rate. A liquid fluid mass flow rate shall be calculated using **Equations D.1a.** or **D.1b.**:

$$\dot{m}_l = \frac{\rho_l \cdot \dot{V}_l}{1000} \quad \text{(D.1a) SI}$$

$$\dot{m}_l = \frac{\rho_l \cdot \dot{V}_l}{(60 \cdot 7.48)} \quad \text{(D.1b) IP}$$

Where:

$\dot{m}_l$ = liquid heat recovery fluid mass flow rate, $\frac{kg}{s}\left(\frac{lbm}{s}\right)$

ρ_l = liquid heat recovery fluid density, $\frac{kg}{\text{m}^3}\left(\frac{lbm}{\text{ft}^3}\right)$

$\dot{V}_l$ = liquid heat recovery fluid volumetric flow rate, $\frac{L}{\text{s}}$ (gpm)

Liquid Volumetric Flow Rate. If a turbine meter is implemented for this measurement, the liquid volumetric flow rate of the heat recovery fluid shall be calculated using **Equations D.2a.** and **D.2b.**:

$$\dot{V}_l = 1{,}000 \cdot A_l \cdot U_l \quad \text{(D.2a) SI}$$

$$\dot{V}_l = 7.48 \cdot A_l \cdot U_l \cdot 60 \quad \text{(D.2b) IP}$$

Where:

$\dot{V}_l$ = liquid heat recovery fluid volumetric flow rate, $\frac{L}{\text{s}}$ (gpm)

U_l = liquid heat recovery fluid local velocity, $\frac{m}{\text{s}}\left(\frac{ft}{s}\right)$

A_l = liquid heat recovery fluid duct cross sectional area, m^2 (ft^2)

D. 3 Flow Rate. The flux of a moving fluid measured in both unit mass and volume.

Volumetric Flow Rate. A flow rate measurement in volume per unit of time. All flowmeters measure volumetric flow rates.
Mass Flow Rate. A flow rate measurement in mass per unit of time. Flowmeters with integrated static pressure and temperature sensors can compensate for fluid density, expansibility, and viscosity changes needed to measure mass flow rates.

Mass Flow Calculation. The mass flow rate of the working fluid shall be calculated from the volumetric flow rate and density measurements using **Equation D.3a** or **D.3b**:

$$\dot{m} = \rho \cdot \dot{V} \quad \text{(D.3a) SI}$$

$$\dot{m} = \frac{\rho \cdot \dot{V}}{60} \quad \text{(D.3b) IP}$$

Where:

$\dot{m}$ = mass flow rate, $\frac{kg}{s}$ $\left(\frac{lbm}{s}\right)$

ρ = density, $\frac{kg}{\mathrm{m}^3}$ $\left(\frac{lbm}{\mathrm{ft}^3}\right)$

$\dot{V}$ = volumetric flow rate, $\frac{\mathrm{m}^3}{\mathrm{s}}$ (cfm)

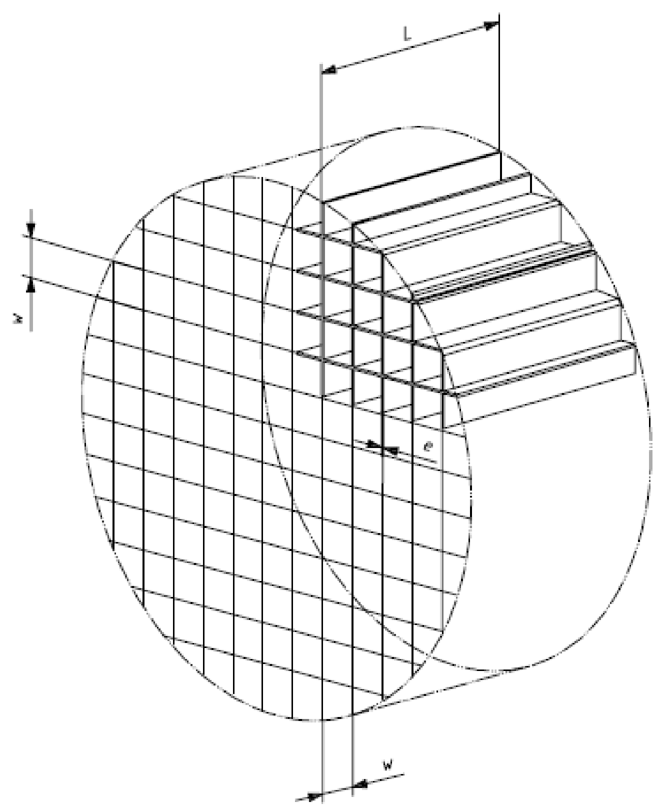

Figure D.1 AMCA flow conditioner.

