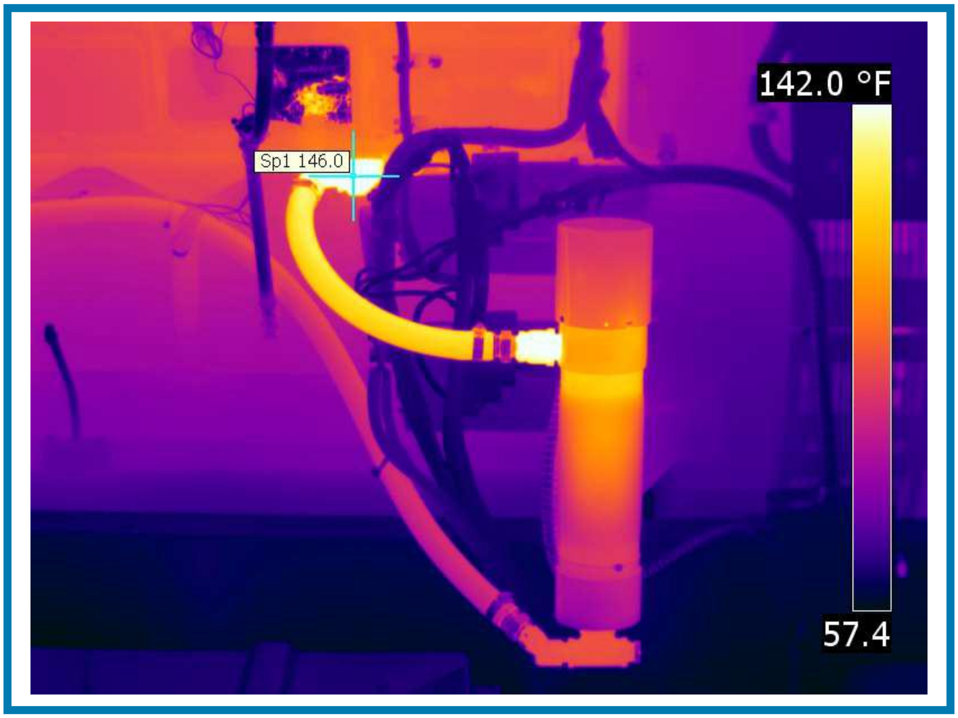
Forced Circulation Engine Generator Block Heater Energy Performance Assessment

ET Project Number: ET13PGE1091



Product Manager: **Sachin Andhare**
Pacific Gas and Electric Company

Prepared By: **Edwin Huestis, P.E.**
Applied Technology Services - PG&E
3400 Crow Canyon Rd.
San Ramon, CA 94583

Issued: **January 10, 2014**

© Copyright, 2014, Pacific Gas and Electric Company. All rights reserved.

Pacific Gas and Electric Company®

ACKNOWLEDGEMENTS

Pacific Gas and Electric Company's Emerging Technologies Program is responsible for this project. It was developed as part of Pacific Gas and Electric Company's Emerging Technology – Technology Assessment program under internal project number ET13PGE1091. Edwin Huestis conducted this technology evaluation for Pacific Gas and Electric Company with overall guidance and management from Sachin Andhare. For more information on this project, contact S1AS@pge.com.

LEGAL NOTICE

This report was prepared for Pacific Gas and Electric Company for use by its employees and agents. Neither Pacific Gas and Electric Company nor any of its employees and agents:

(1) makes any written or oral warranty, expressed or implied, including, but not limited to those concerning merchantability or fitness for a particular purpose;

(2) assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, process, method, or policy contained herein; or

(3) represents that its use would not infringe any privately owned rights, including, but not limited to, patents, trademarks, or copyrights.

ABBREVIATIONS AND ACRONYMS

EGBH	Engine Generator Block Heater
TS	Thermosiphon
Tamb	Temperature Ambient
CT	Current Transformer
OSA	Outside Air
FC	Forced Circulation

FIGURES

TABLES

EQUATIONS

CONTENTS

EXECUTIVE SUMMARY

PROJECT GOAL

The objective of this project was to validate energy savings associated with forced circulation pump driven technology and characterize the energy performance of thermosiphon and forced circulation engine generator block heater technologies under a field testing effort. Anaysis of the field measurements can then be used to evaluate the energy impact of TS versus FC EGBH technology.

PROJECT DESCRIPTION

Emergency backup power availability at a site location may be desired to maintain power to critical end user applications. One method of providing this power includes diesel engine driven power generation. An EBGH serves the purpose of maintaining diesel engine block temperature in a range favorable to reduced engine startup time. The two different approaches, existing thermosiphon and proposed pump driven forced circulation technology, are employed in the EGBH's included in this energy performance evaluation.

A TS EGBH does not use a pump to recirculate coolant through the engine block, resulting in a significant temperature difference across the EGBH. Temperature difference across an EGBH retrofitted with FC technology is reduced due to its pump driven recirculation system. Insight into whether or not these operational characteristics impact energy performance is desired.

PROJECT FINDINGS/RESULTS

At this particular field location, FC EGBH's offered energy saving benefit over TS EGBH's at ambient temperatures below 68F. FC EGBH energy consumption at ambient temperatures above 68F exceeded the TS EGBH. (Please refer to Figure 1 for comparison.) Actual EGBH energy performance depends on several operational parameters, and will be discussed later in this report. Optimization of operational parameters is not part of the scope of this assessment.

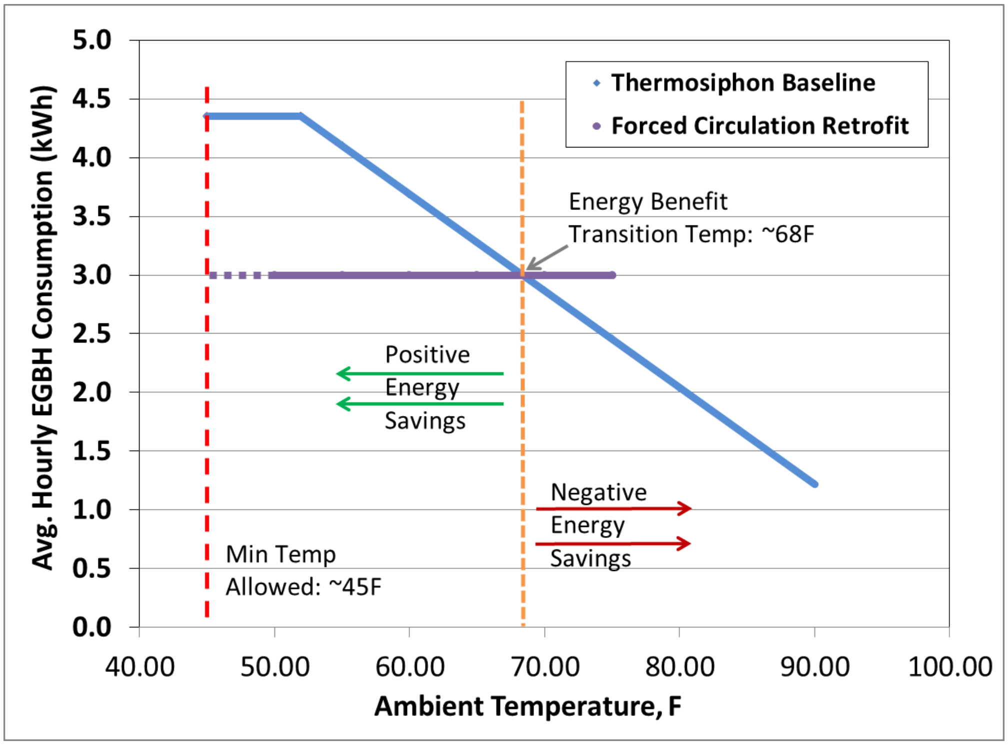


FIGURE 1. COMPARISON OF TS AND FC EGBH ENERGY PERFORMANCE LINES

PROJECT RECOMMENDATIONS

The following recommendations have been made for any future EGBH technology assessment effort:

- Define the range/setpoint of EGBH operational parameters typically seen in the field.
- Perform additional field/laboratory performance monitoring across a range of EGBH operational parameters to establish typical performance.
- Further explore the relationship between temperature setpoint/control and EGBH sizing on energy performance.
- Monitor the performance of an "energy optimized" FC EGBH. Determine eligibility for a potential rebate program.

