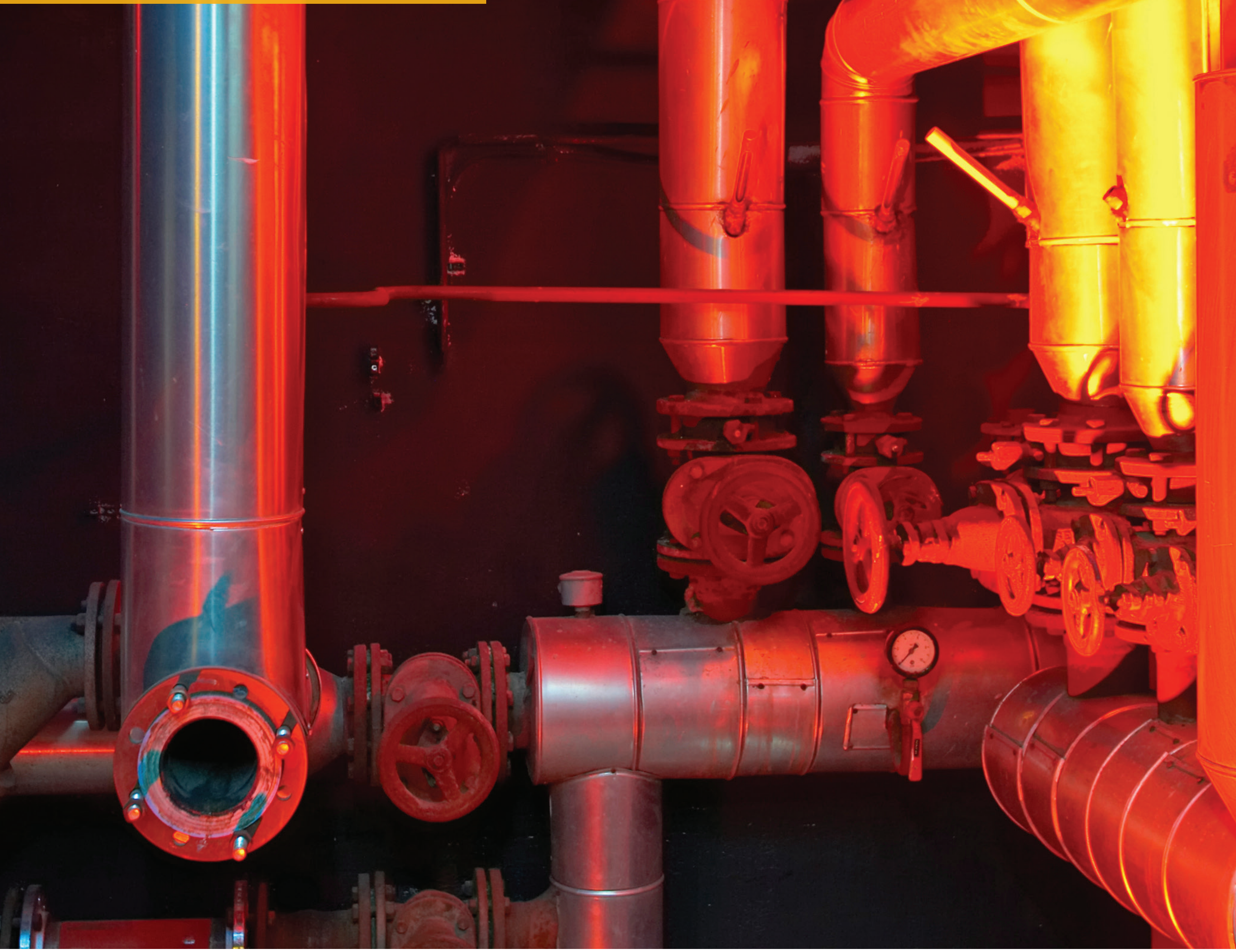
Pump-Driven Block Heaters:
A Study in Energy Efficiency



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Introduction

NFPA code 110 for Emergency Power Systems (EPS) requires that standby generator engine blocks shall be heated as necessary to allow full power within 10 seconds. As such, a heating device must be in place to warm and maintain block temperature. Historically, one technology dominated the block heater market, Thermo-Siphon (TS) heaters. The ubiquity of the TS heater is driven primarily by Original Equipment Manufacturers (OEMs) because they install them at the factory. Recently, another heater style entered the market, and while slightly more complex and expensive to purchase, the Pump-Driven (PD) block heater theoretically costs less to operate and reduces generator maintenance.

TS heaters are simple devices with no moving parts; they work by warming coolant with an electric resistance element. Warmed engine coolant is buoyant and rises to the top of the engine block, forcing cold coolant to circulate back to the heater. This buoyancy driven circulation is directly dependent upon hot and cold coolant which results in a non-uniform engine block temperature; coolant at the top of the block is warmer than the coolant at the bottom. In order to meet requirements, the cold coolant must meet the minimum block temperature. Unfortunately, this means there are sections of the engine, near the top, that needlessly exceed the required temperature. Higher temperatures increase heat transfer to the environment, increasing energy consumption and therefore operating costs. Pump-driven block heaters use a fundamentally different approach to circulate coolant. As the name implies, they have an integrated electric pump circulating coolant throughout the engine. With the pump, coolant circulates quickly and coolant supply and return temperatures have minimal temperature difference. The entire engine block is very near the target temperature, minimizing the heat transfer and operating costs. Homogeneous block temperature also prevents the overheating of coolant hoses which causes failures and increases heater element and engine seal lives.

Energy savings are directly coupled to lower and more consistent block temperatures, and this paper studies the effect of PD heaters. Avista has been capturing data since 2008 to ascertain the savings from pumped block heaters and is still in the process of measuring energy savings of customer generators in our service territory. This paper is an intermediate report on that work.

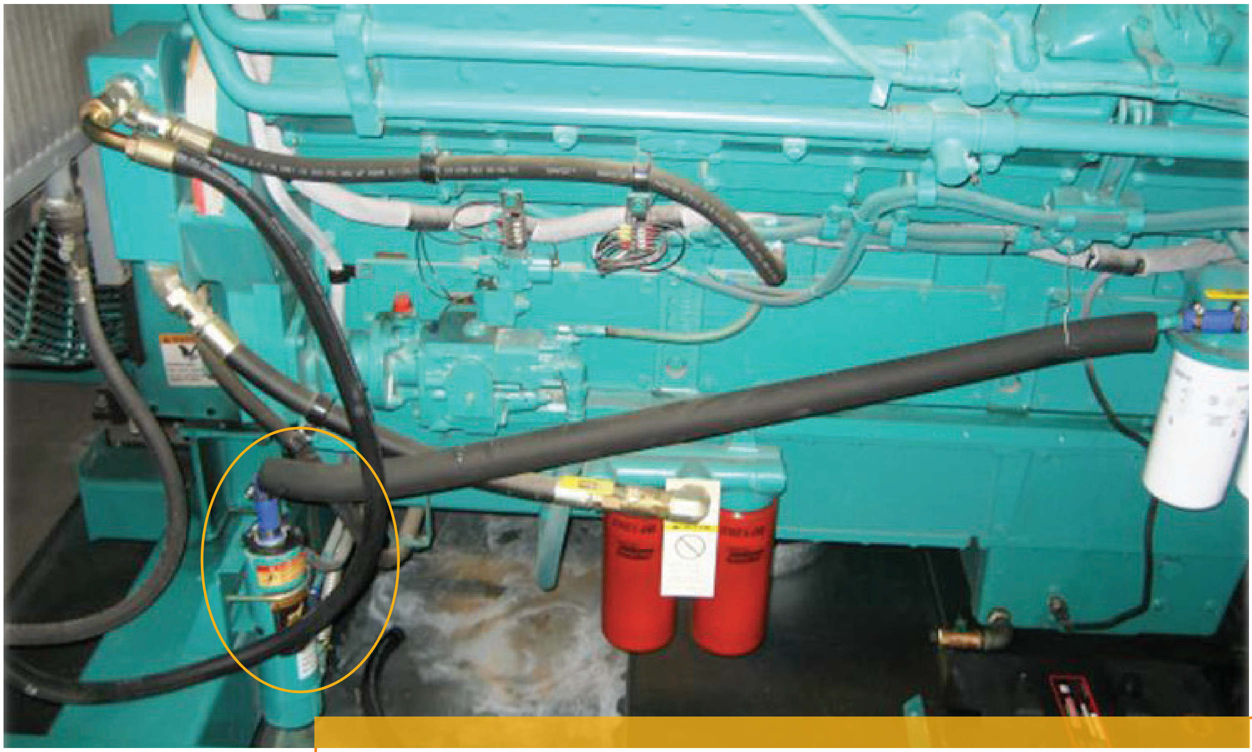


Figure 1: Example of thermosiphon engine block heater as installed on a typical standby generator.