D.4 Density. The density of a working fluid is calculated from the temperature and/or static pressure measurement at the boundary.

Incompressible Fluids. The density of an incompressible fluid is a function of its temperature only. Therefore, the density of an incompressible fluid shall be calculated from its temperature. For water, the specific volume is listed in the *2013 ASHRAE Handbook – Fundamentals, Chapter 6, Table 3-2 based on water temperature*.

Compressible Fluids. The density of a compressible fluid is a function of its temperature and static pressure and shall be calculated using the ideal gas law Equations D.4a or Equation D.4b:

$$\rho = \frac{p \cdot M}{(R_u \cdot T)} \quad \text{(D.4a) SI}$$

$$\rho = \frac{p \cdot 144 \cdot M}{(R_u \cdot T)} \qquad \text{(D.4b) IP}$$

Where:

ρ = density, $\frac{kg}{m^3}\left(\frac{lbm}{ft^3}\right)$

M = molecular weight, $\frac{kg}{kgmol}\left(\frac{lbm}{lbmol}\right)$

p = absolute pressure, hPa (psia)

T = absolute temperature, K (R)

R_u = universal specific gas constant, $1545.35\,\frac{lbf-ft}{lbmol-R}\left(8.314\,\frac{kJ}{kmol-K}\right)$

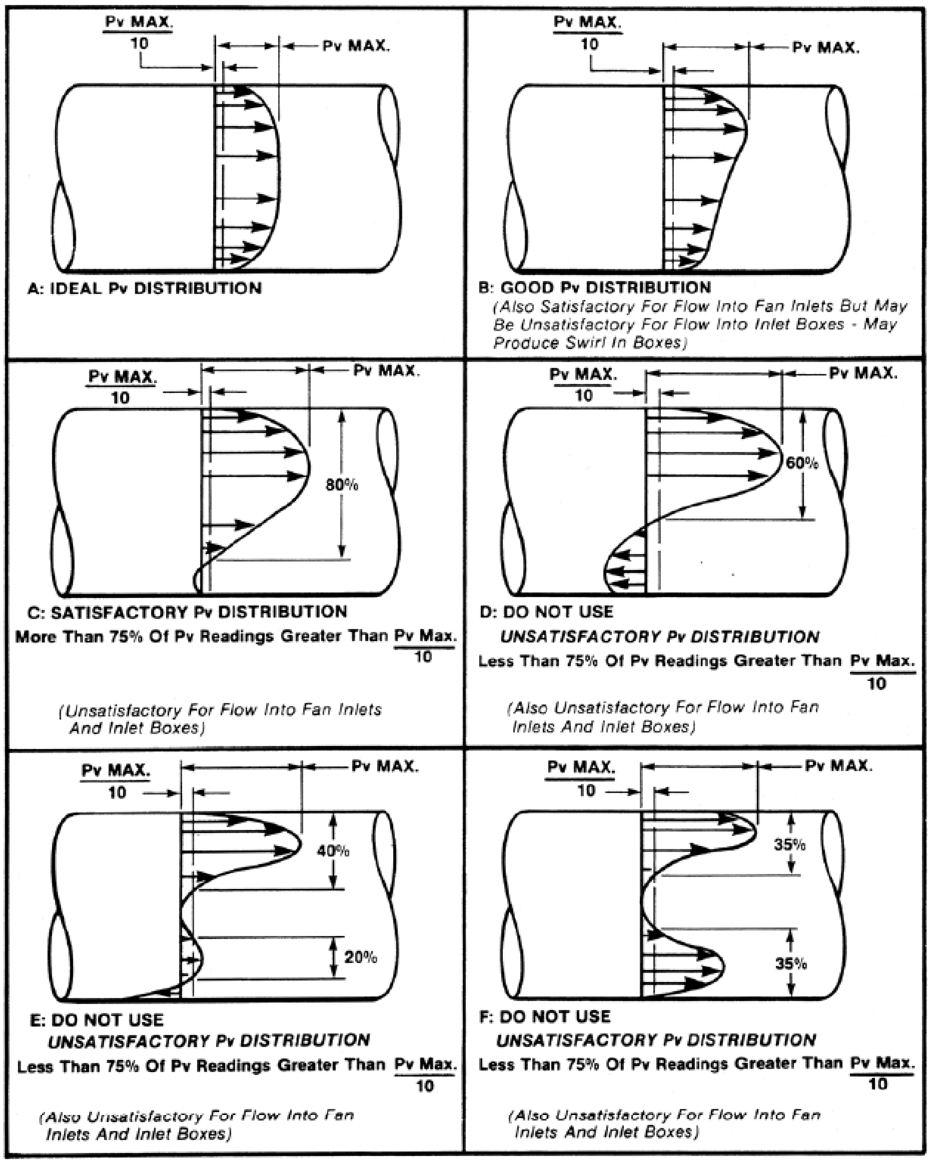

Figure D.2 Velocity pressure distribution examples in a duct.

D.5 Reference Conditions. Volumetric flow rates and velocity shall be reported in standard conditions, standard air conditions being dry air at 20°C (68°F) and 101.325 kPa (14.696 psia). Under these conditions, air has a mass density of 0.075lbm/ft³ (1.204kg/m³).

Actual Volumetric Flow Rate. The actual volumetric flow rate is measured directly from the working fluid at its operating conditions.
Standard Volumetric Flow Rate. The standard volumetric rate shall be determined from the actual volumetric flow rate measurement and standardized working fluid density and shall be calculated using **Equation D.5**:

$$\dot{V}_s = \frac{\dot{V}_a \cdot \rho_a}{\rho_s} \tag{D.5}$$