INTRODUCTION

OPPORTUNITIES FOR ENERGY SAVINGS – REPLACING TS EBGH'S

PG&E program management requested Applied Technology Services (ATS) to complete a field assessment on the potential energy savings resulting from retrofitting TS EGBH's with a FC EGBH. A commercial data center with three identical engine generators agreed to let PG&E monitor energy performance before and after a planned replacement of the TS EGBH on one of their generators with a forced circulation EGBH.

OPPORTUNITIES FOR ENERGY SAVINGS – UNDERSTANDING IMPACTS OF OPERATING PARAMETERS

Bonneville Power Administration identified that the following parameters may have an impact on the energy performance/savings of an EGBH:

- Heater size and number of heaters
- Location of site (ambient temperature range)
- Indoor or outdoor location
- Piping configuration
- For indoor locations –proximity to OSA damper
- Enclosure type (insulated, operable dampers, etc.)
- Engine block temperature setpoint
- Oil heater
- Percent of time that gen-set runs
- "Health" of existing heater

This effort focuses specifically on the performance impact of a retrofit where the following took place:

- Baseline - Two TS EGBH's per engine block (~2.2 kW each)
- Retrofit - One EGBH per engine block (~3.0 kW)
- Indoor location, no space conditioning (ambient temperature approx. between 50F-90F during study)
- Generator #3 approx. 15ft. from OSA damper, Generator #1 ~60ft. from OSA damper, Generator #2 in between, evenly spaced
- Non-insulated enclosure
- Engine block temperature setpoint 120F in retrofit case

- No Oil Heater
- Gen-set runs performed approx. weekly
- No indication that existing heater was close to failure

Energy savings during the monitoring period apply only to the operational characteristics unique to this site location. Energy performance profiles have also been created so that energy performance can be modeled for various ambient conditions for this particular EGBH/engine generator combination.

BACKGROUND

When the engine generators in use at this commercial data center came from the factory, each engine generator was outfitted with a left and right TS heater. This is generally the case for the existing stock of engine generators in the field today. When retrofitting the existing EGBH's with FC technology, both existing EGBH's are removed and replaced with a new heater and pump. For this application, only one replacement heater was installed on the left side of engine generator #2, with both TS heaters removed.

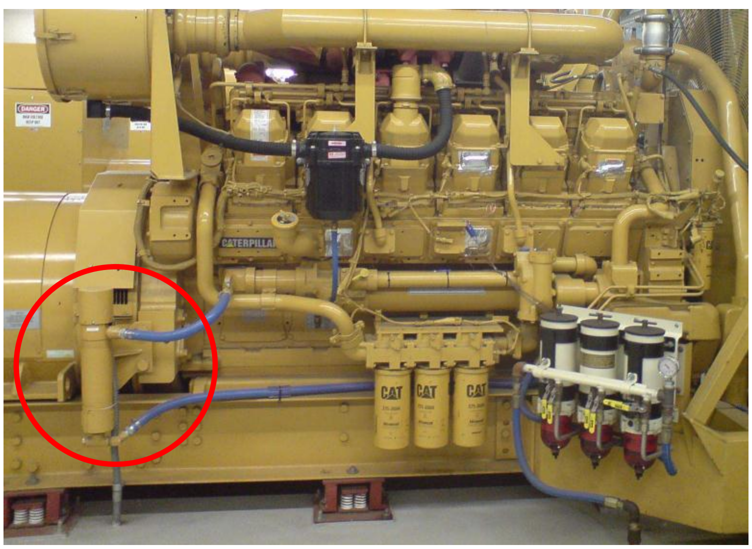


FIGURE 2. TS EGBH TECHONOLOGY (CIRCLED IN RED)

According to a manufacturer of FC EGBH's, "[The heating system] is a complete coolant preheater with thermostat, pump and all required controls. The [model] heats engines ranging in size from 15L-100L displacement. Forced circulation of the coolant delivers uniform heating throughout the entire engine, extends element life and offers a significant reduction in electrical consumption." FC EGBH technology could serve data centers, hospitals and any other market segment where backup power, independent of the power grid is desired.

FIGURE 3. FC EGBH TECHONOLOGY (CIRCLED IN BLUE)

EMERGING TECHNOLOGY/PRODUCT

Both the incumbent and new technologies elevate the temperature of engine coolant used to maintain engine block temperature. An electric resistance heater provides the source of heat for both technologies. The difference between the incumbent and new technology lies in the method of circulating the engine coolant.

- TS heaters rely on buoyancy for circulation, as engine coolant rises as it receives heat from the electric resistance heater. In response, coolant returns from the engine block and repeats the process as it passes through the heater.
- The FC heating system forces coolant past the electric resistance heating element with a circulation pump.

For both cases, the returning coolant temperature must not fall below a minimum temperature required for maintaining adequate engine block temperature. Past studies have suggested that the requirement that a TS heater operate at an elevated supply temperature in order to facilitate the TS effect results in localized hot spots, and thus maintenance issues and wasted energy. FC technology maintains a uniform temperature throughout the engine block through forced circulation, with the heater set to maintain the required coolant return temperature.

ASSESSMENT OBJECTIVES

The main objectives of this project are as follows:

- Evaluate energy performance of two EGBH technologies
  - Thermosiphon
  - FC (Recirculate w/ Pump)
- Identify energy savings potential, if any, resulting from the installation of FC technology in place of TS technology
- Provide recommendations for further testing or market studies

TECHNOLOGY/PRODUCT EVALUATION

The evaluation of both EGBH technologies will be performed in the field for this project phase. Being that the objective of this effort is to provide a rough idea of the energy saving potential of this technology, it was decided that performing this evaluation in the field was sufficient. Performing this evaluation in a laboratory setting provides much better control of ambient conditions, and opportunities for more sophisticated measurement techniques. If deemed worthwhile, this effort could be expanded into testing performed in the laboratory in the future.

A commercial data center with three identical engine generators agreed to let PG&E monitor energy performance before and after a planned replacement of the TS EGBH on one of their generators with FC EGBH's.

There are some significant advantages to this field location, such as:

- All three engine generator set models are identical, all containing the same size and techonology EGBH before a planned installation of FC technology would take place. This allows the performance of three separate EGBH's to be compared for consistency.
- After reducing the data, it was determined that the TS EGBH performance profiles on all three engine generator sets agree within 5% of one another, increasing confidence in both the consistency of the techonoloy performance and the experimental approach.
- Performing testing an EGBH in the laboratory could be cost prohibitive; in the field the equipment is already setup and in operation, ready to test.
- The facility staff were extremely supportive of PG&E's efforts.

This technology assessment was performed by PG&E staff with experience conducting power and temperature measurements on a wide variety of equipment in operating field environments.

TECHNICAL APPROACH/TEST METHODOLOGY

FIELD TESTING OF TECHNOLOGY

All testing was performed on equipment located within the unconditioned engine room. All three units were monitored simultaneously throughout the study before and after the installation of a FC EGBH, which was installed only on generator set #2. With the retrofit only taking place on one of the three engine generators, simultaneous performance measurements were able to be performed on the baseline and retrofitted EGBH's.

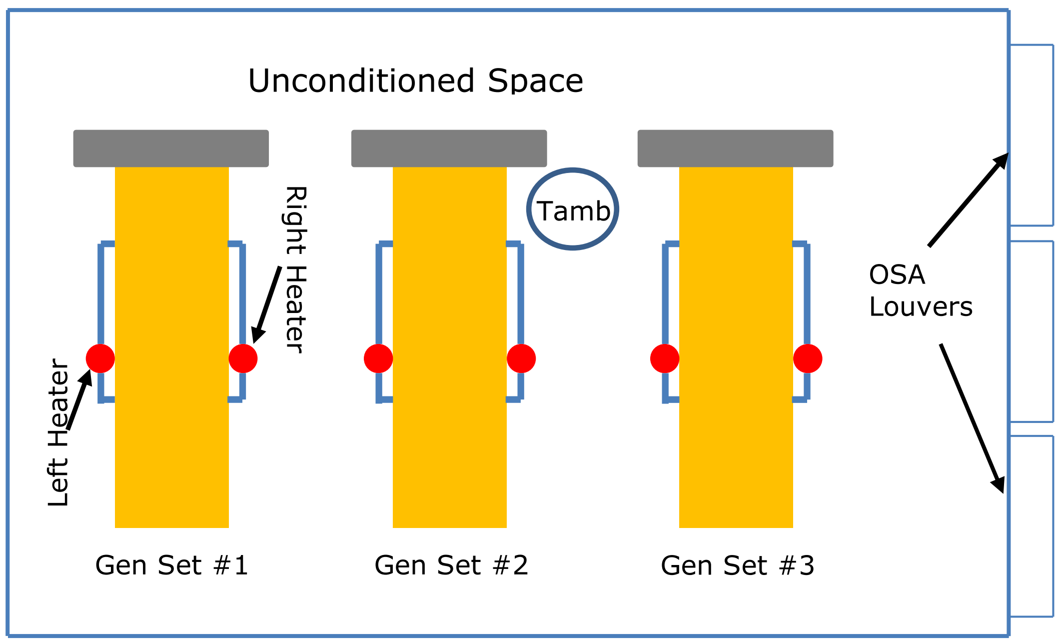


FIGURE 4. EGBH ENERGY CONSUMPTION AND AMBIENT CONDITIONS

MEASUREMENTS TAKEN TO ESTABLISH EGBH PERFORMANCE

- Ambient Temperature, Tamb (F)
- Engine Generator #2 and #3 Block Surface Temperatures (F)
- Engine Generator #2 Post-Retrofit Coolant Return Temperature (F)
- Heater and Heater/Pump True Power (kW)