Block Heating Concepts: Standard Convection Heaters

Let us start by defining an engine block heater for the scope of this paper.
Block heaters are electrically powered, thermostatically controlled coolant warming devices mounted externally to the engine block. Coolant flows between the heater and the engine via reinforced rubber hoses. This generalized definition may conjure images of a small water heater you might use in your home, and for the most part, that is what they look like and how they work. There is, however, one thing that sets a block heater apart from your home's domestic water heater: circulation. The block heater needs to circulate warmed coolant throughout the block, and ideally, the circulating coolant would heat and maintain the entire engine at a uniform temperature. Unfortunately, this is not the case for typical heater technologies.

Generally Original Equipment Manufacturers (OEMs) rely on tried and true technologies for their products. The current standard for standby generator engine block heating, is the thermosiphon heater. It relies on convection heat transfer and the physical properties of the coolant to induce circulation.

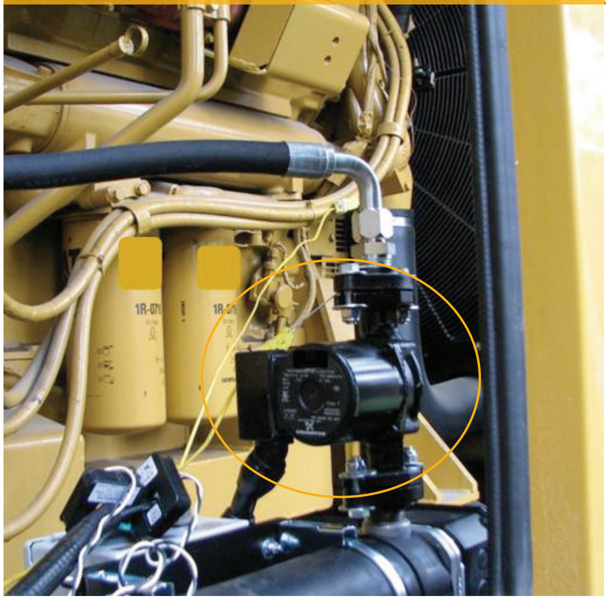
Starting at the heater, coolant is warmed via a resistive element; once warmed, the coolant vs density is reduced and, like a hot air balloon, the warmed coolant begins to rise. Since the heater is located near the lowest point on the engine block, the coolant rises into the block and begins traveling throughout the coolant passages, releasing its heat via natural convection to the block. The heat is then conducted through the block-wall to the block's exterior where the heat is then rejected to outside air via natural convection and radiation. As the coolant loses heat it cools and its density increases causing the coolant to fall to the lower recesses of the engine block. It eventually makes its way back to the block heater where it is reheated.

The TS relies on coolant temperature differences to drive flow, with the heater's thermostat regulating the temperature of the returning coolant. A weakness of the TS heater, with regards to energy efficiency, is the returning coolant must be at the thermostat's set point temperature and must meet NFPA guidelines. The rest of the coolant, and therefore block, temperature is greater than the required guideline temperature.

Pump-Driven Block Heaters

As the name indicates, Pump-Driven (PD) block heaters rely on an electrically-driven mechanical pump to circulate coolant throughout the engine's block. A thermostat, measuring the return coolant temperature, controls the electric heating element to maintain return coolant temperature. Circulation is not dependent on coolant temperature or density differences. The higher flow rates of the pumped coolant shifts the heat transfer mode from natural convection into forced convection realm. The result is a small temperature difference between heater outlet and inlet. As a result, the entire block is a uniform temperature, near the guideline-specified minimum temperature.

Figure 2: Examples of pump-driven engine block heaters on an indoor and an outdoor standby generator.



Block Heating and Energy Efficiency: Operational Differences

There are two characteristic differences between thermosiphon and pump-driven heaters:

1. The PD heated engine block's average coolant temperature is lower than the thermosiphon heater's.

2. The TS heater consumes zero power to circulate coolant; it just heats the coolant, whereas the PD unit also needs to power the pump.

This raises a few interesting questions, such as: How big is the temperature between the thermosiphon and the pumped block heater engine blocks? Would a lower average coolant temperature save an appreciable amount of energy? Wouldn't the increased power consumption of the pump on the PD heater negate the energy savings, if any?

In this situation, physical laws dictate that heat loss to the environment is dependent on two factors: first, the heat transfer rate is proportionally dependent on the temperature difference between the surface of the engine and the atmosphere surrounding the engine. Secondly, the heat transfer rate is also

Figure 3: Generator A thermosiphon, thermal and normal image of top of engine, spot temperature 140°F

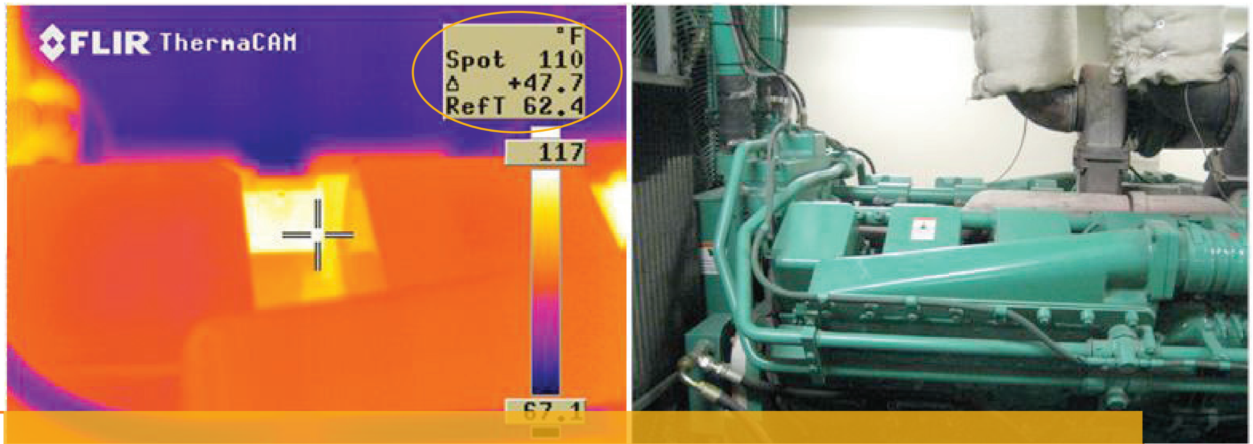


Figure 4: Generator B with the pump-driven heater, thermal and normal image of top of engine, spot temperature 110°F