Where:

ρ_a = actual density, $\frac{lbm}{\mathrm{ft}^3}\left(\frac{kg}{\mathrm{m}^3}\right)$

$\dot{V}_a$ = actual volumetric flow rate, cfm $\left(\frac{\mathrm{m}^3}{\mathrm{s}}\right)$

ρ_s = standard density, $\frac{lbm}{\mathrm{ft}^3}\left(\frac{kg}{\mathrm{m}^3}\right)$

$\dot{V}_s$ = standard volumetric flow rate, cfm $\left(\frac{\mathrm{m}^3}{\mathrm{s}}\right)$

Actual Velocity. The actual velocity is directly measured from the working fluid at its operating conditions.
Standard Velocity. The standard velocity shall be determined from the actual velocity measurement and standardized working fluid density and shall be calculated using **Equation D.6**:

$$U_s = U_a\sqrt{\rho_a/\rho_s} \tag{D.6}$$

Where:

ρ_a = actual density, $\frac{lbm}{\mathrm{ft}^3}\left(\frac{kg}{\mathrm{m}^3}\right)$
U_a = actual velocity, fpm $\left(\frac{\mathrm{m}}{\mathrm{s}}\right)$
ρ_s = standard density, $\frac{lbm}{\mathrm{ft}^3}\left(\frac{kg}{\mathrm{m}^3}\right)$
U_s = standard velocity, fpm $\left(\frac{\mathrm{m}}{\mathrm{s}}\right)$

D.6 Mass. A totalizer is a sensor in flowmeters that measures the total mass circulated into a system boundary. The mass of the fluid shall be determined by total mass flow rated used during a period and calculated using **Equation D.7**:

$$m = \int_{t=0}^{t_\infty} \dot{m}\,(t)dt \tag{D.7}$$

Where:

m = total mass used during the test period, lbm (kg)
$\dot{m}(t)$ = mass flow rate time series during the test period, $\frac{lbm}{\mathrm{s}}\left(\frac{kg}{\mathrm{s}}\right)$
t = time, s
t_∞ = total time of the test period, s

D.7 Temperature

General. Any associated readout instrumentation used for measuring temperature shall be in accordance with *ASHRAE Standard 41.1-2013, Standard Method for Temperature Measurement.*
Temperature. The temperature of a working fluid in a duct shall be measured with a thermocouple grid as shown in **Figure D.3**.