All temperature measurements were recorded with an Agilent Data Logger.

AMBIENT TEMPERATURE

Ambient temperature measurements are taken with a 4-wire RTD inserted into a radiation shield. The probe is placed in between engine generator #2 and #3. EGBH performance as a function of this ambient temperature is established for all EGBH technologies included in this assessment.

ENGINE BLOCK SURFACE TEMPERATURE (ONLY TAKEN ON ENGINE GENERATOR #2 AND #3)

Engine block surface temperature was measured with thermocouples by covering them with thermally conductive grease and adhering them to the engine block surface with insulated tape. Engine block temperature measurements are used establish a relationship between energy performance and engine block temperature.

ENGINE COOLANT RETURN TEMPERATURE (ONLY TAKEN ON GENERATOR #2, POST-RETROFIT)

An engine coolant return temperature measurement was made by placing a thermocouple in a thermal well filled with thermally conductive grease. This thermal well was installed during the FC retrofit of engine generator #2. This measurement provides insight into the electric resistance heater temperature control setpoint.

HEATER AND HEATER/PUMP TRUE POWER

True power measurements of individual TS heaters were taken at the panel. Once the FC retrofit took place, true power measurements were taken of the circuit feeding both the heater and pump.

TEST PLAN

The requested duration of pre and post retrofit monitoring was 30 days.

MONITORING PERIOD

- Pre-Retrofit Period: 8/22/2013 – 10/11/13
- Post-Retrofit Period: 10/21/2013 – 12/02/13
- Sampling Interval: 15 seconds

Some data were lost during the pre and post retrofits, requiring the extension of the monitoring periods as listed above.

INSTRUMENTATION PLAN

TEMPERATURE INSTRUMENTATION

All temperature instrumentation underwent a two-point calibration (ice bath and isothermal block) to ensure measurement accuracy. Due to the large thermal mass of the engine block and slow rate of change of the engine room ambient temperature, it is assumed that a 15 second data collection interval is more than adequate, if not excessive.

TEMPERATURE MEASURMENT CHANNEL LIST

- CH101-CH103 – Engine #2 Lower Left Block Surface Temperature (F)
- CH104-CH106 – Engine #2 Upper Left Block Surface Temperature (F)
- CH107-CH109 – Engine #2 Lower Right Block Surface Temperature (F)
- CH110-CH111 – Engine #2 Upper Right Block Surface Temperature (F)
- CH112 – Engine #2 Coolant Return Temperature (FC Only) (F)
- CH201-CH203 – Engine #3 Lower Left Block Surface Temperature (F)
- CH204-CH206 – Engine #3 Upper Left Block Surface Temperature (F)
- CH207-CH209 – Engine #3 Lower Right Block Surface Temperature (F)
- CH210-CH211 – Engine #3 Upper Right Block Surface Temperature (F)
- CH212 – Spare (F)
- CH301 – Four-Wire RTD Ambient Temperature (F)

EXPECTED RANGE OF TEMPERATURE MEASUREMENTS

Surface/Ambient Temperature Calibration Range: 32F – 150F

*Engine block surface temperatures do not exceed this range during periods when the engine is not operating.

POWER MEASUREMENT EQUIPMENT

Power measurement equipment was purchased within 3 months of installation, and relied on the factory calibration of the equipment, within 1% of reading. CT's rated to 20A were selected to mitigate potential accuracy concerns using larger CT's. The 20A CT rating is consistent with the rating of the circuit breaker.

ENGINE GENERATOR #1

- DENT Instruments Elite Pro SP

ENGINE GENERATOR #2

- DENT Instruments Elite Pro XC

ENGINE GENERATOR #3

- DENT Instruments Elite Pro SP

EXPECTED RANGE OF POWER MEASUREMENTS

The current draw of all heaters was anticipated to be above 10A at all times, or above 50% of the rating of the CT's.

RESULTS

DATA ANALYSIS

Hourly average values of all measurement parameters are presented for the purposes of performance analysis and evaluation.

ENERGY PERFORMANCE BY EGBH TECHNOLOGY

Average hourly energy consumption of all three TS EGBH's and the FC EGBH are plotted below as a function of average hourly ambient temperature. The range of ambient conditions encountered during the pre and post monitoring period varied, as the average hourly ambient temperature did not often exceed 75F during the post-monitoring period. TS EGBH data are included from both the pre-monitoring and post-monitoring period.

The data indicate that the TS EGBH's were able to trim energy consumption to match load through cycling the electric resistance heater on and off, reaching their maximum total energy consumption of about 4.4kW. The FC EGBH was not able to make setpoint under the ambient conditions experienced during the post-monitoring period, operating at a constant 3.0kW demand regardless of ambient conditions.

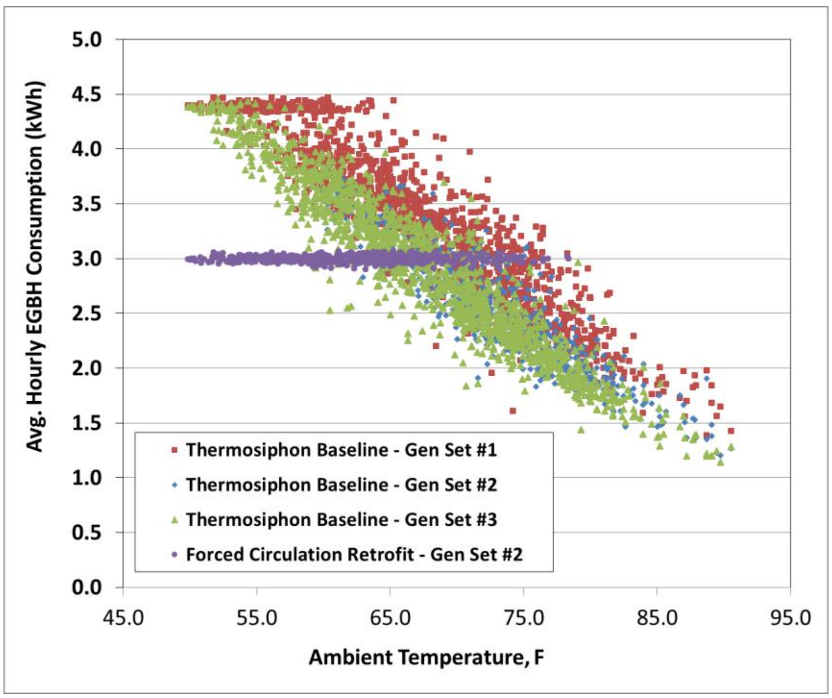


FIGURE 5. ENERGY PERFORMANCE COMPARISON BY EGBH TECHNOLOGY

ENGINE BLOCK SURFACE TEMPERATURE BY EGBH TECHNOLOGY

Average hourly engine block surface temperature is generally maintained lower with the FC EGBH technology at average hourly ambient temperatures below about 68F. This is also the temperature at which there is a shift in energy savings potential. FC EGBH technology offers energy savings when operating in ambient temperatures below 68F.