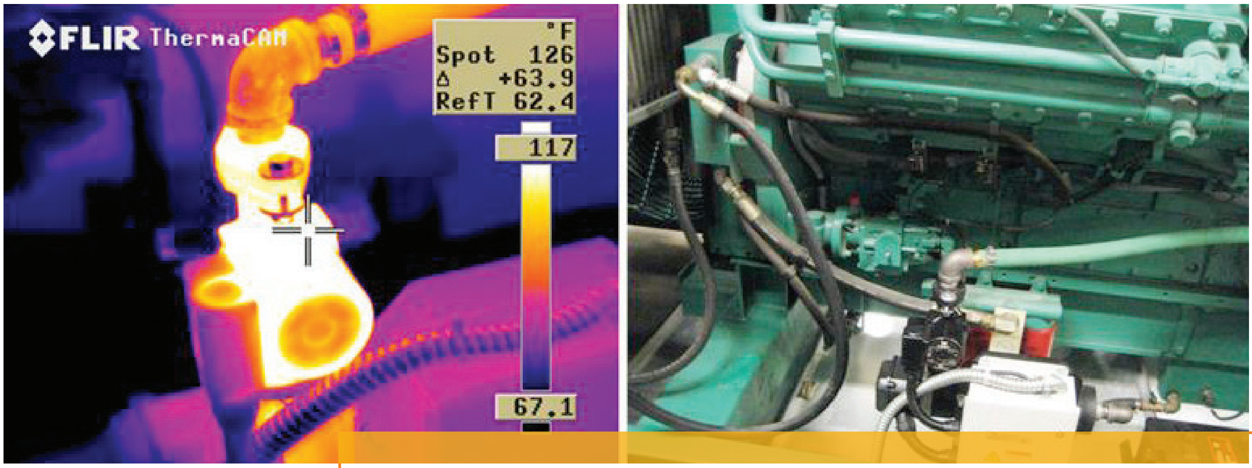


Figure 5: Thermal image of the pump-driven heater with a spot measured temperature of 126°F

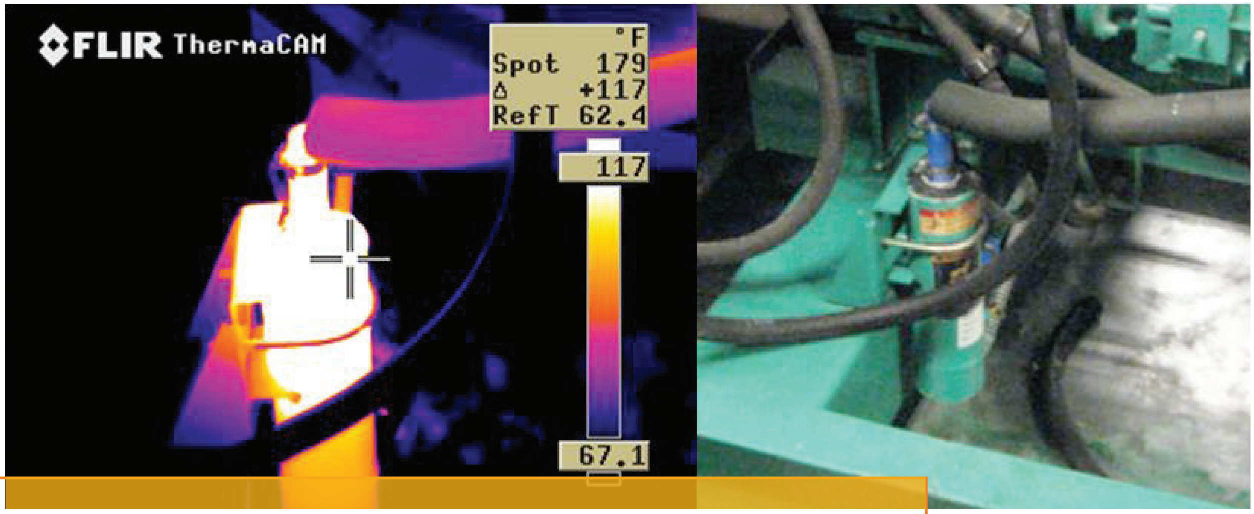


Figure 6: Thermal image of the thermosiphon heater with a spot measured temperature of 179°F

proportionally dependent on the engine's exposed surface area. Since any given engine's surface area is usually fixed, the heat transfer rate is dependent on the engine and surrounding air temperatures.

In order to investigate the effect heater types have on block temperature, thermal images were taken of two standby generators. The units are located in the same indoor facility and are the same make and model. Unit A, shown in Figure 4, is the control unit, with a TS block heater. The image is of the top of the block and the spot imager from the thermal camera indicates the block temperature is 140°F. Compare this to Figure 4, in which Unit B, the experimental unit generator with the PD heater has a block temperature of 110°F. The TS unit's block temperature is 30°F higher than the PD block temperature. Images of the two heaters also demonstrates the temperature differences on the exit side of the two heaters: the pump-driven heater spot temperature is 126°F, as shown in Figure 5, while the thermosiphon heater is 179°F. Average over the TS's block has between a 30°F and 53°F higher block temperature and resulting heat loss.

Something else to consider is that liquid-cooled internal combustion engines have thermostats that control coolant flow from the engine block to the radiator, which open at predetermined temperatures. The thermostats are closed when the engine coolant is cold to speed the engine warming process following startup. Once the coolant reaches operating temperature, the thermostat begins to open, directing coolant to the radiator. While the engine's thermostat is extremely important and beneficial to the process of maintaining the engine at operating temperature, it can be a problem for block heaters; if the fluid near the thermostat is warm enough to trigger the thermostat open, fluid will begin to flow through the generator's radiator as well as the block. This is unfortunate, as radiators are very efficient at transferring heat. Due to the higher coolant temperatures, TS heaters are more likely to encounter this condition. This is evident in Figure 7 and Figure 8, where the TS's average radiator temperature is 135.9°F and the pump-driven radiator is 98.6°F. The PD heater's thermostat housing is 120°F, 20°F less than the average radiator temperature, suggesting that the thermostat is in a closed position. This is not the case with the TS thermostat; the housing is 156.7°F and the average radiator temperature is 135.9°F, which suggests that the thermostat is open and coolant is circulating to the radiator.

Image Description
Regular Radiator
Recommendation
No Action

Label	Value
SP01	156.7° F
SP02	136.6° F
LI02 : max	164.8° F
LI02 : min	75.8° F
AR01 : avg	135.9° F

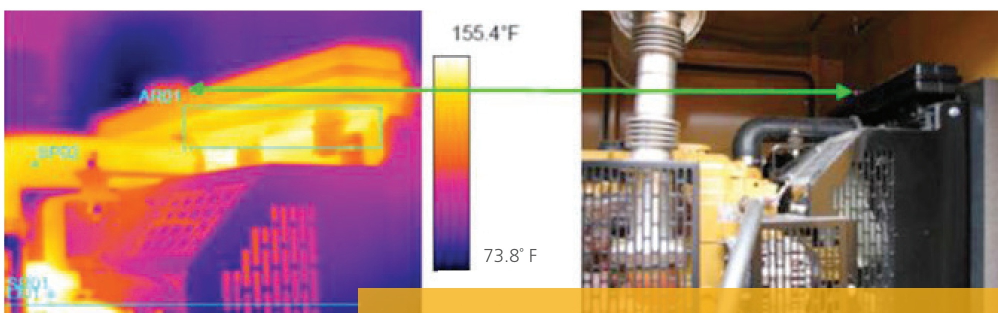


Figure 7: Thermal image of a thermosiphon thermostat and radiator. Note that the average radiator surface temperature is 135.9°F

Image Description
Pump Radiator
Recommendation
No Action

Label	Value
SP01	120.0° F
SP02	106.9° F
LI02 : max	120.5° F
LI02 : min	69.3° F
AR01 : avg	98.6° F

