M&V Case Study

Heat Pump Generator Heaters

Published August 15, 2023

Prepared By CLEAResult

Table of Contents

List of Figures

Executive Summary

This case study looks at the method for calculating the energy savings from (2) heat pump generator heater (HPGH) retrofits in Little Rock, AR. This case study is derived from a measurement and verification report. The original report was generally guided by the International Performance Measurement and Verification Protocol (IPMVP) Option A - Key Parameter Measurement. Using this option, savings were determined by performing field measurements of the existing conditions and taking post-measurements after the project was implemented.

Savings

The savings associated with this project are 3.40449 peak kW and 72,272.78534 annual kWh. The individual savings for each generator is shown in the table below.

	Generator 1	Generator 2
Annual Energy Savings (kWh)	35,885.57	36,387.22
Demand Savings (kW)	1.66	1.75

Estimated Useful Life

The Estimated Useful Life (EUL) for this project is 15 years based on the measure “Unitary and Split System AC/HP Equipment” in AR TRM V9.2 Vol. 2 §3.1.16.

Energy Conservation Measure

Site Details

This facility is a large office building operating from 8:00AM – 5:00PM, Monday through Friday.

Project Description & Purpose

The energy conservation measure (ECM) implemented at this facility was a heat pump generator heater retrofit for (2) generators. A reliable, functioning diesel generator is crucial to facility operation in the event of a power outage. To ensure the generator can start at any time, it must be warm enough to ensure the successful combustion of diesel fuel. Because diesel engines have no spark-ignition system, they rely solely on pressure and temperature to ignite the fuel and start the engine. If the engine block is too cold, the engine will never start until heat is introduced. As a result, many diesel engines are equipped with an engine block heating system that heats the engine coolant and circulates it through the coolant passages. Common block heaters use two electric resistance heaters, one on each side of the engine block, but this form of heating is not very efficient. Heat pumps can provide the same level of heating as electric heaters, while using a fraction of the energy to do so.

The existing equipment affected for this project was four electric resistance heaters on two backup diesel generators that serve the entire facility.

The new equipment was two heat pump heaters that each replaced one electric heater per generator, while the remaining heaters became backup heat sources. The remaining electric heaters operate as the primary heaters when ambient temperatures drop below heat pump operating range (roughly 40°F and below.) Both generators involved in this project were CAT 3516 models. The factory-installed heaters for these units are either dual 6 kW electric heaters or single 9 kW thermosiphon heaters. In this case, both generators were equipped with (2) 9 kW heaters each.

This ECM reduced the energy required to heat the generators to a given temperature. Therefore, the key variables that affected the realization of energy savings included heater power (kW), generator enclosure air temperature (°F), and outdoor dry-bulb (ambient) temperature (°F).

Measurement & Verification Procedure

Measurement Boundary

The measurement boundary included power outputs of the left and right engine block heaters for both generators, and the ambient temperature inside both generator enclosures. Logged power data is shown in Appendix A.

Baseline Period

The baseline period of measurement was from 9/11/20 to 10/27/20. During this baseline period, the following parameters were measured:

- Current (Amps) for each heater leg was measured. There were (4) heaters total, each having two legs of single-phase power, but only current for (4) of the wires was logged in 30 second intervals for the duration of the baseline measurement period due to logger limitations.
- Voltage (V) spot readings for each of the (8) heater legs were taken at the start of the baseline measurement period.
- Enclosure air temperature for both generators was logged in 30 second intervals for the duration of the baseline measurement period.

Reporting Period

The post-ECM reporting period lasted from 9/25/22 to 10/22/22. This data was used to extrapolate year-round energy savings. During this baseline period, the following parameters were measured:

- Power (kW) for each heater leg was measured. The heat pump heater and the electric heater each had two legs of single-phase power in both generators, so power for (8) wires was logged in 30 second intervals for the duration of the post-ECM measurement period.
- Enclosure air temperature for both generators was logged in the same interval as the baseline reporting period.

Adjustments, Assumptions & Estimated Values

In the baseline measurement period, the voltage was assumed to remain constant, and the product of the respective current and spot voltage readings were used to derive power (kW) for each heater leg.

Due to logger limitations, the post-ECM reporting period required the logging of power as opposed to the logging of current and spot voltage readings like the baseline measurement period.

Savings Calculations

The following calculations were used to determine the peak demand kW and annual energy kWh savings associated with this project.

For the baseline data, interval current data (A) and spot voltage readings (V) were used to calculate the baseline power (kW), using Equation 1. Electric resistance heaters operate with a power factor of one, and dividing by 1000 converts the power units from W to kW. This step was not required for the post-retrofit data because power was logged directly.

$$P = \frac{V * I * PF}{1000} \tag{1}$$

Where:

P = Power (in kW)

V = Spot Voltage (in V)

I = Current (in A)

PF = Power Factor = 1 for the electric resistance heaters

Once the various interval data was collected, the heater power (kW) and enclosure air temperature (°F) was matched to outdoor dry-bulb temperature (°F). The outdoor temperature data was provided by NOAA at Little Rock Adam's Field in hourly intervals. The respective power and enclosure air temperature interval data was converted to hourly averages for each generator.

Once the data was averaged to hourly intervals based on the NOAA data timestamp values, two bin analyses were used to correlate outdoor dry-bulb temperature (°F) to enclosure air temperature (°F) for both generators. The correlations were found to be linear for the baseline and post-retrofit data for both generators. The linear regression formula from the baseline and post-retrofit temperature bin analyses for generators 1 and 2 are shown in Equation 3 below. Graphs of the regressions are shown in Appendix B.

$$T_{Enclosure} = mT_{DB} + b \tag{2}$$

Where:

$m =$ *slope;* $Gen\ 1 \begin{cases} Baseline = 0.867 \\ Post - Retrofit = 0.699 \end{cases}; Gen\ 2 \begin{cases} Baseline = 0.722 \\ Post - Retrofit = 0.699 \end{cases}$

$b =$ *intercept;* $Gen\ 1 \begin{cases} Baseline = 13.304 \\ Post - Retrofit = 20.249 \end{cases}; Gen\ 2 \begin{cases} Baseline = 18.387 \\ Post - Retrofit = 20.249 \end{cases}$

T_{DB} *= NOAA – Outdoor Dry-Bulb (°F)*

Next, another series of bin analyses were used to correlate enclosure air temperature (°F) to heater power (kW). This correlation was also found to be linear for both generators. The combination of all the regressions allows the temperatures and heater power inside the generator enclosures to be normalized using TMY3 data for Little Rock, AR. The TMY3 data uses a variety of temperatures taken between 1977 and 2004 to estimate temperatures throughout a typical year. The linear regression formula from the baseline power bin analyses for generators 1 and 2 are shown in Equation 4 below. Graphs of the regressions are shown in Appendix B.