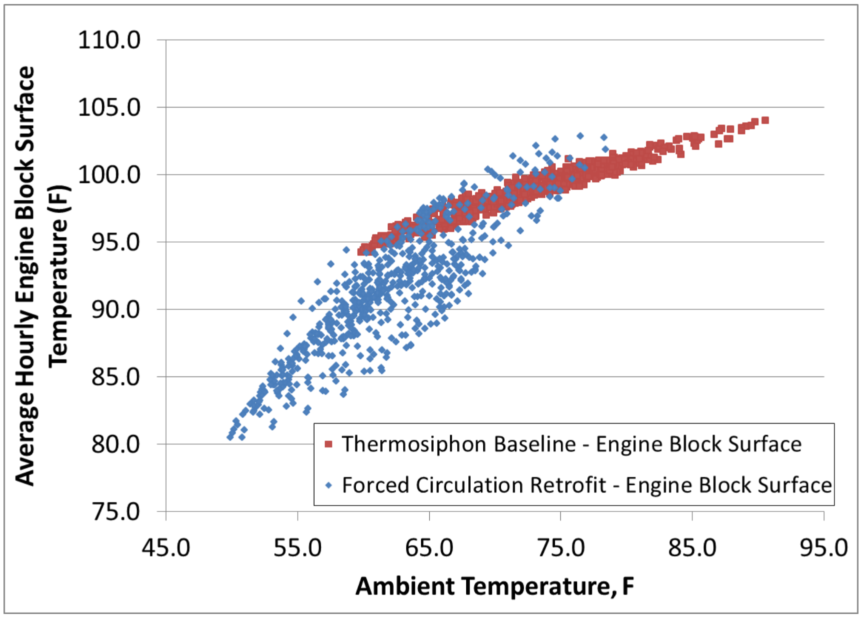


FIGURE 6. ENGINE BLOCK AVERAGE HOURLY SURFACE TEMPERATURE BEFORE AND AFTER FC RETROFIT

ENGINE COOLANT RETURN TEMPERATURE AND FC EGBH TECHNOLOGY

According to the Operation and Maintenance Manual for the engine generators included in this study, "*For an ambient temperature of 0 °C (32 °F), the heater should maintain the jacket water coolant temperature at approximately 32 °C (90 °F)*." During the post-installation monitoring period, the minimum coolant return temperature encountered was about 93F at an average ambient temperature of 50F. It is unlikely that the FC EGBH would be able to meet the criteria listed in the Operation and Maintenance Manual at 32F ambient, but it may also be unlikely that the ambient conditions in the engine room would ever drop this low. For the purposes of these analyses, energy saving benefit will be capped at ambient conditions that favor the coolant return temperature meeting the 90F criteria. This corresponds to a minimum allowed ambient engine room temperature of about 45F.

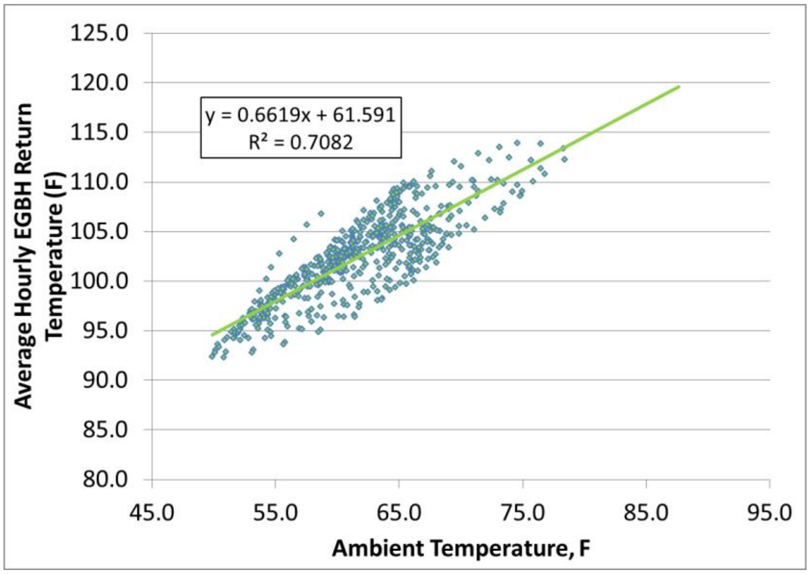


FIGURE 7. ENGINE BLOCK AVERAGE HOURLY COOLANT RETURN TEMPERATURE AFTER FC RETROFIT

ENERGY PERFORMANCE PROFILE BY EGBH TECHNOLOGY

ESTABLISHING EGBH ENERGY PERFORMANCE LINE

The EGBH energy performance profile line for the pairing of the engine generator/EGBH in this effort can be charachterized using the following equation.

EQUATION 1. HOURLY ENERGY CONSUMPTION AS A FUNCTION OF AMBIENT TEMPERATURE

$$kWh_{Heater} = m * T_{AMB} + b$$

Where:

kWh_{Heater} =Modeled total average hourly EGBH consumption (kWh)

m = Slope of EGBH energy performance line

b = y-intercept of EGBH energy performance line

EGBH ENERGY PERFORMANCE LINE RESULTS – TS EGBH

The TS EGBH energy performance line slope and intercept of generator set #2 and #3 were much closer to one another than generator set #1.

TABLE 1. TS EGBH ENERGY PERFORMANCE LINE RESULTS

	EGBH #1	EGBH #2	EGBH #3	AVERAGE
Slope	-0.0857	-0.0796	-0.0818	-0.0824
Intercept	9.1193	8.3350	8.4334	8.6292

EGBH Energy Performance Line Results – FC EGBH

The FC EGBH never met its setpoint of 120F throughout the post-installation monitoring period. The ambient conditions during the post-installation monitoring period varied between 50F and 75F. It is assumed that the FC EGBH would continue to operate at temperatures below 50F. Above 75F, Figure 7 would indicate that it would operate continuously until an ambient temperature of 90F where it would meet an approximately 120F coolant return temperature. No conclusions will be made about the performance of the FC EGBH in ambient conditions above 75F since this was not verified with monitoring data.

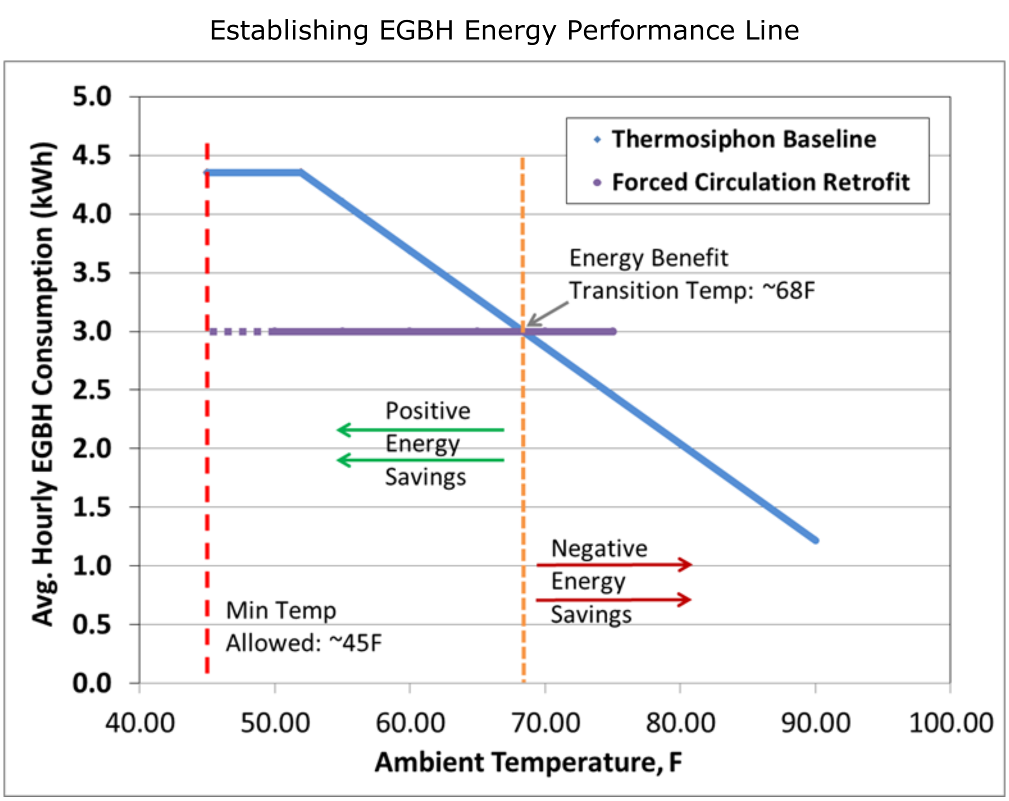


Figure 8. Comparison of TS and FC EGBH Energy Performance Lines

When operating in ambient temperatures between 45F and 55F, the demand saving benefit resulting from the replacement of TS EGBH technology with FC EGBH technology is at its maximum, reaching as high as 1.36kW. This demand savings reduces to zero as ambient conditions reach temperatures of 68F. Negative demand savings result at ambient temperatures above 68F to at least 75F.