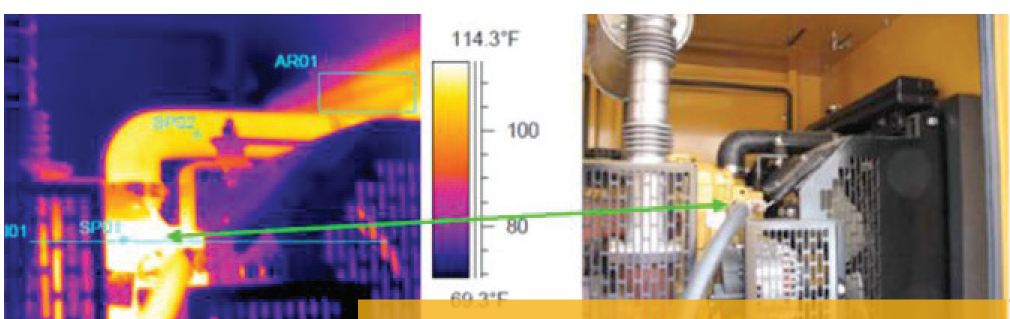


Figure 8: Thermal image and analysis of the pump-driven radiator. Note that the average radiator surface temperature is 98.6°F

Testing and Results
Laboratory Experiments

Thermal imaging is a powerful tool, but when investigating energy consumption, it provides only a qualitative picture. From the thermal images, it is clear that the TS heaters are responsible for higher block temperatures, but is that enough to make a discernible difference in energy consumption? For quantifiable heater energy consumption, laboratory and onsite performance testing is required.

Laboratory experiments were conducted with experimental and control units in a thermal chamber. In addition to exploring the effects of block temperature, the laboratory testing also evaluated the effect of engine size on heater energy consumption. Two different test mules were used, including a relatively small John Deere 6068 6.8 Liter engine and a larger Detroit Diesel S60 14 Liter engine. Each engine was first fitted with an appropriately sized TS heater and allowed to soak in the thermal chamber at 0, 30, 50, and 80°F for 24 hours with the heater energized. Engine fluids, ambient temperatures and power consumption were all measured during each test. This process was then repeated in the same conditions for each engine with a PD heater.

Data was analyzed and correlated based on engine size and ambient air temperature to predict average energy consumption. Figure 9 plots average energy consumption for (4) different experimental configurations: TS and PD heater on the 6.8L and 14.0L engines.

Heater Energy Consumption vs. Ambient Temp

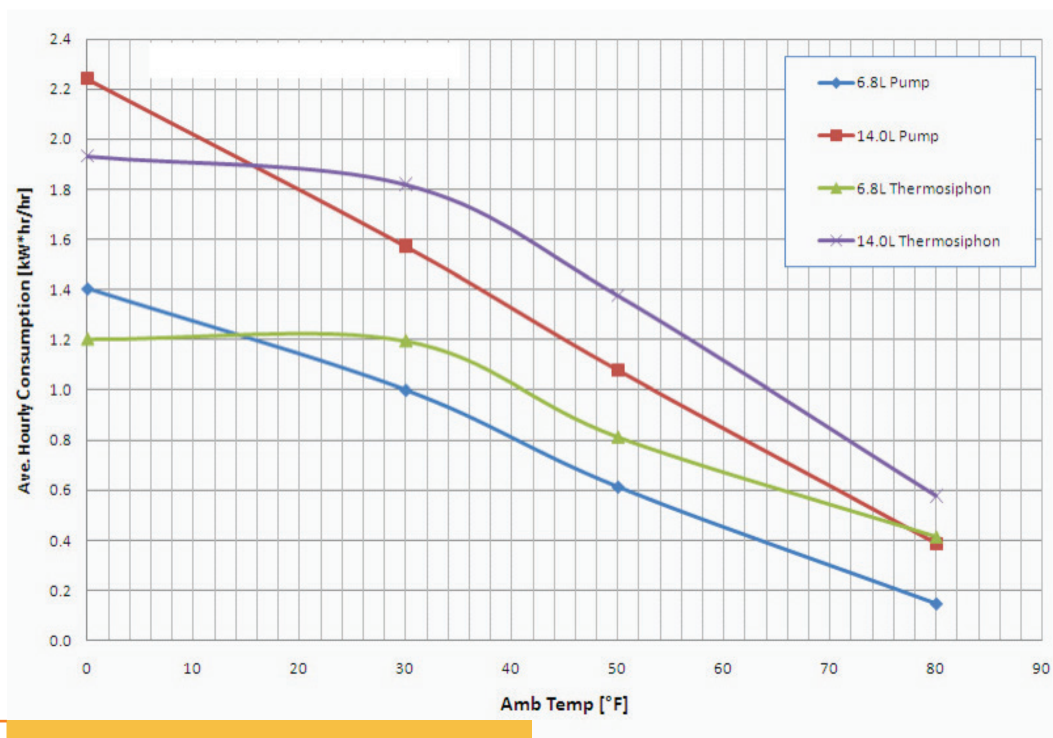
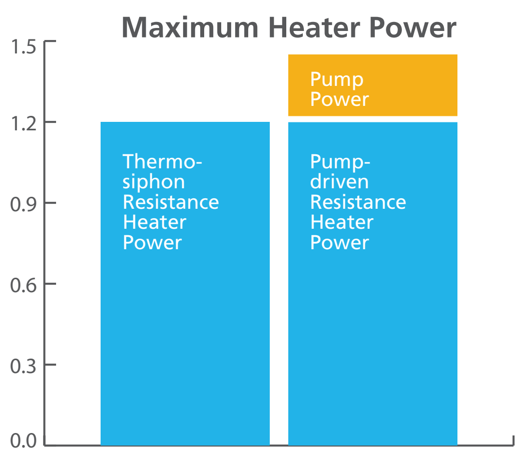


Figure 9: Graph of lab measured heater performance.

When comparing the energy consumption of the thermosiphon and pump-driven heaters, it becomes clear that the pump-driven heaters consume less energy at air temperatures greater than 15°F. At this temperature, the thermosiphon heater energy consumption appears to level off while the pump-driven heater continues to increase energy consumption as air temperature drops. A review of heater power data indicates that the TS heater reached max capacity at around 15°F; the heater's thermostat kept the heater energized 100% of the time. The pump-driven heater had not yet reached maximum heating capacity, so energy consumption continues to increase, eclipsing the TS's consumption. If testing had included temperatures below 0°F, it is reasonable to assume that the PD heater's power would have eventually reached its maximum draw. Comparing the maximum power draw of the two heaters would reveal that the power difference would be roughly equal to the PD's pump power (for example see table below).



From 30°F to 80°F, it appears that for the two engines, the TS and PD heaters energy consumption is inversely proportional to air temperature. With the ability to predict energy consumption based on air temperature, energy savings with the TS heater becomes a relatively simple calculation.

The question then becomes, will the linear relationship and energy savings hold true for generators with un-tested engine sizes, and outdoor applications where temperatures vary quickly and often?