$$P_{Baseline} = mT_{Enclosure} + b \tag{3}$$

Where:

m = *slope; Gen 1 Baseline = -0.151, Gen 2 Baseline = -0.171*

b = *intercept; Gen 1 Baseline = 15.342, Gen 2 Baseline = 16.297*

$T_{Enclosure}$ = *Enclosure Air Temperature (°F)*

These equations provide hourly heater kW for a typical year in Little Rock for both the baseline and post-retrofit conditions for both generators. The post-retrofit differed slightly in that it required additional bin analyses to account for the non-linear responses of the heating systems when the enclosure air temperatures force the heat pumps to cycle off and the single electric heaters to cycle on for each respective generator. The additional bin analyses also yield linear correlations for both generators, but they are specifically for heater operation below the heat pump shut off points. The linear regression formula from the post-retrofit power bin analyses for enclosure air temperatures greater than or equal to 38°F for generator 1 and 46°F for generator 2 are shown in Equation 5 below. Graphs of the regressions are again shown in Appendix B.

$$P_{Post,\geq T_{HP\ Shutoff}} = mT_{Enclosure} + b \tag{4}$$

Where:

m = *slope; Gen 1 Post-Retrofit = -0.040, Gen 2 Post-Retrofit = -0.020*

b = *intercept; Gen 1 Post-Retrofit = 3.572, Gen 2 Post-Retrofit = 2.338*

$T_{Enclosure}$ = *Enclosure Air Temperature (°F)*

$T_{HP\ Shutoff}$ = *Heat Pump Shutoff Temperature (Gen 1 = 38°F, Gen 2 = 46°F)*

The linear regressions from the post-retrofit power bin analyses for enclosure air temperatures less than 38°F for generator 1 and 46°F for generator 2 are shown in Equation 6 below. Graphs of the regressions are again shown in Appendix B.

$$P_{Post,<T_{HP\ Shutoff}} = mT_{Enclosure} + b \tag{5}$$

Where:

m = *slope; Gen 1 Post-Retrofit = -0.177, Gen 2 Post-Retrofit = -0.402*

$b = intercept$; *Gen 1 Post-Retrofit = 9.909, Gen 2 Post-Retrofit = 19.128*

$T_{Enclosure}$ = *Enclosure Air Temperature (°F)*

$T_{HP\ Shutoff}$ = *Heat Pump Shutoff Temperature (Gen 1 = 38°F, Gen 2 = 46°F)*

Heater power is normalized for a typical weather year using a piecewise function to choose the correct heater power regression for a given enclosure air temperature for each generator. Boundary conditions for both the baseline and post-retrofit heater power regressions also prevent the heater power from going below 0 kW and above the maximum rated power of the heaters for each generator. The results from these calculations are shown in Appendix D.

Once the annual hourly heater power values are known for the baseline and post-retrofit data for both generators, the sum of each respective list provides the baseline and post-retrofit annual heater energy consumptions, respectively. The difference between these two numbers yields the annual heater energy savings (in kWh). The results of all annual energy calculations are shown in Appendix D. The following formulas were used to calculate baseline annual energy use, post-retrofit annual energy use, and annual energy savings for each generator. The constants in each equation are slopes and intercepts referenced in the power bin analyses above.

$$Baseline\ Annual\ Energy\ (kWh)_{G1} = \sum_{i=0}^{8760} -0.151346803\ x\ Hourly\ TMY3\ (°F) + 15.34177147 \quad (6)$$

$$Baseline\ Annual\ Energy\ (kWh)_{G2} = \sum_{i=0}^{8760} -0.171089458\ x\ Hourly\ TMY3\ (°F) + 16.29686803 \quad (7)$$

$$Post\ Annual\ Energy\ (kWh)_{\geq G1} = \sum_{i=0}^{8760} -0.040019915\ x\ Hourly\ TMY3\ (°F) + 3.571736237 \quad (8)$$

$$Post\ Annual\ Energy\ (kWh)_{\geq G2} = \sum_{i=0}^{8760} -0.020054802\ x\ Hourly\ TMY3\ (°F) + 2.337635959 \quad (9)$$

$$Post\ Annual\ Energy\ (kWh)_{<G1} = \sum_{i=0}^{8760} -0.176812751\ x\ Hourly\ TMY3\ (°F) + 9.908679986 \quad (10)$$

$$Post\ Annual\ Energy\ (kWh)_{<G2} = \sum_{i=0}^{8760} -0.401792069\ x\ Hourly\ TMY3\ (°F) + 19.12829901 \quad (11)$$

$$Annual\ Savings\ (kWh) = Basline\ Annual\ Energy\ (kWh) - (Post\ Annual\ Energy\ (kWh)_{\geq} + Post\ Annual\ Energy\ (kWh)_{<}) \quad (12)$$

The annual hourly heater power values are used to calculate the baseline and post-retrofit peak demand power, and the peak demand savings for both generators. The results of the peak demand calculations are shown in Appendix D. Equation 11 was used to calculate both baseline and post-retrofit peak demand for generators 1 and 2.

$$Peak\ Demand\ kW = AVERAGEIFS(Average\ Range, Criteria\ Range_{1-6}, Criteria_{1-6}) \quad (13)$$

Where:

Average Range = Avg. kW Range

Criteria $Range_{1,2}$ *= Weekday Range*

$Criteria_1$ *= Weekday >1 (Starting after Sunday; Monday at 12:00 AM)*

$Criteria_2$ *= Weekday <7 (Ending before Saturday; Friday at 11:59 PM)*

Criteria $Range_{3,4}$ *= Hour Range*

$Criteria_3$ *= Hour ≥13 (Starting at 1:00 PM)*

$Criteria_4$ *= Hour <20 (Up to 8:00 PM)*

Criteria $Range_{5,6}$ *= Month Range*

$Criteria_5$ *= Month ≥ 6 (Starting at the 1*st *of June)*

$Criteria_6$ *= Hour ≤ 9 (Through the end of September)*

Appendix A: Measured Data

Figure 1. Generator 1 and 2 Combined Baseline Data

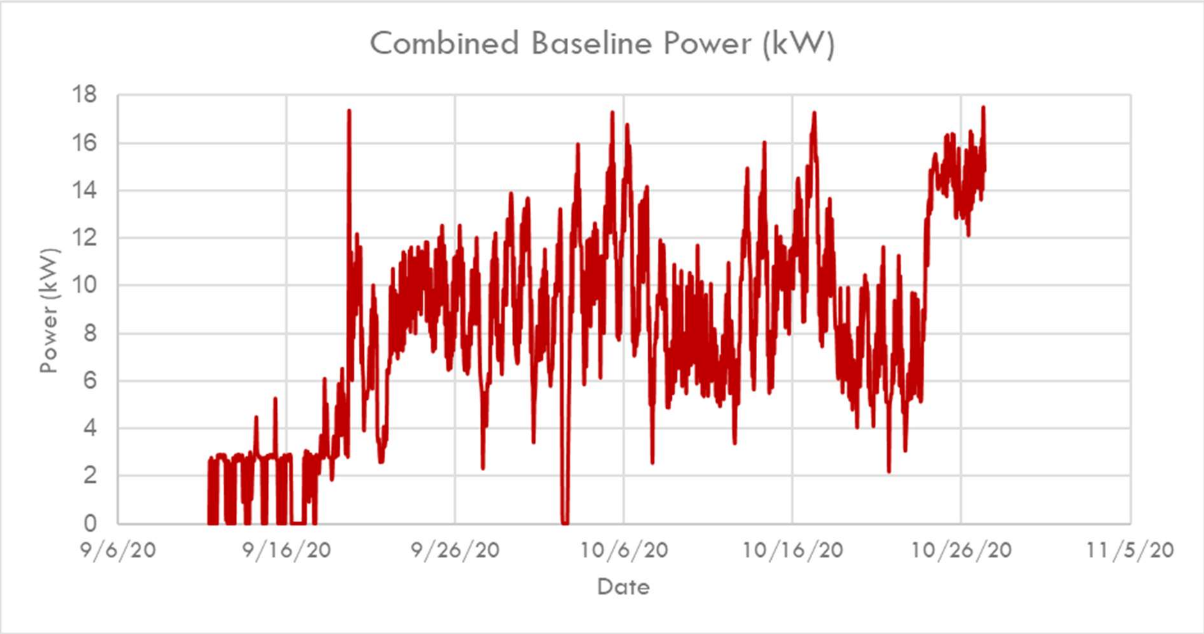
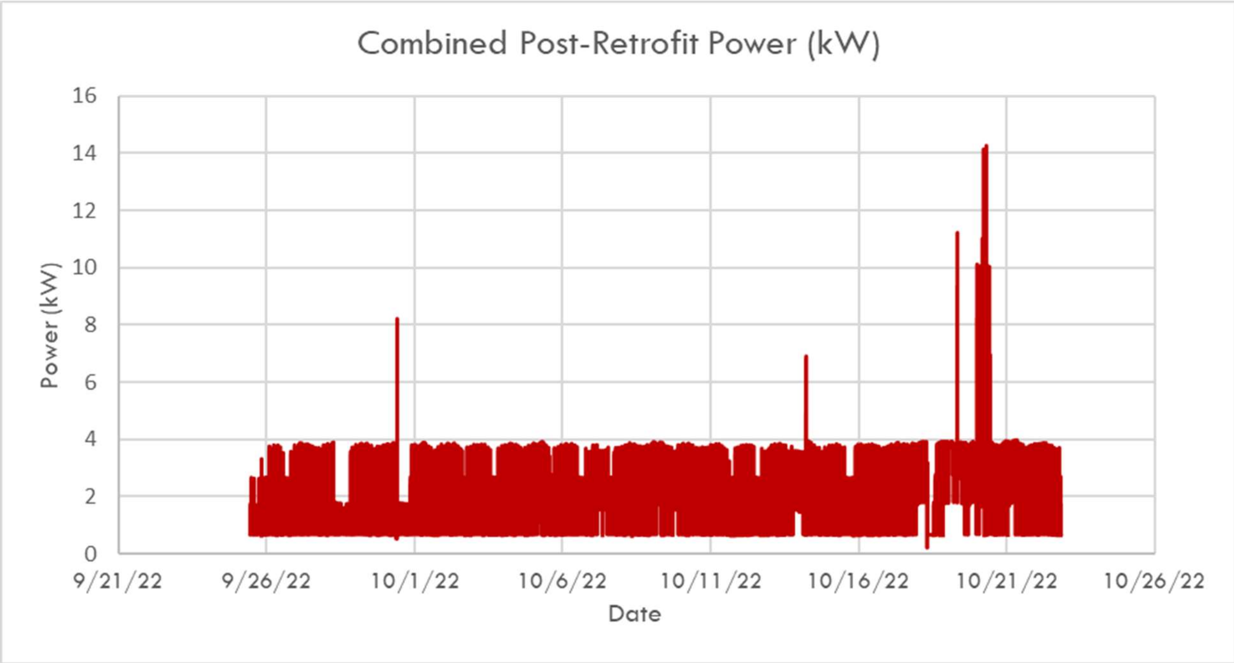


