B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

Engine Generator Block Heater
M&V & Test Plan (Phase 2 Research)

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Measurement and Verification/Test Plan

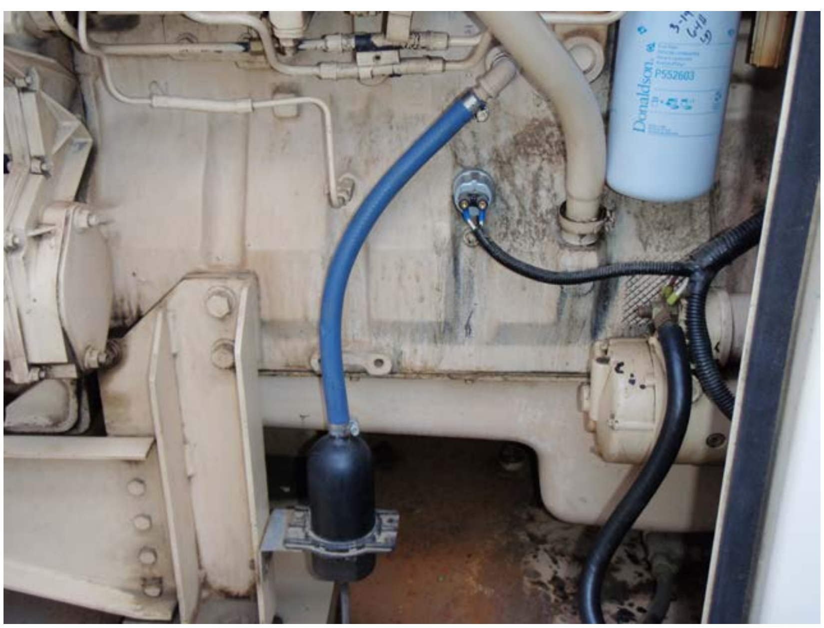
The purpose of this specific M&V/Test Plan was a result of BPA's Phase 1 research with the EGBHs as shown in Table 1.

Table 1: Phase 1 Results

			Piping	
Nominal Heating requirements	Rating (kW)	savings kWh	Good	Bad
NA	3.0 and Under	NA	NA	NA
.5 kW	3.1 to 5.0	NA	NA	NA
	5.1 to 10.0	NA	NA	NA
1 kW	10.1 to 15.0	1003	NA	1003
	15.1 to 30.0	1816	-143	3774
1.5 kW	30.1 to 50.0	433	-341	1207
	50.1 to 150.0	1302	-626	2459
1.8/2/3 kW	150.1 to 250.0	1827	1827	NA
	250.1 to 500.0	-512	-512	NA
3 kW	500.1 to 750.0	8704	8704	NA
6/9 kW	750.1 to 1000.0	16995	11374	33858
9/12 kW	1,000.1 to 2000.0	NA	NA	NA
12 kW	2000.1 to 4000.0	NA	NA	NA

It can be seen that the majority of savings for generators that are less than 500kW and have "good" piping are showing negative savings. These applications used Hotstart's TPS model thermosyphon heater as shown in figure 1.

Figure 1: Hotstart TPS Model Thermosyphon heater



It is hypothesized that the reason for the negative savings under this specific application is that the TPS heater is prematurely turning off and not heating the engine to its required set point.

This document contains the measurement and verification (M&V)/test plan for quantifying the energy usage & savings for retrofitting Hotstart's TPS model heaters with Hotstart's CTM model heaters in generator applications with adequate piping configuration. The location(s) of this testing will be at the following locations:

1. Hotstart's Controlled Atmosphere (CA) Test Chamber

The test method for Hotstart's test chamber will be to test two identical generators concurrently under the same ambient conditions; one with Hotstart's TPS heater and one with Hotstart's CTM heater. These results will be compared as referenced below.

Baseline Development (Hotstart's TPS Heater)

Hotstart's CA Test Chamber

Data collection for the baseline will be collected during the same time as the post-condition as this will be a side by side comparison. It is advantageous to test as many generators as possible but this testing will be limited by Hotstart's ability to obtain identical generator sets. The following parameters will be collected:

1. Spot Power Measurements (spot kW, PF, Volts, Amps)
2. Continuous Power Monitoring (true RMS kW)
3. Outside Air Temperature (°F) – test chamber
4. Engine Generator Block Temperatures (4 to 8 depending on generator size and geometry)

Post Condition Development (Hotstart's CTM Heater)

Hotstart's CA Test Chamber

Data collection for the post-condition will be collected during the same time as the baseline as this will be a side by side comparison. It is advantageous to test as many generators as possible but this testing will be limited by Hotstart's ability to obtain identical generator sets. The following parameters will be collected:

1. Spot Power Measurements (spot kW, PF, Volts, Amps)
2. Continuous Power Monitoring (true RMS kW)
3. Outside Air Temperature (°F) – test chamber
4. Engine Generator Block Temperatures (4 to 8 depending on generator size and geometry)