Field Testing

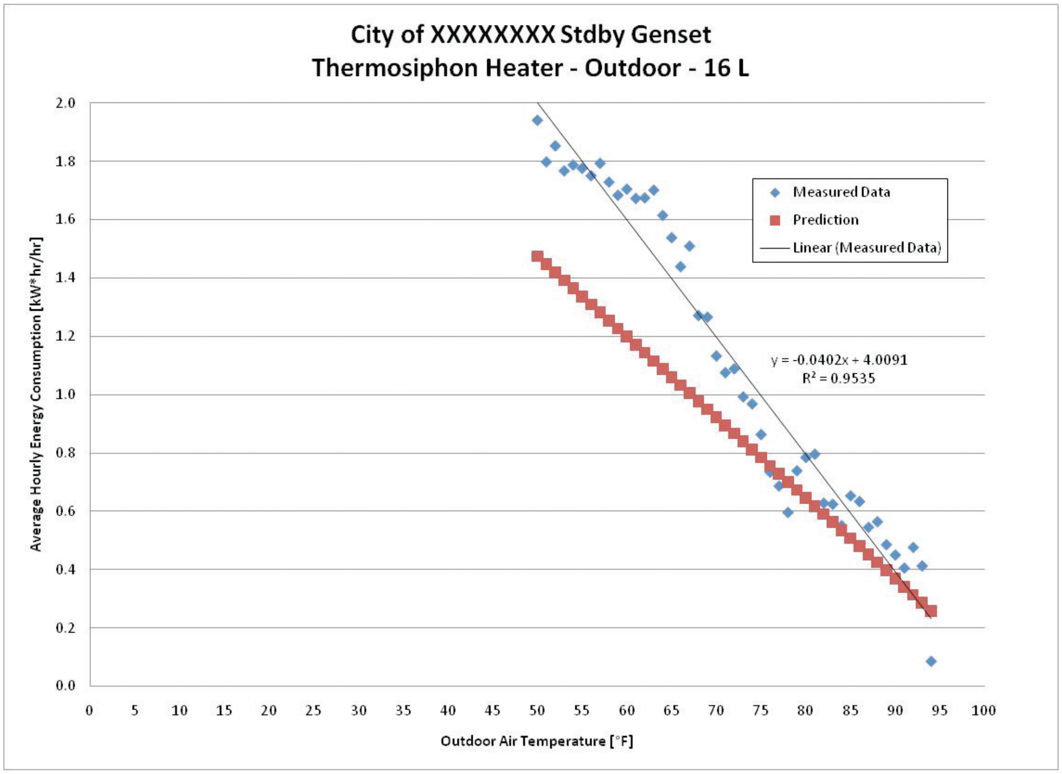
With initial laboratory data gathered and analyzed, the logical next step is to explore real world energy consumption and establish the relationship to engine size. To encourage customers to install a PD heater, Avista Utilities created a pilot program to explore real world performance of both heater types. The program incentivizes customers to retrofit their standby generator engines with PD heaters. The only edict placed upon the customer is that they contact the utility prior to the retrofit, and that they allow the utility's engineering team to measure energy consumption of the TS and PD heaters for at least 2-weeks. The data is collected, sorted, analyzed and compared to the original laboratory results.

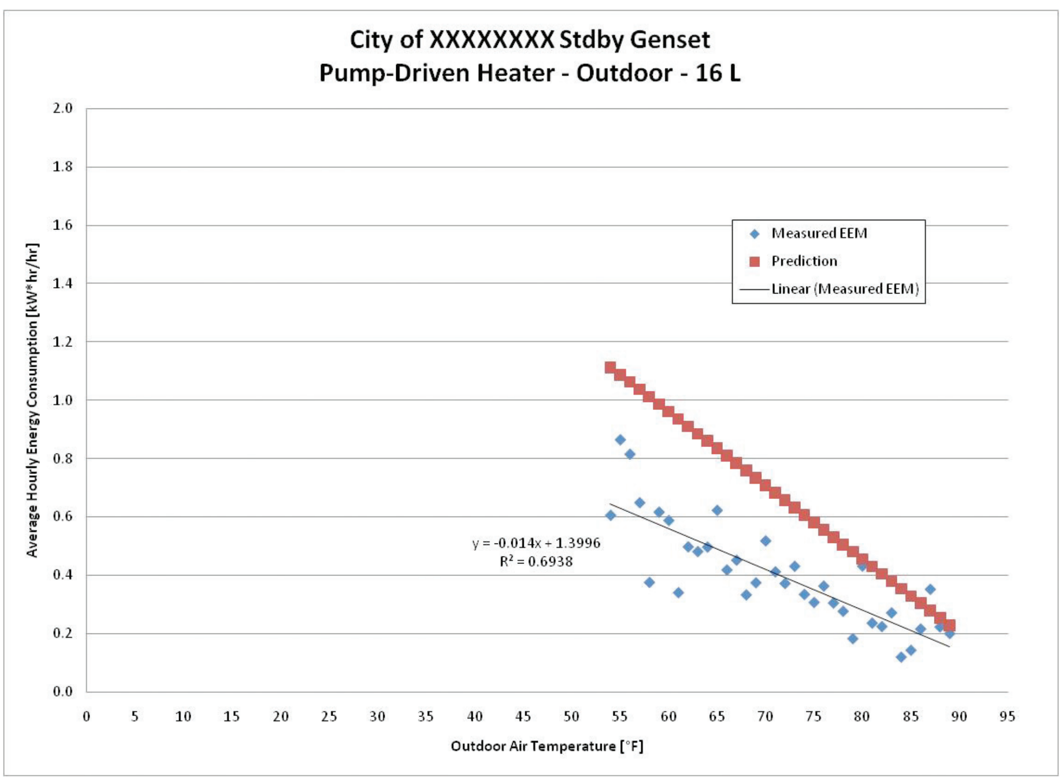
To date, 14 generators have been logged for at least 2-weeks with a thermosiphon and pump-driven heater. Engine sizes have varied from 3.9 L to 27 L, with ambient temperatures from 20°F to 90°F. Analysis (see appendix A) seems to indicate that the energy consumption predictions based on the original laboratory tests are conservative. Thermosiphon heated engine blocks tend to consume more energy than predicted. Pump-driven heated engines tend to consume less energy than predicted. This is not a statistically valid sample size, but general trending supports the lab results. The real world data also seems to support the idea that energy consumption is proportionally tied to engine size. However, more samples are required to validate this initial observation.