Figure 2. Generator 1 and 2 Combined Post Data



Appendix B: Temperature and Power Regressions

Figure 3. Generator 1 Baseline Temperature Regression

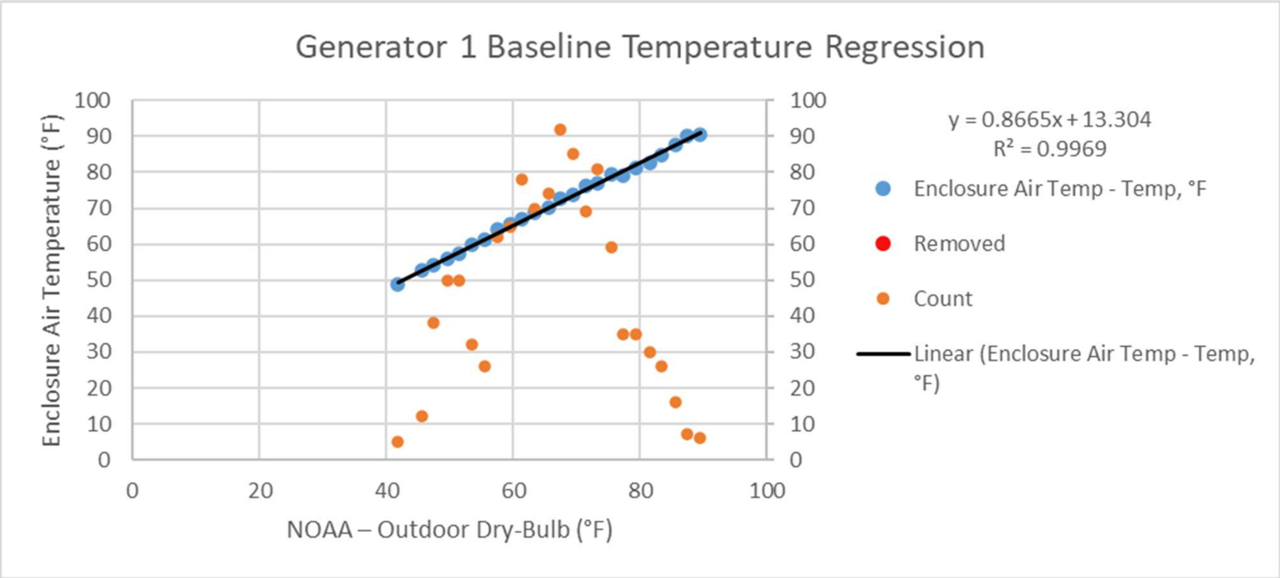


Figure 4. Generator 1 Baseline Power Regression

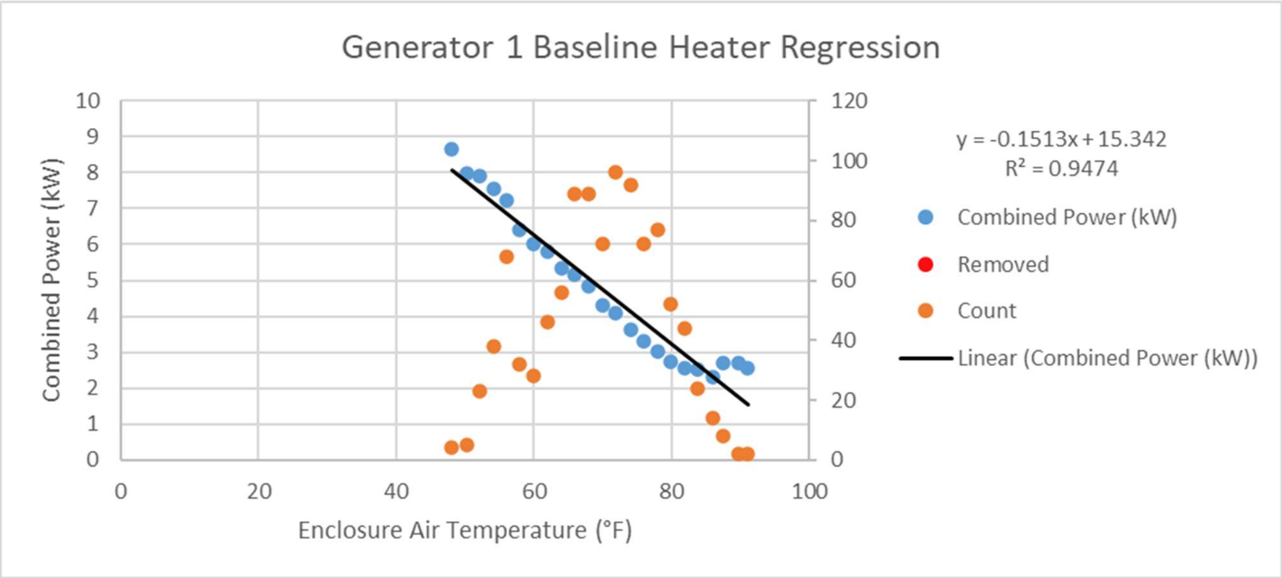


Figure 5. Generator 2 Baseline Temperature Regression

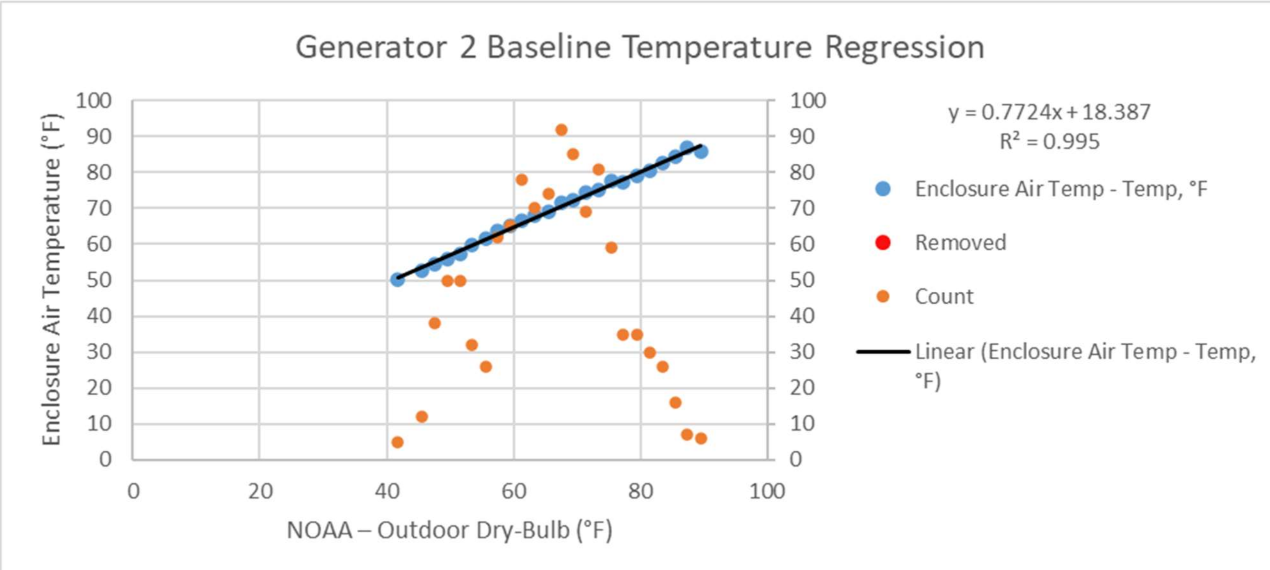