Opportunities for Energy Savings with FC EGBH

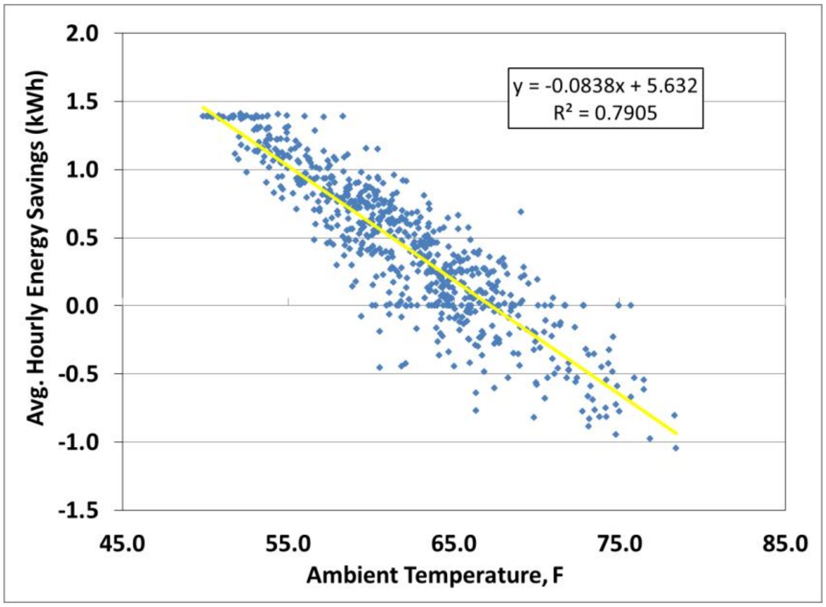


Figure 9. Hourly Energy Savings – Hourly Simultaneous Energy Performance Difference of Post-Installation TS EGBH on Engine Generator #3 and FC EGBH on Engine Generator #2

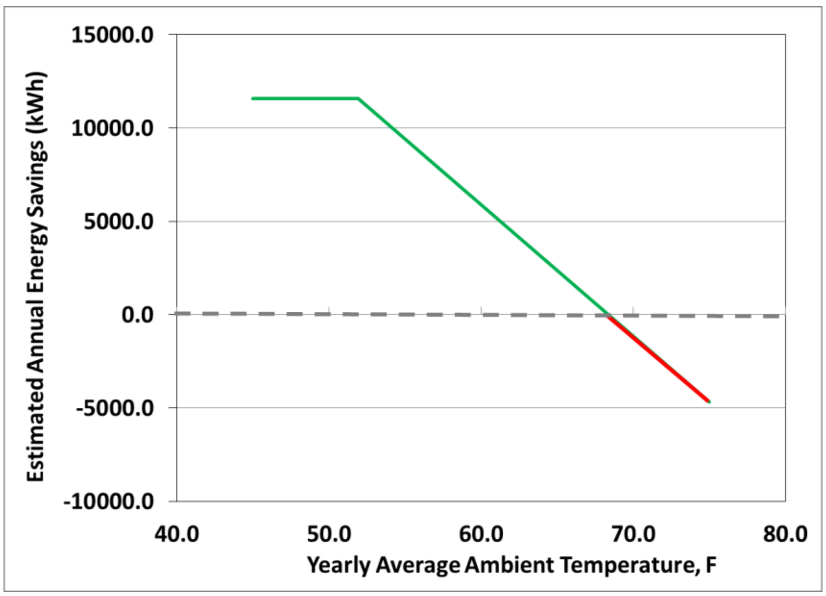


Figure 10. Yearly Energy Savings Opportunities – Established With Energy Performance Line Difference Across Ambient Temperatures

*The plot above required the assumption that the EGBH would operate 8760 hours/year minus four hours per week for routine startup.

EVALUATIONS

SUMMARY OF RESULTS

The results discussed below are specific to the equipment under study in this effort. Actual EGBH energy performance of depends on the many different operational parameters discussed in the introduction.

- FC EGBH's can offer energy saving benefits over TS EGBH's at lower ambient temperatures (below 68F in this effort).
  - Return coolant temperature must stay above a specific value, identified as 90F in the Operation and Maintenance Manual for the engine generator. This required value may change depending on the requirements of the engine manufacturer.
- FC EGBH's can consume more energy than TS EGBH's at higher ambient temperatures (above 68F in this effort).
  - If the criteria for return coolant temperature is that it remain above a specific temperature, the return coolant temperature setpoint can be adjusted downward to yield energy savings if return temperatures in excess of 90F are reached and can be maintained. For example, the FC EGBH was still operating continuously at coolant return temperatures of 115F.
- Due to limitations in ambient conditions on site, performance of the FC EGBH was not determined above ambient temperatures of 80F.
- FC EBGH coolant supply temperature is almost 40F lower than TS EGBH coolant supply temperature based on thermal imaging measurements.
- Energy performance lines established for all three TS EGBH's agreed within 5% of the average slope and offset of the three lines.

RECOMMENDATIONS

- Define the range of EGBH operational parameters seen in the field (as identified in the introduction), including engine generator block displacement.
- Perform additional performance monitoring across this range of operational parameters:
  - Field Monitoring – Expand field monitoring effort to characterize the energy performance line (operational parameter adjustment limited, requires involvement of multiple customers).
  - Laboratory Testing – Using an environmental chamber to control ambient conditions, characterize energy performance (operational parameters can be adjusted, generally better instrumentation can be used, requires engine generators be obtained, loaned or purchased, for testing).

- Explore the relationship between temperature setpoint control and EGBH sizing on energy performance.
    - Determine from TS EGBH manufacturer the typical factory temperature setpoint.
    - Determine from FC EGBH manufacturers how a coolant return temperature setpoint can be reduced while maintaining an adequate engine block temperature (Optimize the design for energy performance).
    - Monitor the performance of an "energy optimized" FC EGBH. Determine eligibility for a potential rebate program.