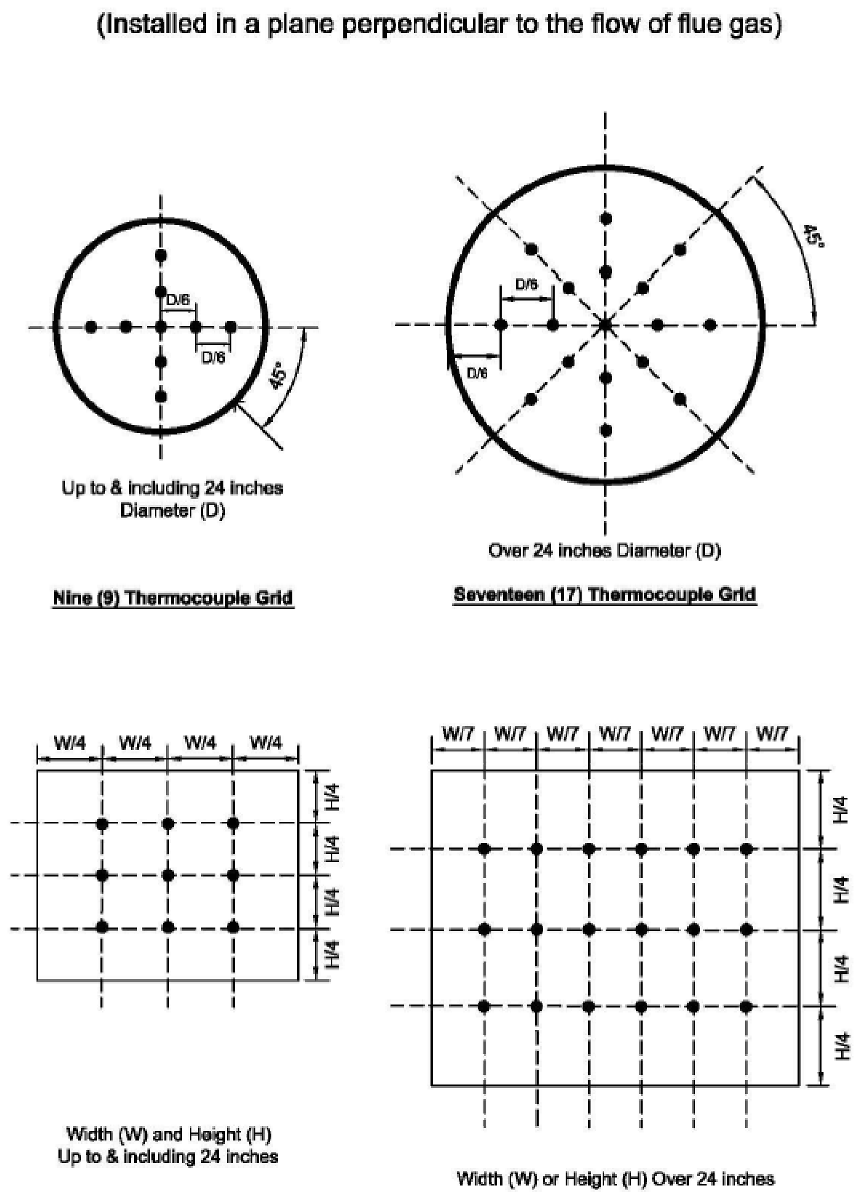

Figure D.3 Thermocouple grid layout.

Absolute Temperature. The absolute temperature is the temperature measurement in units of °C (°F) based upon an absolute scale K (R) and shall be calculated using **Equations D.8a** or **D.8b**:

$$K = °C + 273.15 \quad \text{(D.8a) SI}$$
$$R = °F + 459.75 \quad \text{(D.8b) IP}$$

Where:

K = absolute temperature scale in SI

R = absolute temperature scale in IP

°F = degree temperature scale in IP

°C = degree temperature scale in SI

D.8 Pressure

Gauge Pressure. The gauge pressure is a pressure minus the barometric pressure measurement.
Static Pressure. The static pressure measurement of fluid in a duct shall be performed with four taps as shown in **Figure D.4**. The static pressure measured at each tab shall be connected to a manifold that is connected to the pressure transmitter.
Barometric Pressure. The barometric pressure commonly referred to as ambient air pressure is the measurement of the pressure of the air in the atmosphere.
Absolute Pressure. The absolute pressure measurement of a fluid is a gauged pressure measurement of a working fluid referenced to a preferred vacuum and shall be calculated using **Equation D.9**:

$$p_a = p_0 + p_\infty \tag{D.9}$$

Where:

p_a = absolute pressure, psia (kPa)

p_0 = static pressure, psig (kPa)

p_∞ = barometric pressure, psia (kPa)

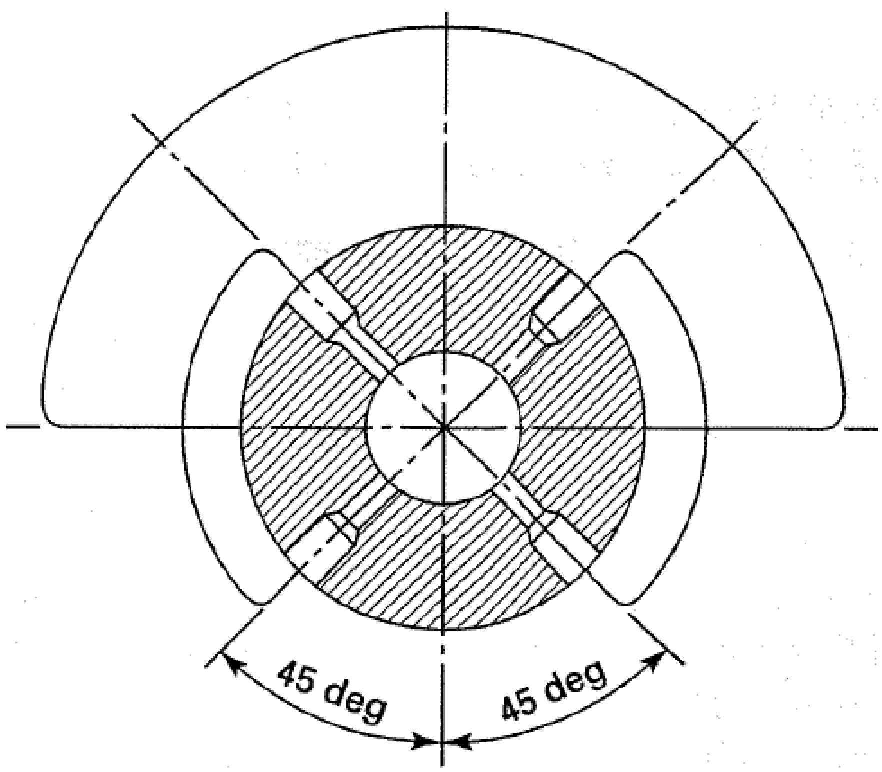

Figure D.4 Static pressure measurement in a circular duct

NORMATIVE APPENDIX E - REPORTS

Data Collection Report. This section shall summarize the data collection and reporting methods used during testing and shall express the compliance with protocol requirements for parameter stability, identified in **Table E.1**.

Electrical Output and Heat Recovery Energy Production Test Report. Table E.1 shall be used to record data taken at test conditions.

Table E.1 Heat Recovery Energy Production Test Results

Date of the test		mm/dd/yyyy	Duration of the test run		
Parameter		Units	Average	Minimum	Maximum
Combustion air	Temperature	°C (°F)			
	Barometric pressure	kPa (in Hg)			
	Relative Humidity	%			
Exhaust gas	Temperature	°C (°F)			
	Backpressure	kPa (In. H_2O)			
Resistive Load		%			
Voltage		V			
Frequency		Hz			
Current		A			
Auxiliary Electrical Energy Input		kW-h			
Gross Electrical Energy Output		kW-h			
Fuel	Static Pressure	kPa (psig)			
	Mass Flow Rate	$\frac{kg}{s}\left(\frac{lbm}{s}\right)$			
Heat Recovery Fluid	Inlet Temperature	°C (°F)			
	Outlet Temperature	°C (°F)			
	Volumetric Flow Rate	$\frac{L}{s}$ (gpm)			
	Specific Heat	$\frac{kJ}{kg-K}\left(\frac{BTU}{lbm-°F}\right)$			
	Density	$\frac{kg}{m^3}\left(\frac{lbm}{ft^3}\right)$			
	Pressure	kPa (psig)			
Gross Electrical Output		kW-h			
Net Electrical Output		kW-h			
Total Energy Input		BTU (kW-h)			
Net Electrical Efficiency		%			
Heat Recovery Efficiency		%			
Total Energy Efficiency		%			
Fuel Heating Value	HHV	$\frac{MJ}{kg}\left(\frac{BTU}{lbm}\right)$			