Figure 6. Generator 2 Baseline Heater Regression

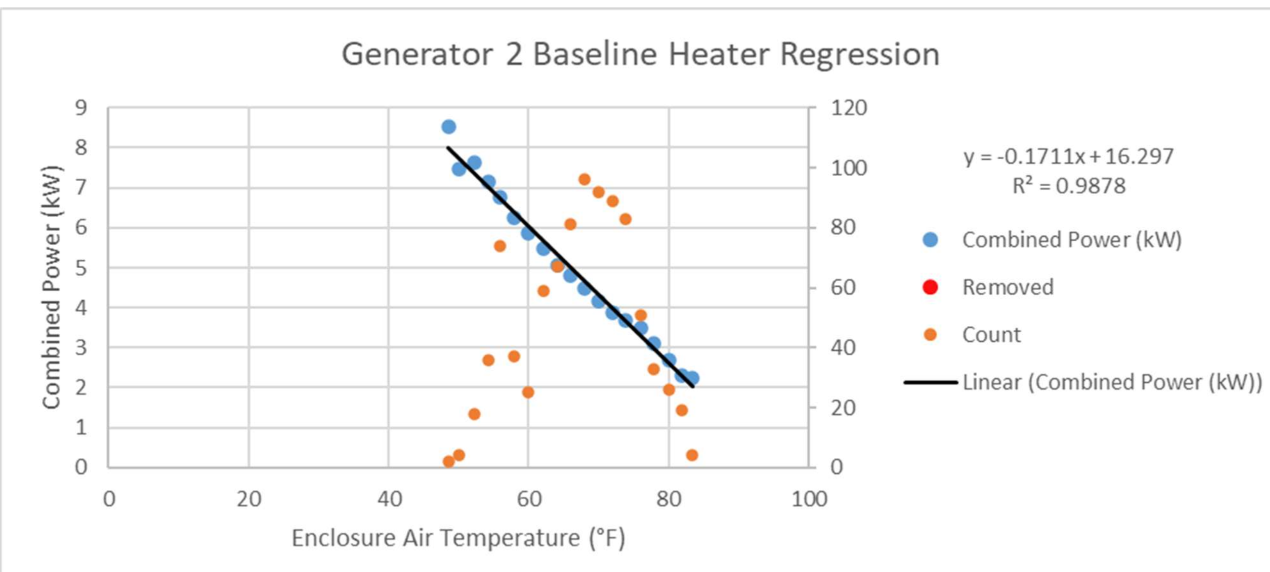


Figure 7. Generator 1 Post-Retrofit Temperature Regression

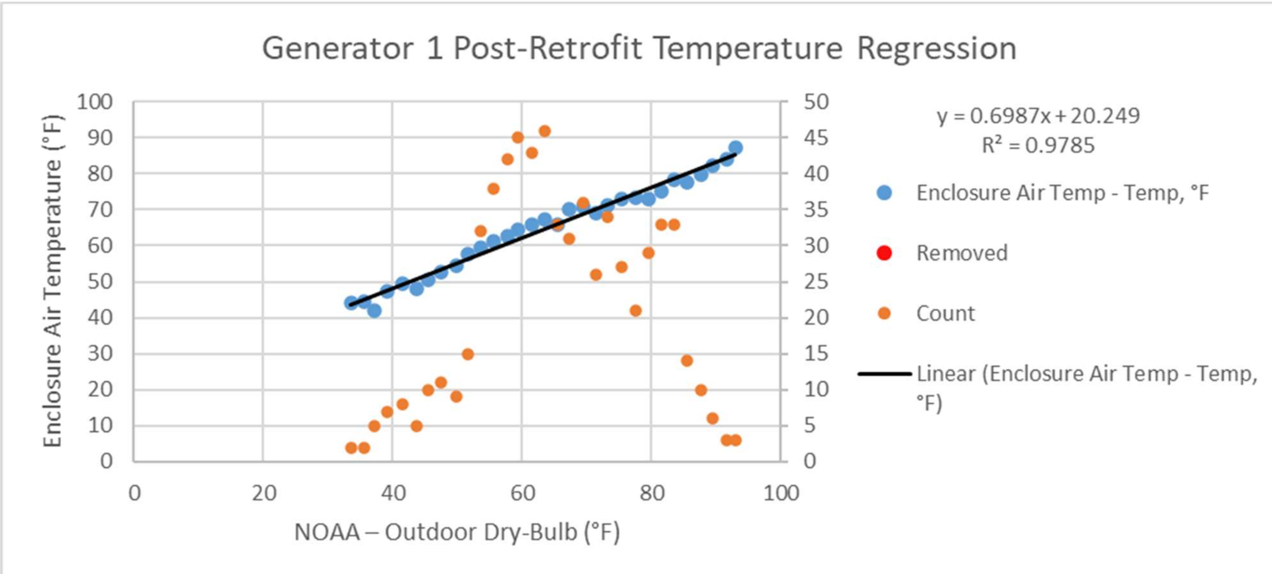


Figure 8. Generator 1 Post-Retrofit Power Regression (≥38°F)

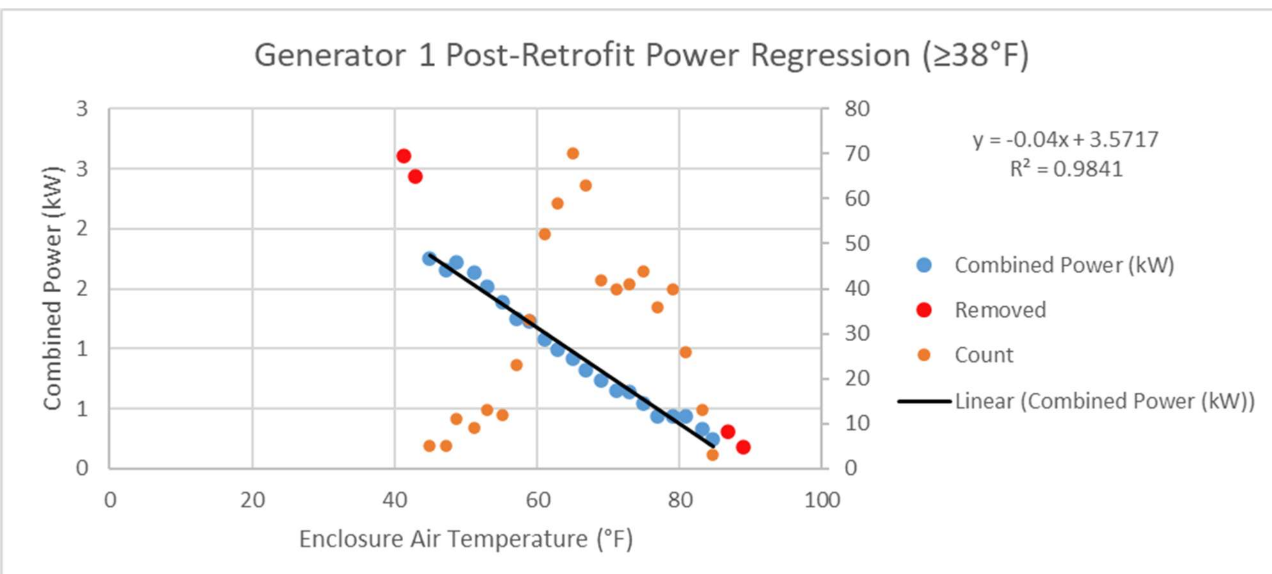


Figure 9. Generator 1 Post-Retrofit Power Regression (<38°F)