APPENDICES

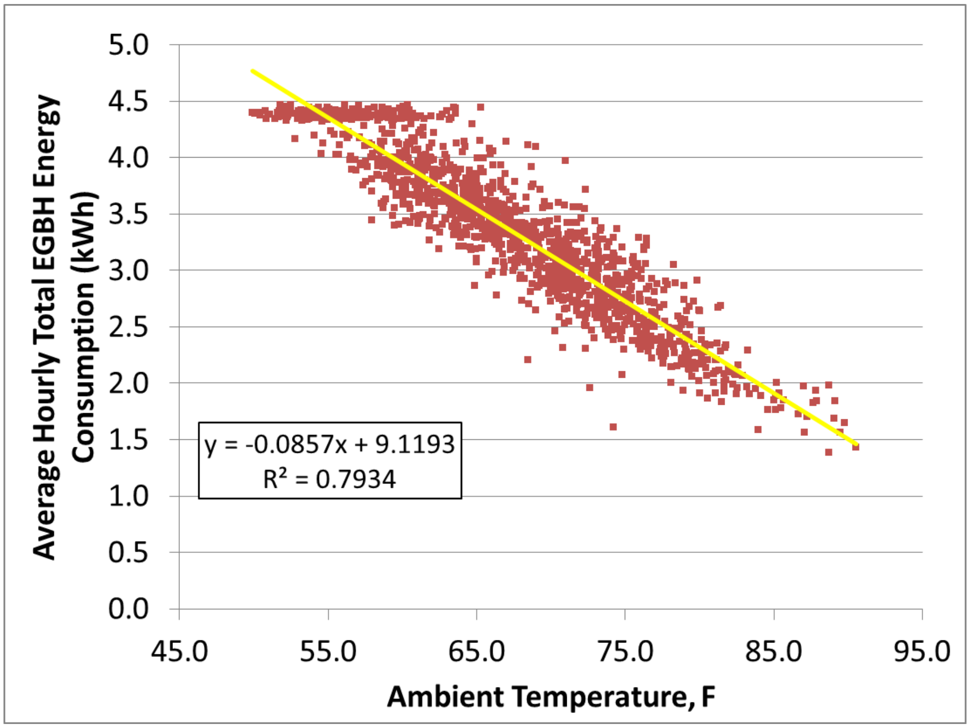


FIGURE 11. ENGINE GENERATOR #1 TS EGBH ENERGY PERFORMANCE LINE DETERMINATION

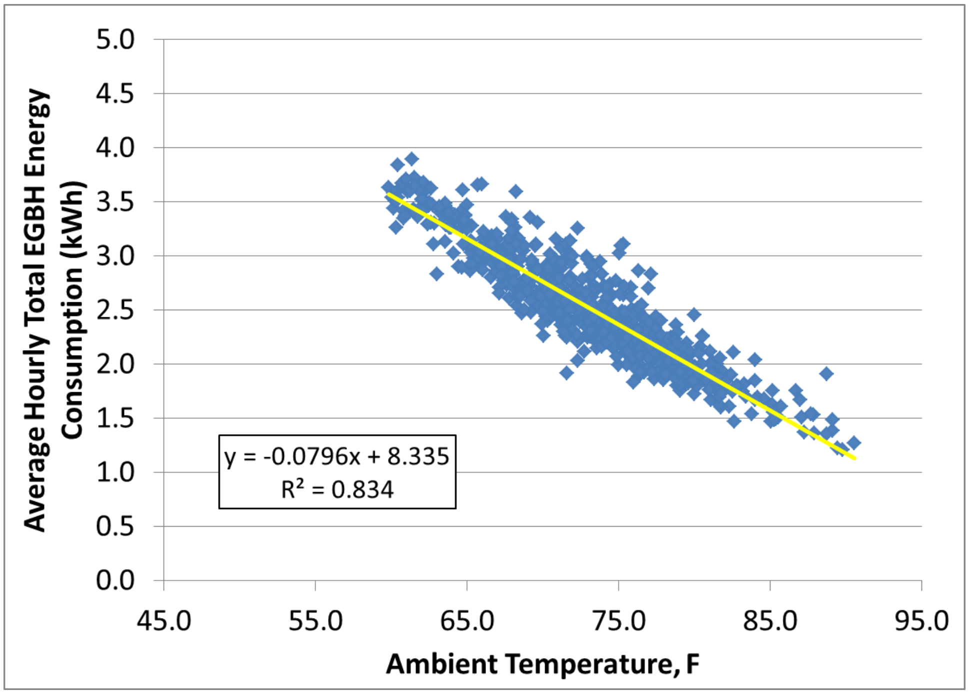


FIGURE 12. ENGINE GENERATOR #2 TS EGBH ENERGY PERFORMANCE LINE DETERMINATION

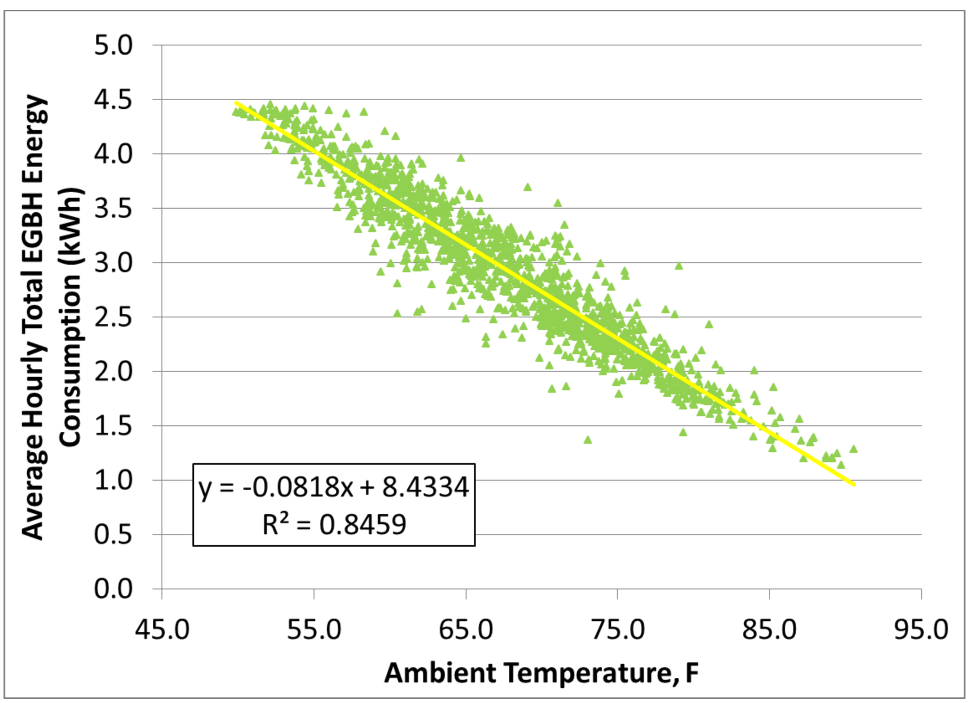


FIGURE 13. ENGINE GENERATOR #3 TS EGBH ENERGY PERFORMANCE LINE DETERMINATION

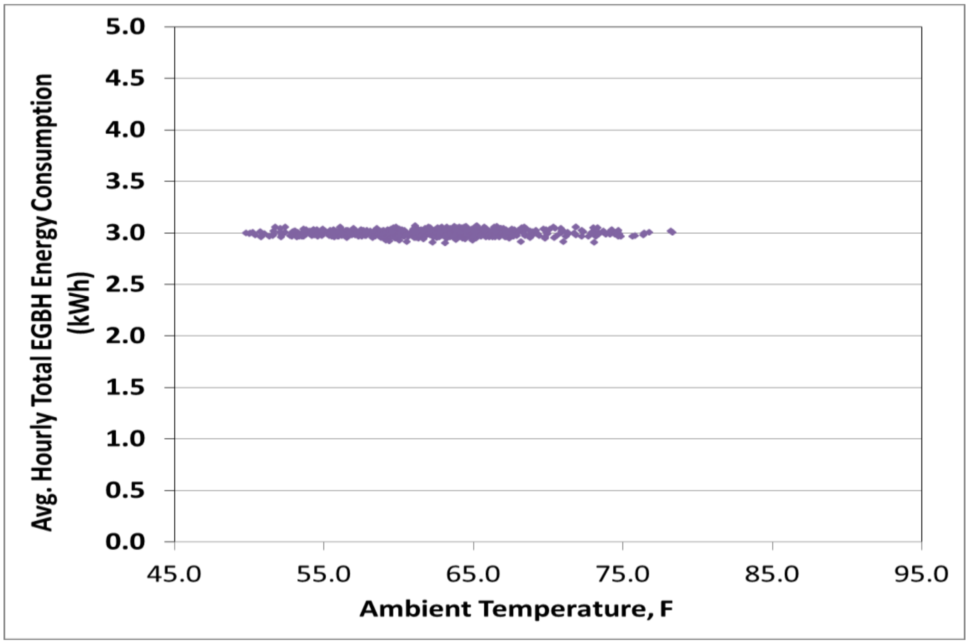
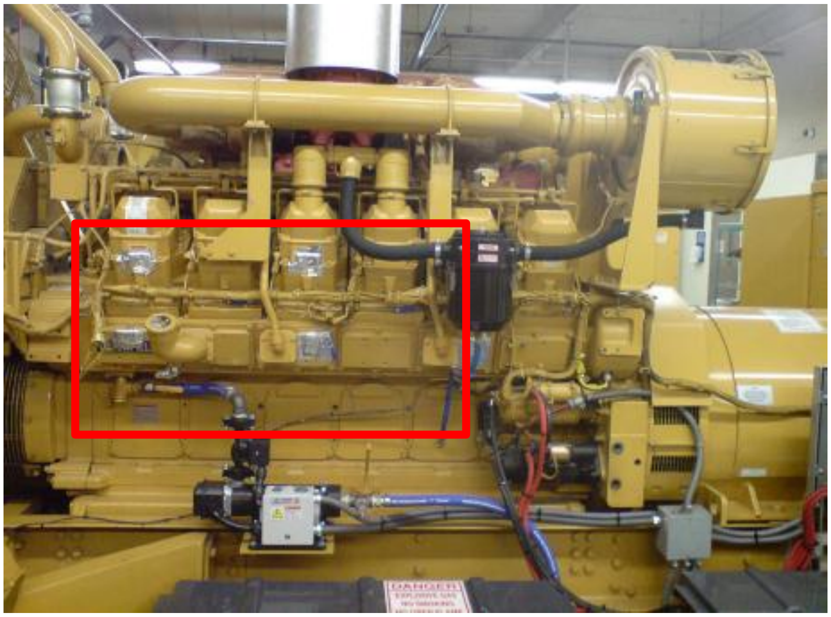