In addition to **Table E.1**, the following results shall be presented in graphical format:

a. Total energy input with respect to net electrical output operating at:
    i. Maximum heat recovery fluid outlet temperature
    ii. Nominal heat recovery fluid flow rate
b. Total energy input with respect to heat recovery fluid supply temperature operating at:
    i. Rated electrical output
    ii. Nominal heat recovery fluid flow rate
c. Heat with respect to heat recovery fluid flow rate operating at:
    i. Rated electrical output
    ii. Maximum heat recovery fluid outlet temperature.

Summary Performance Test Report. This Summary Performance Report shall provide a summary of performance based on the testing results given in **Table E.1**.

Table E.2 Summary Performance Report

Performance Test Results at [*Temperature Range*] ºC ([*Temperature Range*] ºF)					
Test Report number					
Date					
Prepared by					
Device trade name, capacity					
Type: Unitary or Non-Unitary					
Items		Units	Measured Performance	Manufacturer Specifications	Comments
Electrical Output	Power Output	kW-h			*Example: measured at load-side of transformer*
		kVA			*Example: measured at load-side of transformer*
	Frequency	Hz			*Example: tested at load-side of transformer*
	Voltage	V			*Example: tested at load-side of transformer*
	Current	A			*Example: tested at load-side of transformer*
	Parasitic load	kW			*Example: test results include parasitic load*
Heat recovery fluid	Heat recovery output	kW-h			Note: HHV basis
	Outlet temperature	°C (°F)			*Example: limited by testing to 85.5°C [177.0°F] Maximum*
	Inlet temperature	°C (°F)			*Example: limited by testing to 85.5°C [177.0 °F] Maximum*
	Flow rate	$\frac{L}{s}$ (gpm)			
Fuel	Fuel Consumption	kW $\left(\frac{BTU}{h}\right)$			Note: HHV basis
	Static pressure	hPa (psia)			
Efficiency	Net electrical efficiency	%			*Example: manufacturer result tested at 20°C (68°F)*
	Heat recovery efficiency	%			*Example: manufacturer result tested at 20°C (68°F)*

	Total efficiency		%			*Example: manufacturer result tested at 20°C (68°F)*
Sound level (optional)	Fan off		dB(A)			
	Fan on					
Emissions (optional)	Oxygen		%			*Example: EPA Test Method*
	Carbon Monoxide		$\frac{ng}{J}$ (ppm)			*Example: EPA Test Method*
	Carbon Dioxide		%			*Example: EPA Test Method*
	Nitrogen Oxides	Standard	$\frac{ng}{J}$ (ppm)			*Example: EPA Test Method*
		Corrected				*Example: EPA Test Method*

INFORMATIVE APPENDIX F - CRITERIA POLLUTANT EMISSIONS (OPTIONAL)

Measurement of exhaust emissions is not part of ASHRAE SPC 204, Method of Test for Rating Micro Combined Heat and Power Devices. Some state or local jurisdictions may require a determination and reporting of select criteria pollutant emissions. The key pollutants EPA regulates include nitrogen oxides (NOx), carbon monoxide (CO), and volatile organic compounds (VOC)[3]. The EPA publishes test methods used in determining criteria pollutants[4].

The State of California Air Resources Board (CARB) publishes methods for determining stationary source compliance with District Nonvehicular (Stationary Source) Emission Standards[5]. The methods are similar to the EPA published methods[6] but include modification in determining compliance with local California air pollution control district (APCD) or the air quality management district (AQMD) rules and regulations on certain types of sources.