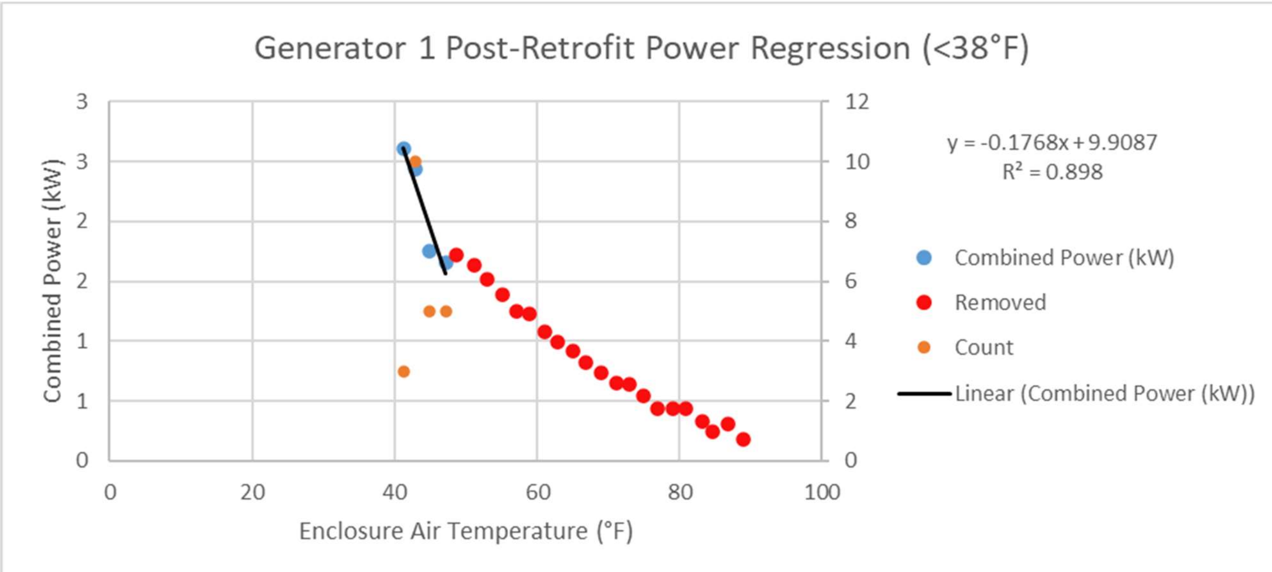


Figure 10. Generator 2 Post-Retrofit Temperature Regression

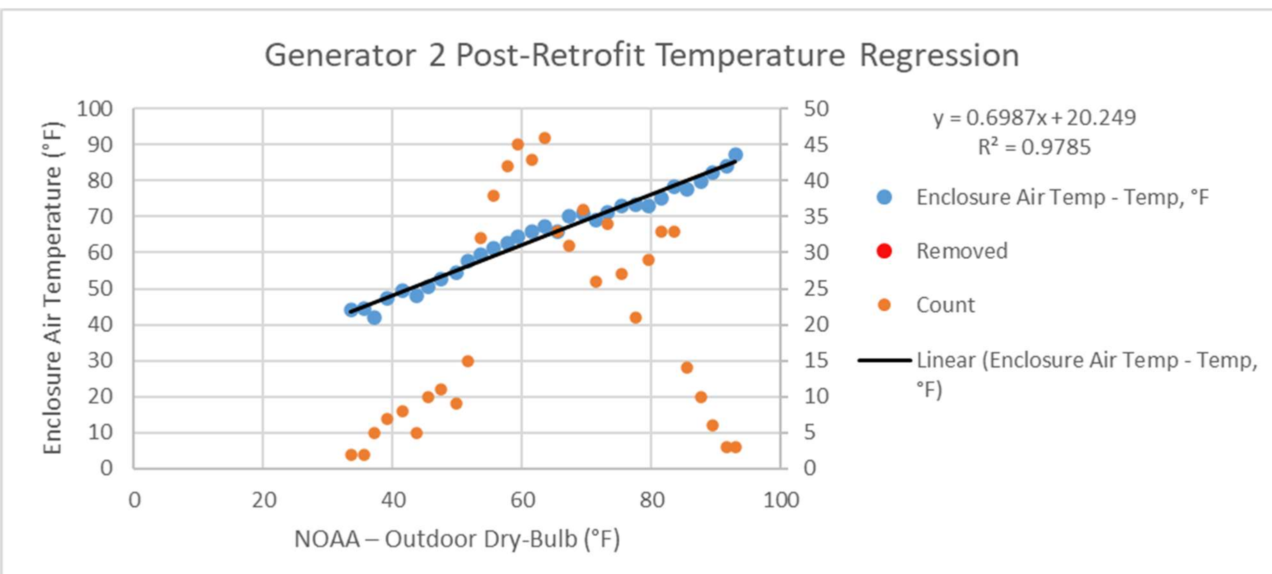


Figure 11. Generator 2 Post-Retrofit Power Regression (≥46°F)