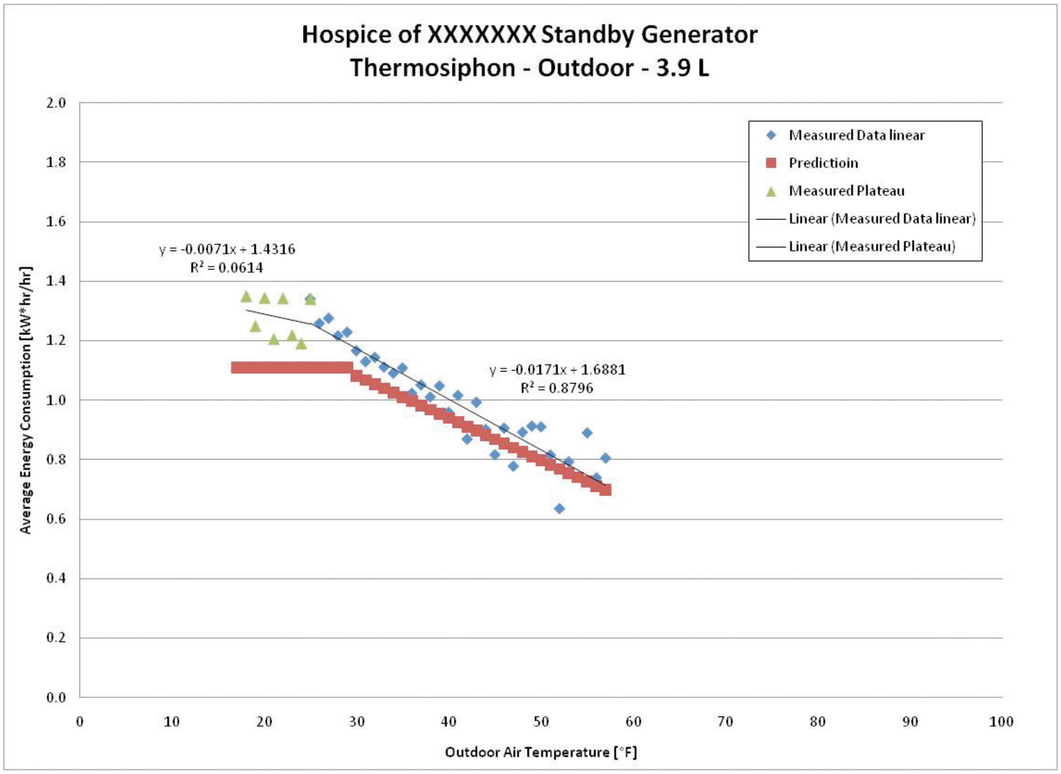
Summary

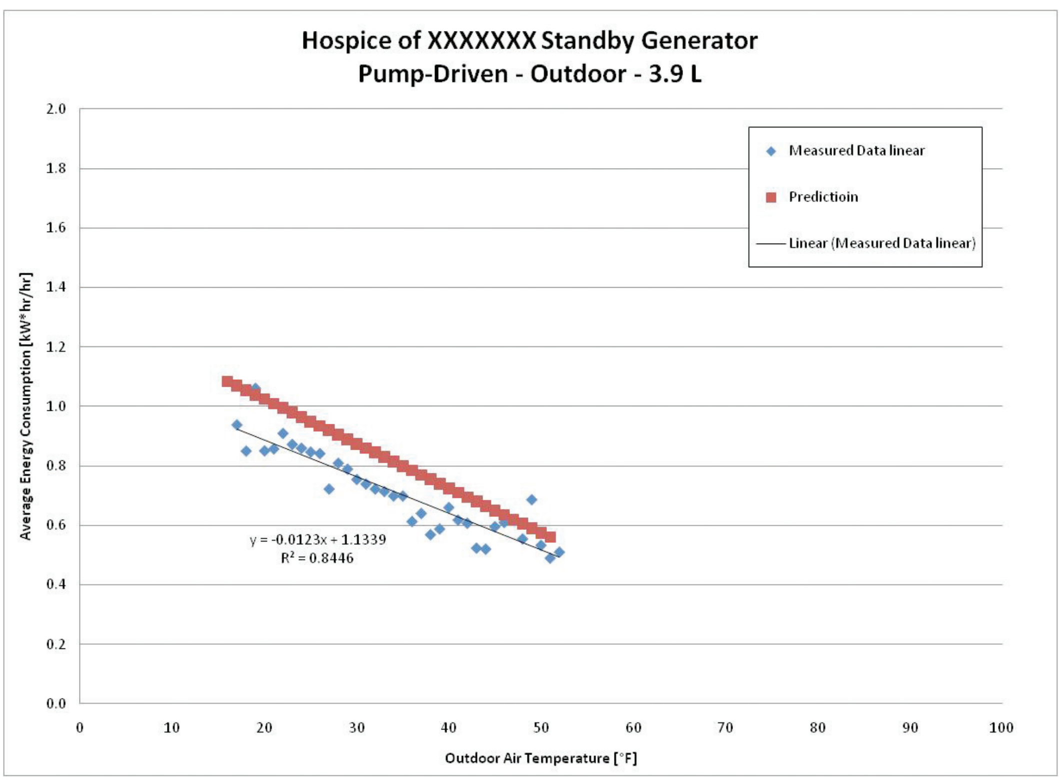
Thermosiphon heaters heat engine blocks to a higher coolant temperature than pump-driven units, to ensure coolant circulation. Increased engine temperatures will result in higher heat transfer rates to the environment thereby requiring more energy to keep the engine warm. Pump-driven heaters operate at a lower average coolant temperature than thermosiphon units; this reduces heat transfer to the environment, but requires energy to operate the pump. Initial laboratory testing indicates that the pump-driven unit uses less energy than the thermosiphon unit. Analysis of the data also indicates that the savings is dependent on the outside air temperature and the size of the engine. A pilot program is in place to drive field testing; initial results appear to support that the laboratory test trends are applicable to the field. The pilot program will continue until a statistically relevant sample size is reached.