The following equations are used in calculating emissions (Non-CARB-compliant).
Corrected Gas Concentration

$$C_{gas} = \frac{(C - C_o) * C_{ma}}{(C_m - C_o)}$$

Where:

C_{gas} = Corrected gas concentration, ppm or %
C = Average gas concentration of readings from analyzer, ppm or %
C_o = Average of the initial and final system calibration bias check response for the zero gas, ppm or %
C_m = Average of the initial and final system calibration bias check response for the upscale calibration gas, ppm or %
C_{ma} = Actual concentration of the upscale calibration gas, ppm or %

F Factor

The emission rates of pollutants are determined using an "F" factor calculation specified in US EPA Method 19. This method relies on fuel analysis, oxygen, or carbon monoxide content and fuel flow. The calculation for computing F factor is listed below. Gross calorific value and the weight percents of the fuel are determined by an on-line gas chromatograph.

$$F_{O2,dry} = \frac{106 \cdot [3.64(\%H) + 1.53(\%C) + 0.57(\%S) + 0.14(\%N) - 0.46(\%O)]}{HHV}$$

Where:

%H = hydrogen concentration from natural gas fuel analysis (weight %)
%C = carbon concentration from natural gas fuel analysis (weight %)
%O = oxygen concentration from natural gas fuel analysis (weight %)
%S = sulfur concentration from natural gas fuel analysis (weight %)
%N = carbon concentration from natural gas fuel analysis (weight %)
HHV = higher heating or gross calorific value of fuel, (Btu/lb)

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[3] Federal EPA Title 40, Protection of Environment 40 CFR Part 60 Subpart JJJJ Standards of Performance for Stationary Spark Ignition Internal Combustion Engines
[4] Stationary Source Criteria Pollutant Test Methods, Particularly Methods 1, 2, 3, 4, and 100
[5] California Air Resources Board, "SUPPLEMENT TO STATIONARY SOURCE TEST METHODS, Vol.1, Methods for Determining Compliance with District Nonvehicular (Stationary Source) Emission Standards".
[6] Federal Register: Methods 1 through 9 Promulgated August 18, 1977.

Emission Rates

Emission Rate in Unit of Mass per Unit of Energy $\left(\frac{lb}{106\ BTU}\right)$ can be calculated for the various components by multiplying the measured concentration by the F factor.

$$\mathrm{EH}_i = \frac{(C_{gas}, (lb/scf)\ * FO2, dry\ \ * 20.95)}{(20.95 - \%O2)}$$

Where:

Cgas, $\left(\frac{lb}{scf}\right)$ = Corrected gas concentration, $\left(\frac{lb}{scf}\right)$

FO2, dry = US EPA F factor for oxygen, $\left(\frac{dscf}{106\ BTU}\right)$

% O2 = Measured oxygen concentration of exhaust gas, %

Table F.1 Conversion Factors for Criteria Pollutant Concentrations

From	To	Multiply by
ppm NO2	$\frac{lb}{scf}$	1.194 x 10-7
ppm CO	$\frac{lb}{scf}$	0.726 x 10-7
ppm CH4	$\frac{lb}{scf}$	0.338 x 10-7

Emission rates in mass per unit time $\left(\frac{lb}{h}\right)$ can be calculated by the following equation.

$$m_i = \mathrm{EH}_i\ \cdot\ \mathrm{m}_{fuel}\ \cdot\ \mathrm{HHV}\ \cdot\ 10^{-6}$$

Where:

m_i = mass flow rate of pollutant, $\left(\frac{lb}{h}\right)$

EH_i = Emission rate in unit of mass per unit energy, $\left(\frac{lb}{106\ BTU}\right)$

m_{fuel} = fuel flow rate, $\left(\frac{lb}{h}\right)$

HHV= higher heating or gross calorific value of fuel, $\left(\frac{BTU}{lb}\right)$

INFORMATIVE APPENDIX G - SOUND EMISSIONS (OPTIONAL)

Measurement of sound emissions is not part of ASHRAE SPC 204, Method of Test for Rating Micro Combined Heat and Power Devices. Some state or local jurisdictions may require a determination and reporting of sound emissions. The Air-conditioning, Heating, and Refrigeration Institute (AHRI) publishes test procedures for determining sound power from HVAC equipment[7].

[7] AHRI Standard 230. “Standard for Sound Intensity Testing Procedures for Determining Sound Power of HVAC Equipment, AHRI, 2013.