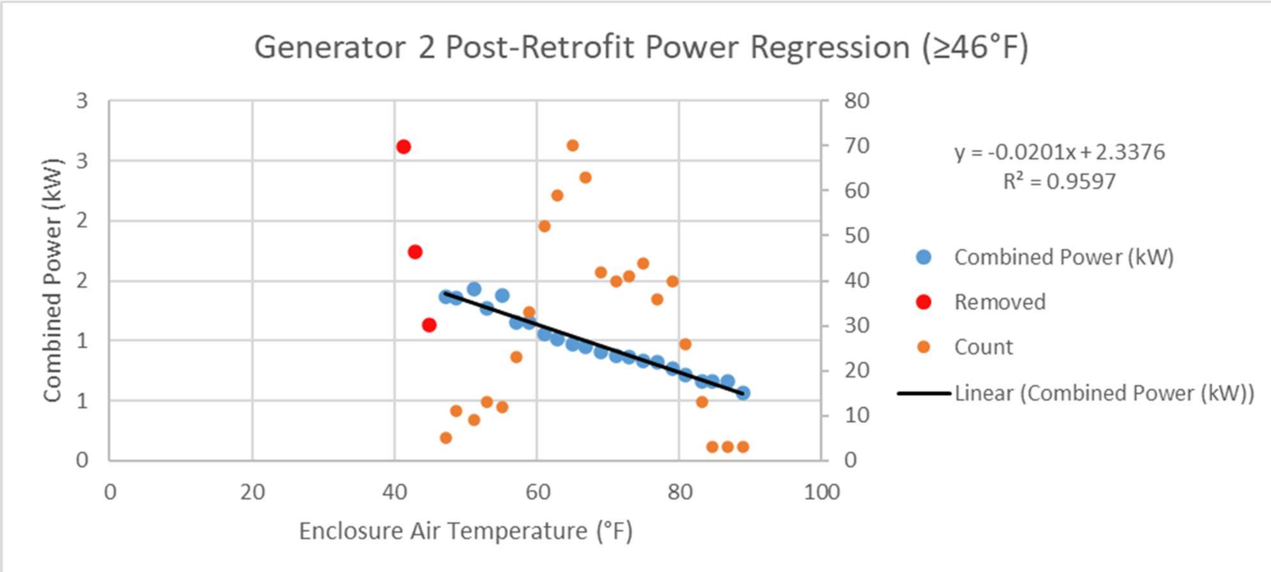
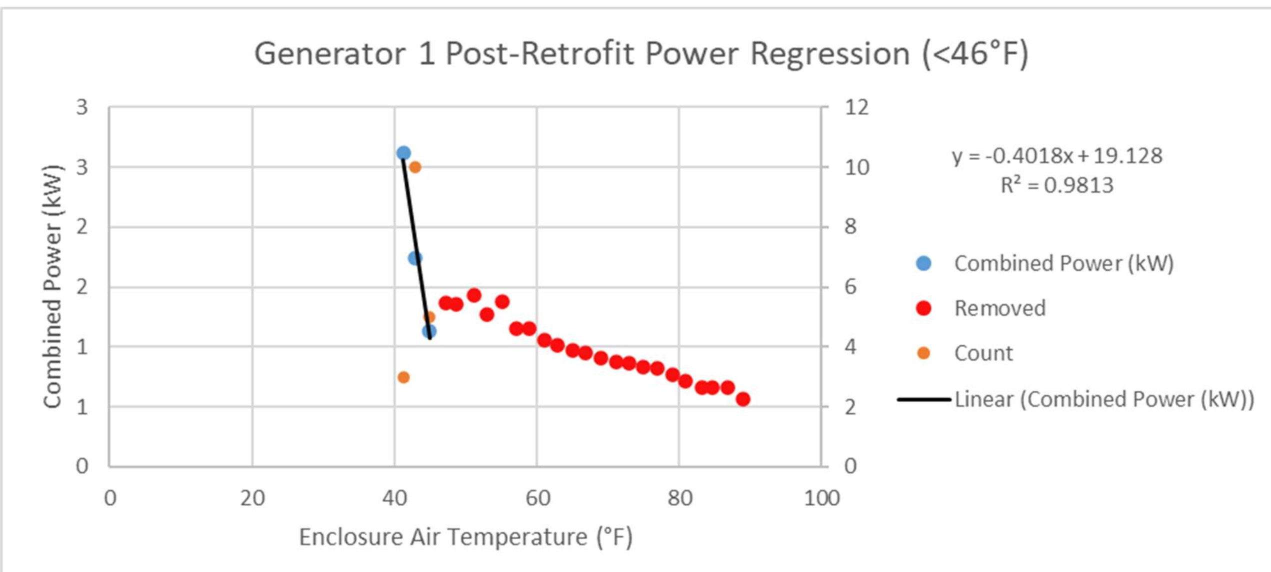


Figure 12. Generator 2 Post-Retrofit Power Regression (<46°F)



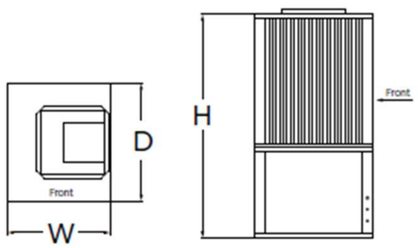
Appendix C: Data Sheets

The data sheet for the equipment can be found below.

Hotstart THERMAL MANAGEMENT

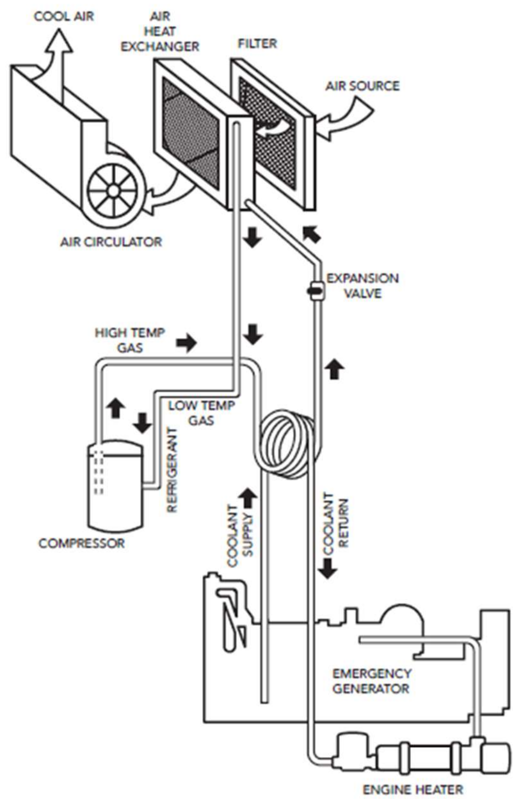
High Efficiency Heating System

HE



HE-24			
Depth (D)	Width (W)	Height (H)	Weight
25.6"	22.4"	48.5"	266 lbs
650 mm	569 mm	1231 mm	121 kg

Specifications	
Phase	single-phase (1 Ø)
Voltage (AC)	208 / 230
Environment Rating	Indoor locations*
Certification	ETL/C-US, AHRI, ASHRAE
Refrigerant	HFC-410A
Coolant Type	Water | Coolant mix (50% water/50% glycol)
Circuit Ampacity	20
Total FLA.	15.5
Inlet/Outlet	3/4" NPT
Heat Capacity**	7 kW



Heat is removed from the air and is transferred to the engine coolant system through pressurized refrigerant.

* Outdoor installations require additional guarding package.
** Heat capacity dependent on ambient temperatures.
Contact Hotstart for recommendations based on your project specifications.

For assistance with your heating system application, contact Hotstart at 509.536.8660 or heatpumps@hotstart.com.

hotstart.com sales@hotstart.com

DS-HE-E
2023-1/rev1

Heat Pump Data Sheet

Appendix D: Calculations

Figure 13. Generator 1 Baseline Temperature and Power Annualized Regression Calculations