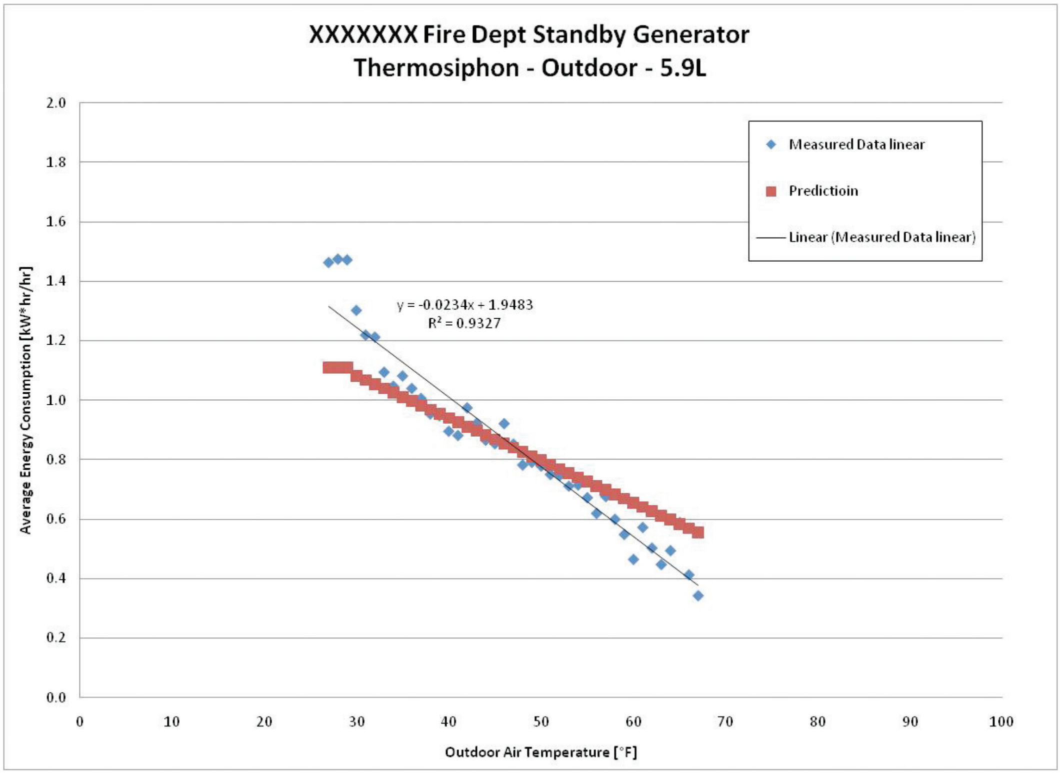
Appendix A

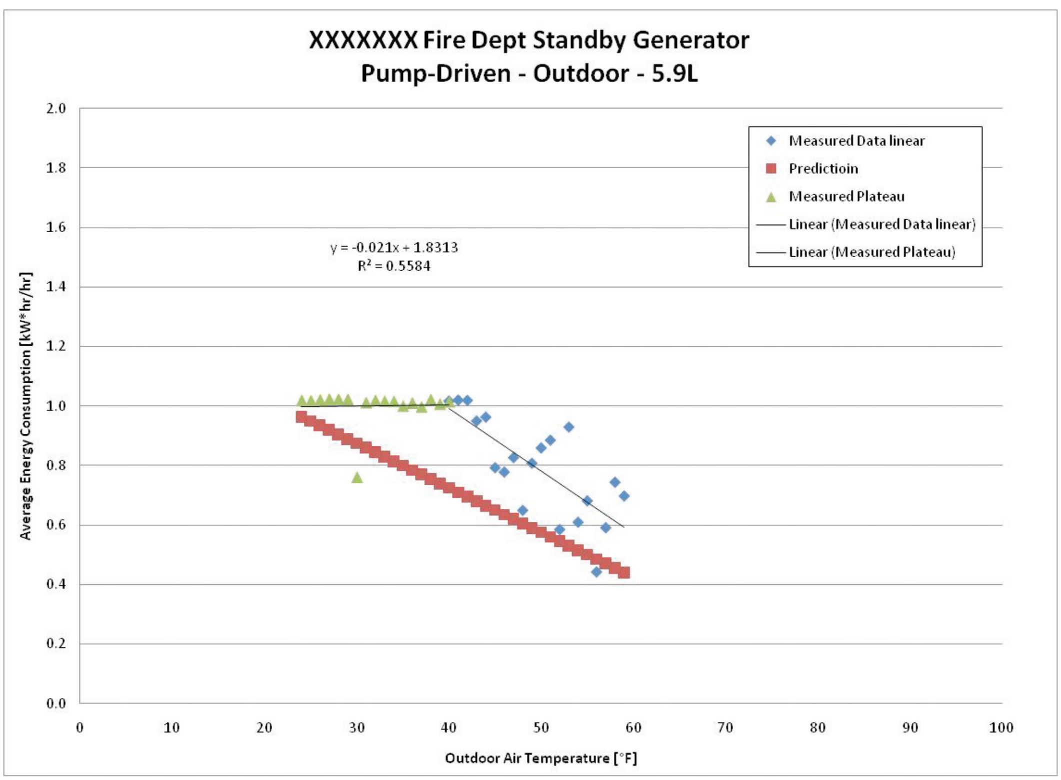

City of XXXXXXXX Stdby Genset
Thermosiphon Heater - Outdoor - 16 L
Measured Data
Prediction
Linear (Measured Data)
y = -0.0402x + 4.0091
R² = 0.9535
Average Hourly Energy Consumption [kW*hr/hr]
Outdoor Air Temperature [°F]

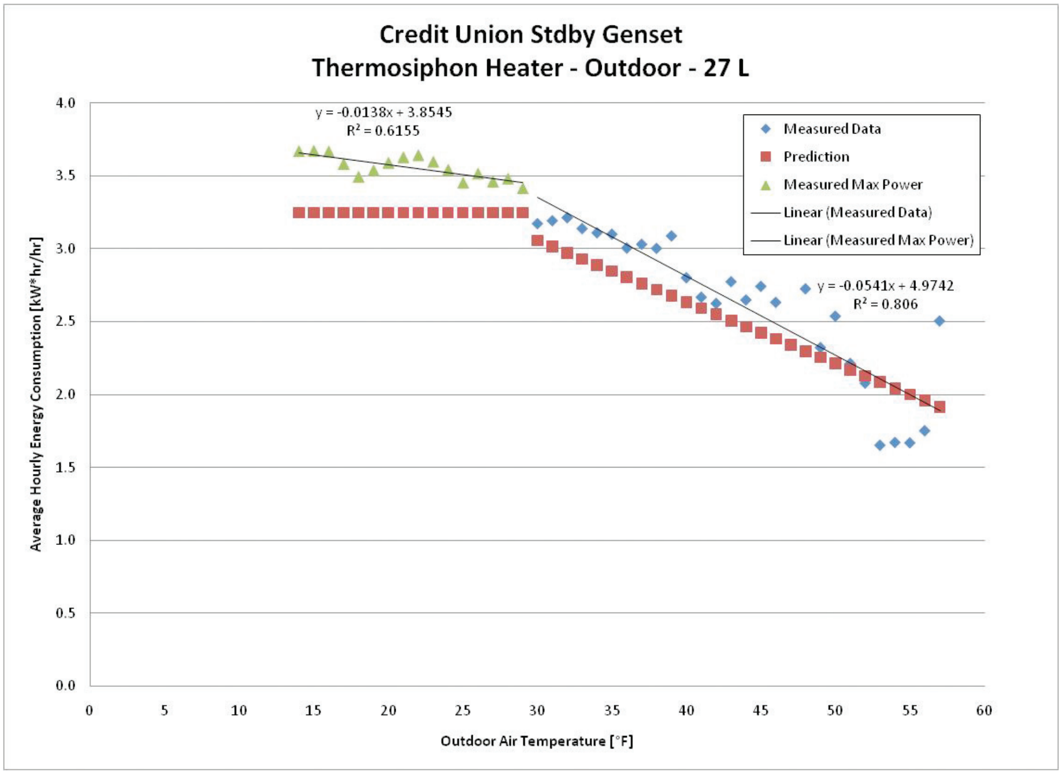

City of XXXXXXXX Stdby Genset
Pump-Driven Heater - Outdoor - 16 L
Measured EEM
Prediction
Linear (Measured EEM)
y = -0.014x + 1.3996
R² = 0.6938
Average Hourly Energy Consumption [kW*hr/hr]
Outdoor Air Temperature [°F]


Hospice of XXXXXXX Standby Generator
Thermosiphon - Outdoor - 3.9 L
Measured Data linear
Predictioin
Measured Plateau
Linear (Measured Data linear)
Linear (Measured Plateau)
y = -0.0071x + 1.4316
R² = 0.0614
y = -0.0171x + 1.6881
R² = 0.8796
Average Energy Consumption [kW*hr/hr]
Outdoor Air Temperature [°F]

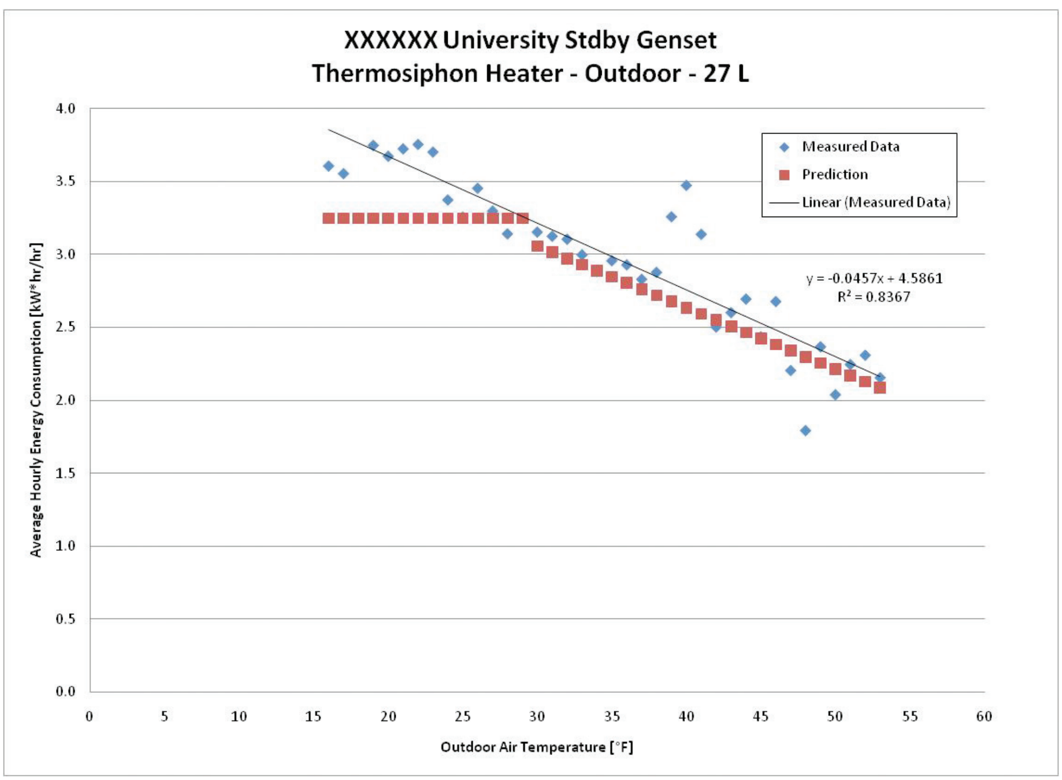

Hospice of XXXXXXX Standby Generator
Pump-Driven - Outdoor - 3.9 L
Measured Data linear
Predictioin
Linear (Measured Data linear)
y = -0.0123x + 1.1339
R² = 0.8446
Average Energy Consumption [kW*hr/hr]
Outdoor Air Temperature [°F]