FIGURE 14. ENGINE GENERATOR #2 FC EGBH ENERGY PERFORMANCE



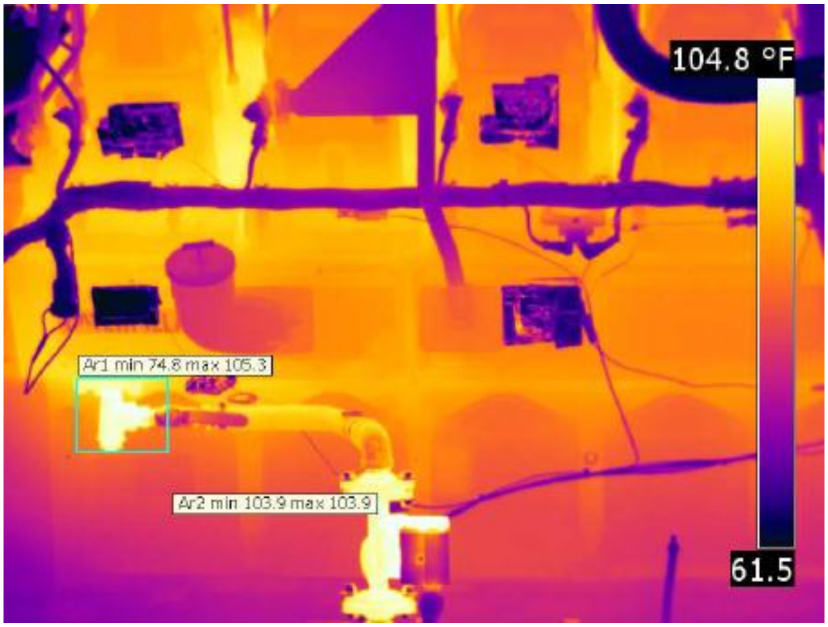


FIGURE 15. ENGINE GENERATOR #2 (FC EGBH) – FC EGBH SUPPLY LINE

FIGURE 16. ENGINE GENERATOR #2 (FC EGBH) – TOP #1

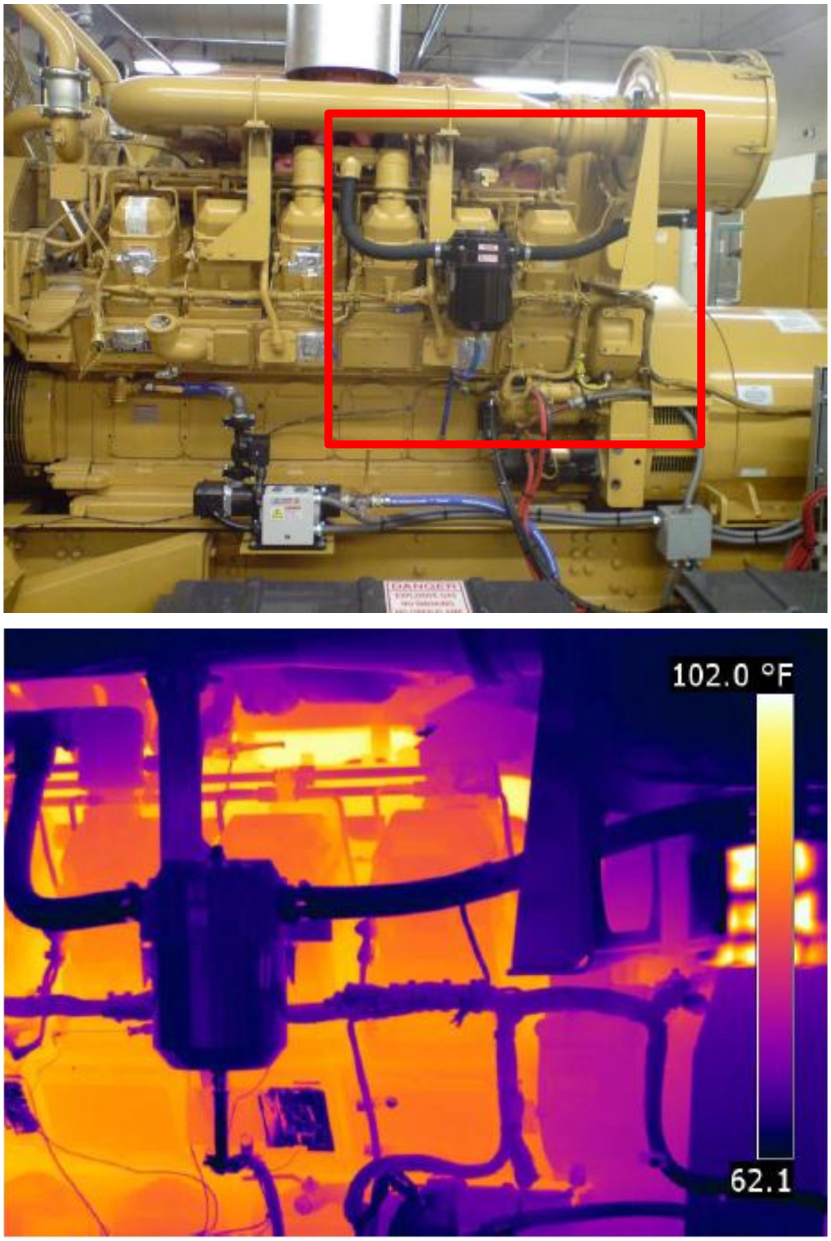


FIGURE 17. ENGINE GENERATOR #2 (FC EGBH) – TOP #2

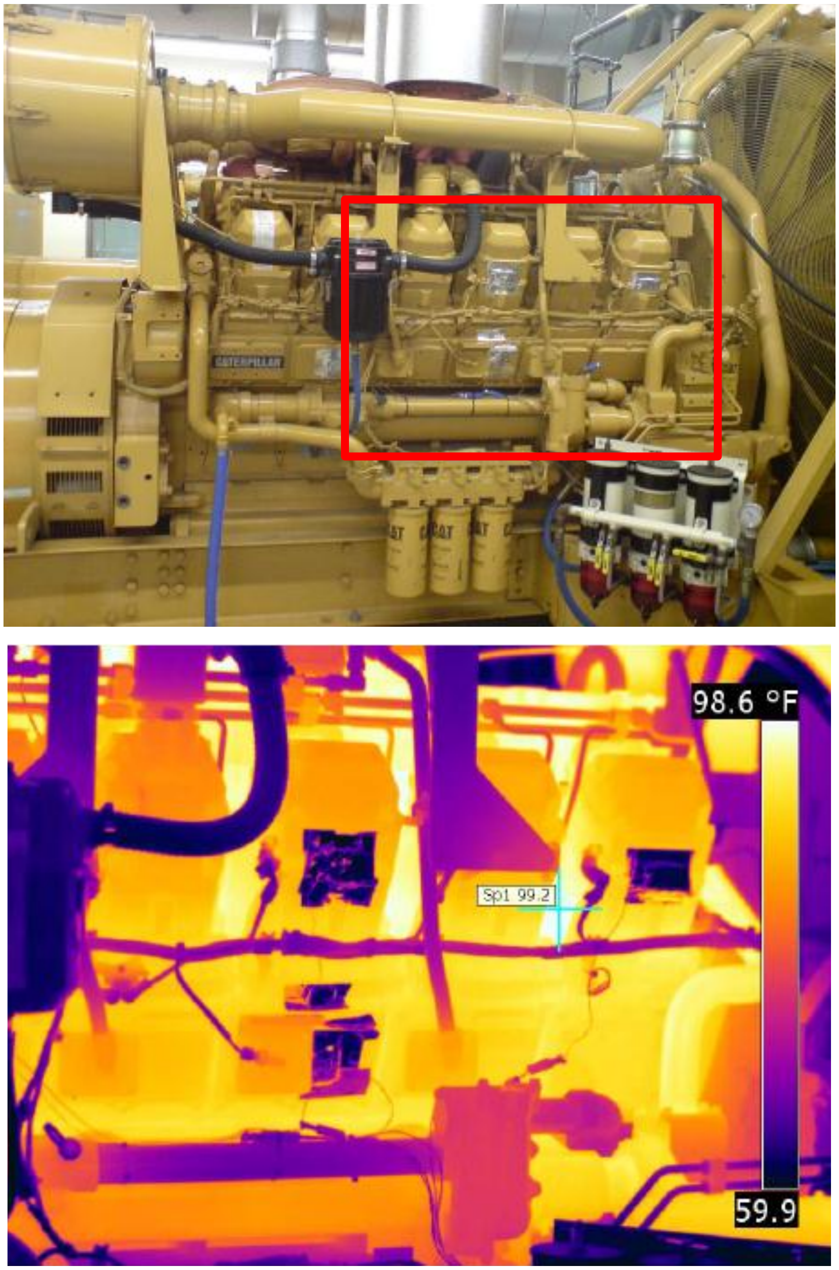