Energy Savings

Baseline Performance Curve

BPA plans on developing the baseline block heater performance curve with respect to OSA temperature (kWh vs. OSA), which will be simulated by the CA chamber. It is assumed that the primary independent variable in EGBH energy consumption is OSA temperature. This baseline performance curve will be developed thru linear regression techniques and will be based on the following equation:

$$y_{base} = -m_{base}(x) + b_{base}$$

Where,

y_{base} = baseline daily energy at a given ambient temperature

m_{base} = slope of the baseline daily energy regression curve fit model

b_{base} = y-intercept of the baseline daily energy curve fit model

Historical monitoring EGBHs has shown that block heaters can develop full saturation. Full saturation means that the heater is running constantly for long periods of time (or 100% on). This usually happens in cold climates, improper piping arrangements and/or undersized heaters. As a result, it is important to note that the saturation temperature must be calculated prior to normalization. The saturation temperature is thus calculated by the following equation:

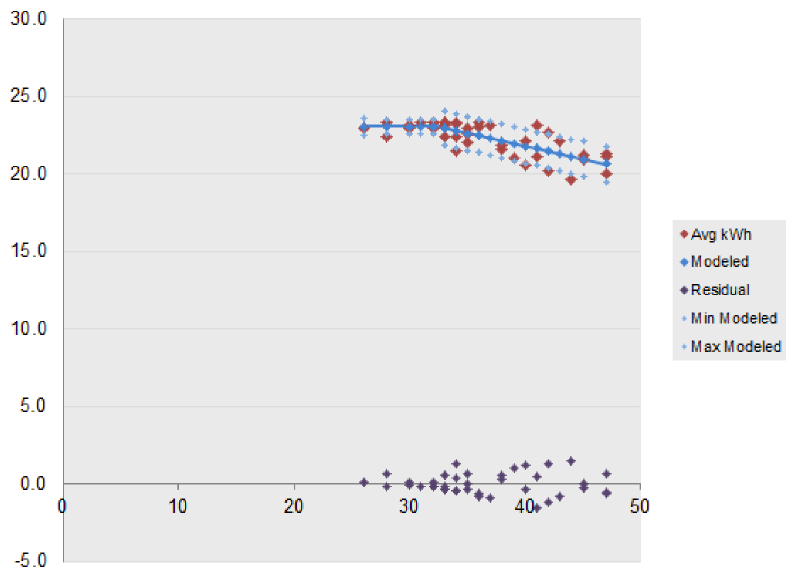
$$x_{base.sat} = \frac{b_{base} - y_{base.full}}{m_{base}}$$

Where,

$x_{base.sat}$ = temperature saturation temperature of baseline heater

$y_{base.full}$ = baseline daily energy usage of the heater's measured power (kW) at 24hrs/day

A graphical representation of this is shown below:



The total annual energy consumption of the baseline heater is calculated with the following equation:

$$kWh_{base} = \sum_{i \le x_{base.sat}} y_{base.full} + \sum_{i > x_{base.sat}, y_{base} \ne 0} - m_{base}(x_i) + b_{base}$$

In addition to energy consumption, engine block temperatures will be monitored, approximately (4-8) locations, with the primary purpose of understanding how well the heater is satisfying the temperature setpoints. If the engine is not being heated to the required setpoint, based on the lowest temperature location, then a non-routine energy adjustment will be made. The equation for the non-routine energy adjustment is calculated by the following:

$$kWh_{base.adj} = \frac{T_{block.adj} - T_{block.actual}}{T_{block.actual} - T_{amb}} (kwh_{actual})$$

Where,

$kWh_{base.adj}$ = the adjusted baseline energy usage above what was actually used

$T_{block.adj}$ = the baseline engine temperature setpoint

$T_{block.actual}$ = the baseline actual engine block temperature

T_{amb} = the ambient temperature (test chamber)

The total baseline annual energy consumption (including non-routine adjustments) is calculated by the following equation:

$$kWh_{total.base} = kWh_{base} + kWh_{base.adj}$$

Proposed Performance Curve

BPA plans on developing the proposed block heater performance curve with respect to OSA temperature (kWh vs. OSA) similar to baseline. It is also assumed that the primary independent variable in EGBH energy consumption is OSA temperature. This proposed performance curve will be developed thru linear regression techniques and will be based on the following equation:

$$y_{proposed} = -m_{proposed}(x) + b_{proposed}$$

Where,

$y_{proposed}$ = proposed daily energy at a given ambient temperature

$m_{proposed}$ = slope of the proposed daily energy regression curve fit model

$b_{proposed}$ = y-intercept of the proposed daily energy curve fit model

Historical monitoring EGBHs has shown that block heaters can develop full saturation. Full saturation means that the heater is running constantly for long periods of time (or 100% on). This usually happens in cold climates, improper piping arrangements and/or undersized heaters. As a result, it is important to note that the saturation temperature must be calculated prior to normalization. The saturation temperature is thus calculated by the following equation:

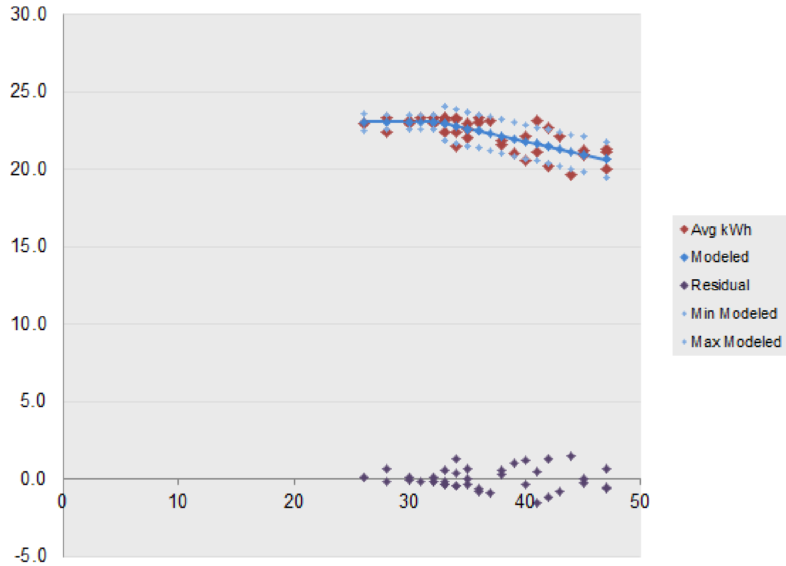
$$x_{proposed.sat} = \frac{b_{proposed} - y_{proposed.full}}{m_{proposed}}$$

Where,

$X_{proposed.sat}$ = temperature saturation temperature of proposed heater

$y_{base.full}$ = proposed daily energy usage of the heater’s measured power (kW) at 24hrs/day

A graphical representation of this is shown below:



The total annual energy consumption of the baseline heater is calculated with the following equation:

$$kWh_{proposed} = \sum_{i \le x_{proposed.sat}} y_{proposed.full} + \sum_{i > x_{proposed.sat}, y_{proposed} \neq 0} - m_{proposed}(x_i) + b_{proposed}$$

Energy Savings Calculations

The energy savings will be calculated by comparing the baseline and proposed performance curves reflecting normal conditions. The normalized conditions will use typical meteorological year (TMY) data. The normalized energy savings will be calculated based on the following equations.

$$\Delta kWh = kWh_{total.base} - kWh_{proposed}$$

Spot Measurements

A single spot measurement is to be taken on both the baseline and proposed EGBHs. This spot measurement information to be collected is the following:

1. Amps
2. Volts
3. kW
4. EGBH Temperature Setpoint (if available)

Continuous Measurements

Continuous Measurements will be performed on each EGBH for the following parameters:

Continuous Measurements:

1. EGBH operation (kW)
2. EGBH operation (Duty Cycle/hrs)
3. Outside Air Temperature (°F) – test chamber
4. Engine Generator Block Temperatures (4 to 8 depending on generator size and geometry)

Continuous Measurement Interval:
The measurement interval on the heater operation (kW) will be set at 30sec. The measurement interval on the temperatures (both test chamber and block temperatures) will be set at 1 min.

Testing Procedure

The test plan includes utilizing two identical generator sets located in Hotstart's CA test chamber. The proposed schedule of testing is as follows:

Gen Set #: _________ Gen Set Size (kW): _________ Heater Type/Size(kW): _________

Hotstart CA Test Chamber Ambient Temperature Setpoint	Duration at Setpoint	Avg. Minimum Block Temperature	Avg. Maximum Block Temperature	Avg. Block Temperature	Average kW
0°F	12 Hours				
20°F	12 Hours				
40°F	12 Hours				
60°F	12 Hours				
80°F	12 Hours				
100°F	12 Hours				

Logging Equipment

BPA will take short term continuous measurements with the following data loggers.

1. 1x ONSET U30 Data Logger with power adapter.
2. 8x ONSET S-TMB-M006 Waterproof Temperature Probe.
3. Dent Instruments ELITEpro Poly Phase Energy Logger.
4. 1x AC line Splitter Accessory for TOU-CT-4G.
5. 1x Dent Instruments TOU-CT-4G Time of Use logger.
6. Tube of Thermal Conductive paste, roll of insulating rubber, and roll of insulating tape.

The Dent Instruments CT loggers will be used to collect short term EGBH run-time thru a change of state signal using the AC line splitter for ease of installation. The HOBO U30 with temperature probes will record short term site outside air temperatures and various surface temperatures of the engine block and associated equipment.

A Fluke 41B will be used to take baseline/proposed power spot measurements. This will include amperage, voltage, power factor and power draw.