XXXXXXX Fire Dept Standby Generator
Thermosiphon - Outdoor - 5.9L
Measured Data linear
Predictioin
Linear (Measured Data linear)
y = -0.0234x + 1.9483
R² = 0.9327
Average Energy Consumption [kW*hr/hr]
Outdoor Air Temperature [°F]

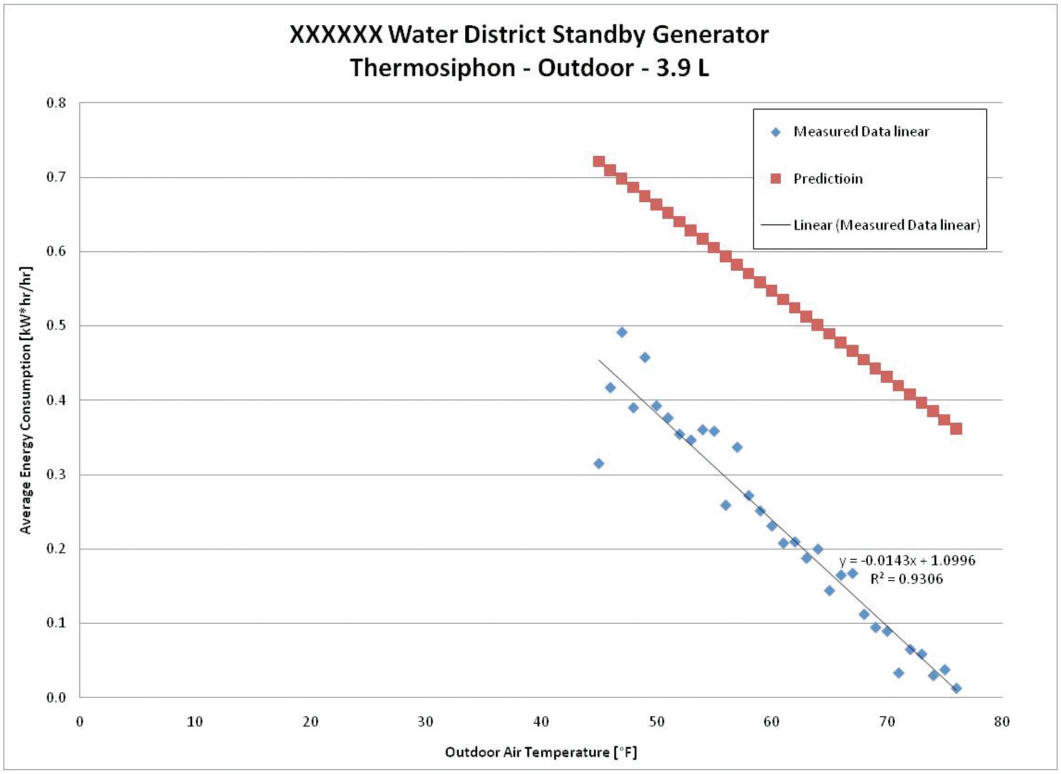

XXXXXXX Fire Dept Standby Generator
Pump-Driven - Outdoor - 5.9L
Measured Data linear
Predictioin
Measured Plateau
Linear (Measured Data linear)
Linear (Measured Plateau)
y = -0.021x + 1.8313
R² = 0.5584
Average Energy Consumption [kW*hr/hr]
Outdoor Air Temperature [°F]

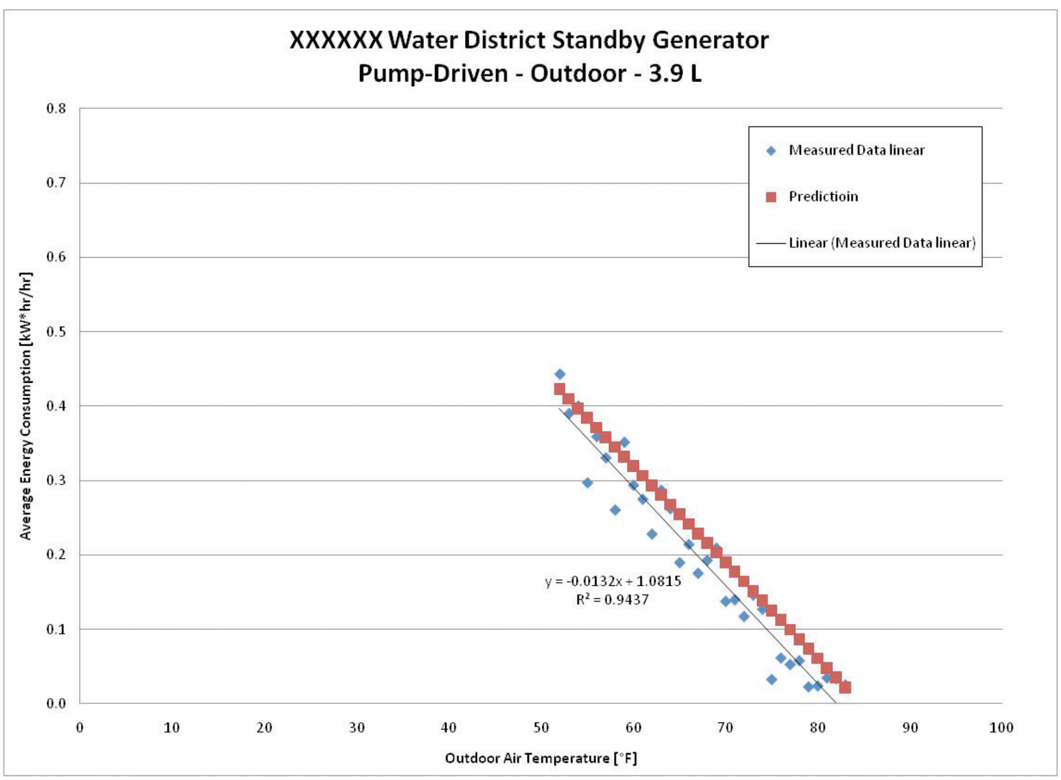


Credit Union Stdby Genset
Thermosiphon Heater - Outdoor - 27 L
y = -0.0138x + 3.8545
R² = 0.6155
y = -0.0541x + 4.9742
R² = 0.806
Measured Data
Prediction
Measured Max Power
Linear (Measured Data)
Linear (Measured Max Power)
Average Hourly Energy Consumption [kW*hr/hr]
Outdoor Air Temperature [°F]



XXXXXX University Stdby Genset
Thermosiphon Heater - Outdoor - 27 L
y = -0.0457x + 4.5861
R² = 0.8367
Measured Data
Prediction
Linear (Measured Data)
Average Hourly Energy Consumption [kW*hr/hr]
Outdoor Air Temperature [°F]


XXXXXX Water District Standby Generator
Thermosiphon - Outdoor - 3.9 L
Measured Data linear
Predictioin
Linear (Measured Data linear)
y = -0.0143x + 1.0996
R² = 0.9306
Average Energy Consumption [kW*hr/hr]
Outdoor Air Temperature [°F]


XXXXXX Water District Standby Generator
Pump-Driven - Outdoor - 3.9 L
Measured Data linear
Predictioin
Linear (Measured Data linear)
y = -0.0132x + 1.0815
R² = 0.9437
Average Energy Consumption [kW*hr/hr]
Outdoor Air Temperature [°F]

Appendix B

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