FIGURE 18. ENGINE GENERATOR #2 (FC EGBH) – TOP #3

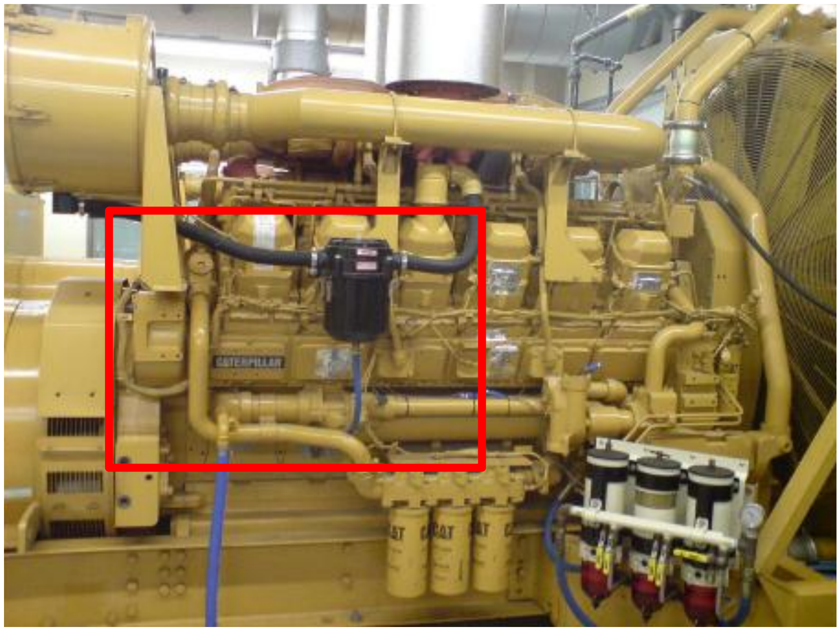


FIGURE 19. ENGINE GENERATOR #2 (FC EGBH) – FC EGBH RETURN LINE

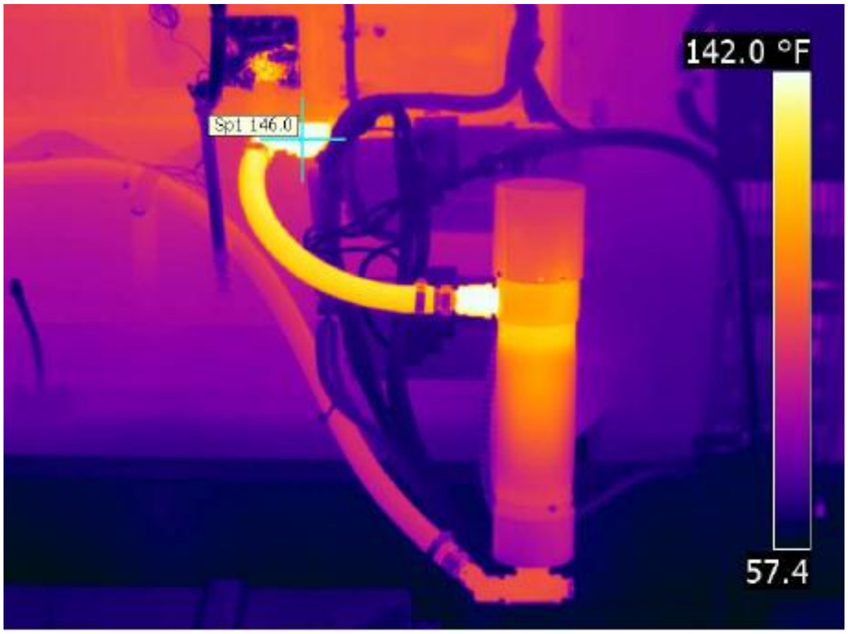


FIGURE 20. ENGINE GENERATOR #3 (TS EGBH) – TS HEATER CLOSEUP/SUPPLY LINE

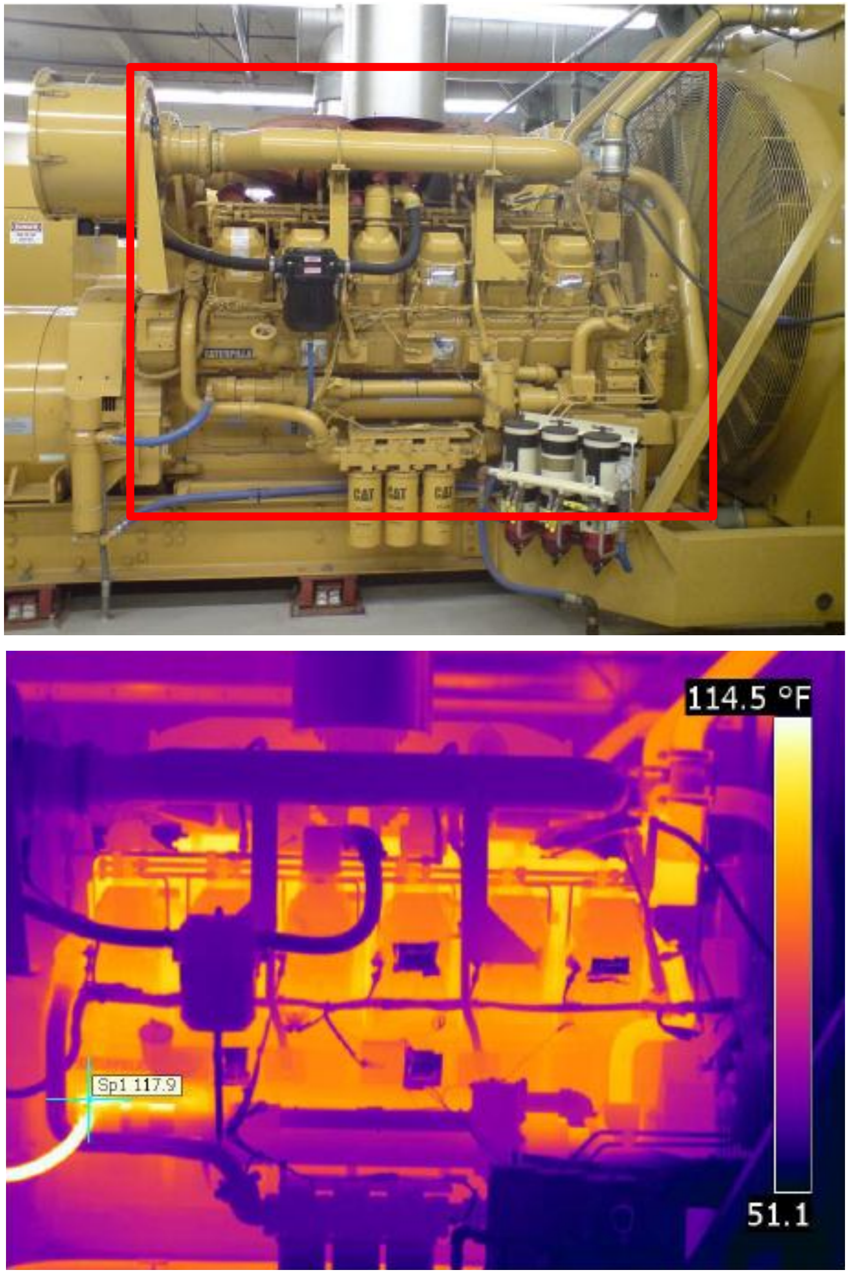


FIGURE 21. ENGINE GENERATOR #3 (TS EGBH)