Little Rock TMY3 Data								*Generator 1 (COB)	
Date (MM/DD/YYYY)	Month	Day	Weekday	Time (HH:MM)	Hour	Dry-bulb (C)	Dry-bulb (°F)	Modeled Post Enclosure Air Temp	Post Heater Power (kW)
1/1/1982	1	1	6	1:00:00 AM	1	5	41	48.90	1.61
1/1/1982	1	1	6	2:00:00 AM	2	4.4	39.92	48.14	1.65
1/1/1982	1	1	6	3:00:00 AM	3	2.2	35.96	45.37	1.76
1/1/1982	1	1	6	4:00:00 AM	4	1.7	35.06	44.75	1.78
1/1/1982	1	1	6	5:00:00 AM	5	0	32	42.61	1.87
1/1/1982	1	1	6	6:00:00 AM	6	-0.6	30.92	41.85	1.90
1/1/1982	1	1	6	7:00:00 AM	7	-1.1	30.02	41.22	1.92
1/1/1982	1	1	6	8:00:00 AM	8	-1.1	30.02	41.22	1.92
1/1/1982	1	1	6	9:00:00 AM	9	0.6	33.08	43.36	1.84
1/1/1982	1	1	6	10:00:00 AM	10	2.2	35.96	45.37	1.76
1/1/1982	1	1	6	11:00:00 AM	11	3.9	39.02	47.51	1.67
1/1/1982	1	1	6	12:00:00 PM	12	4.4	39.92	48.14	1.65
1/1/1982	1	1	6	1:00:00 PM	13	5	41	48.90	1.61
1/1/1982	1	1	6	2:00:00 PM	14	6.1	42.98	50.28	1.56
1/1/1982	1	1	6	3:00:00 PM	15	6.1	42.98	50.28	1.56
1/1/1982	1	1	6	4:00:00 PM	16	5.6	42.08	49.65	1.58
1/1/1982	1	1	6	5:00:00 PM	17	4.4	39.92	48.14	1.65
1/1/1982	1	1	6	6:00:00 PM	18	2.8	37.04	46.13	1.73
1/1/1982	1	1	6	7:00:00 PM	19	1.7	35.06	44.75	1.78
1/1/1982	1	1	6	8:00:00 PM	20	2.2	35.96	45.37	1.76
1/1/1982	1	1	6	9:00:00 PM	21	2.8	37.04	46.13	1.73
1/1/1982	1	1	6	10:00:00 PM	22	2.2	35.96	45.37	1.76
1/1/1982	1	1	6	11:00:00 PM	23	2.2	35.96	45.37	1.76
1/1/1982	1	1	6	12:00:00 AM	0	0.6	33.08	43.36	1.84
1/2/1982	1	2	7	1:00:00 AM	1	0.6	33.08	43.36	1.84
1/2/1982	1	2	7	2:00:00 AM	2	1.1	33.98	43.99	1.81
1/2/1982	1	2	7	3:00:00 AM	3	1.1	33.98	43.99	1.81
1/2/1982	1	2	7	4:00:00 AM	4	1.1	33.98	43.99	1.81
1/2/1982	1	2	7	5:00:00 AM	5	1.1	33.98	43.99	1.81
1/2/1982	1	2	7	6:00:00 AM	6	1.1	33.98	43.99	1.81
1/2/1982	1	2	7	7:00:00 AM	7	1.7	35.06	44.75	1.78
1/2/1982	1	2	7	8:00:00 AM	8	2.8	37.04	46.13	1.73
1/2/1982	1	2	7	9:00:00 AM	9	3.3	37.94	46.76	1.70
1/2/1982	1	2	7	10:00:00 AM	10	5	41	48.90	1.61
1/2/1982	1	2	7	11:00:00 AM	11	7.2	44.96	51.66	1.50
1/2/1982	1	2	7	12:00:00 PM	12	10.6	51.08	55.94	1.33
1/2/1982	1	2	7	1:00:00 PM	13	10.6	51.08	55.94	1.33
1/2/1982	1	2	7	2:00:00 PM	14	6.1	42.98	50.28	1.56
1/2/1982	1	2	7	3:00:00 PM	15	7.2	44.96	51.66	1.50
1/2/1982	1	2	7	4:00:00 PM	16	7.2	44.96	51.66	1.50
1/2/1982	1	2	7	5:00:00 PM	17	7.8	46.04	52.42	1.47
1/2/1982	1	2	7	6:00:00 PM	18	7.8	46.04	52.42	1.47
1/2/1982	1	2	7	7:00:00 PM	19	7.8	46.04	52.42	1.47
1/2/1982	1	2	7	8:00:00 PM	20	7.8	46.04	52.42	1.47
1/2/1982	1	2	7	9:00:00 PM	21	8.3	46.94	53.05	1.45
1/2/1982	1	2	7	10:00:00 PM	22	8.9	48.02	53.80	1.42
1/2/1982	1	2	7	11:00:00 PM	23	8.9	48.02	53.80	1.42
1/2/1982	1	2	7	12:00:00 AM	0	9.4	48.92	54.43	1.39

Figure 14. Generator 2 Baseline Temperature and Power Annualized Regression Calculations

*Generator 2 (CDOC)	
Modeled Post Enclosure Air Temp (°F)	Post Heater Power (kW)
48.90	1.36
48.14	1.37
45.37	0.90
44.75	1.15
42.61	2.01
41.85	2.31
41.22	2.56
41.22	2.56
43.36	1.71
45.37	0.90
47.51	1.38
48.14	1.37
48.90	1.36
50.28	1.33
50.28	1.33
49.65	1.34
48.14	1.37
46.13	1.41
44.75	1.15
45.37	0.90
46.13	1.41
45.37	0.90
45.37	0.90
43.36	1.71
43.36	1.71
43.99	1.45
43.99	1.45
43.99	1.45
43.99	1.45
43.99	1.45
44.75	1.15
46.13	1.41
46.76	1.40
48.90	1.36
51.66	1.30
55.94	1.22
55.94	1.22
50.28	1.33
51.66	1.30
51.66	1.30
52.42	1.29
52.42	1.29
52.42	1.29
52.42	1.29
53.05	1.27
53.80	1.26
53.80	1.26
54.43	1.25

Figure 15. Generator 1 Post-Retrofit Temperature and Power Annualized Regression Calculations

Little Rock TMY3 Data								*Generator 1 (COB)		*Generator 1 (COB)
Date (MM/DD/YYYY)	Month	Day	Weekday	Time (HH:MM)	Hour	Dry-bulb (C)	Dry-bulb (°F)	Modeled Post Enclosure Air Temp	Post Heater Power (kW)	Final Savings (kW)
1/1/1982	1	1	6	1:00:00 AM	1	5	41	48.90	1.61	6.34
1/1/1982	1	1	6	2:00:00 AM	2	4.4	39.92	48.14	1.65	6.45
1/1/1982	1	1	6	3:00:00 AM	3	2.2	35.96	45.37	1.76	6.86
1/1/1982	1	1	6	4:00:00 AM	4	1.7	35.06	44.75	1.78	6.95
1/1/1982	1	1	6	5:00:00 AM	5	0	32	42.61	1.87	7.13
1/1/1982	1	1	6	6:00:00 AM	6	-0.6	30.92	41.85	1.90	7.10
1/1/1982	1	1	6	7:00:00 AM	7	-1.1	30.02	41.22	1.92	7.08
1/1/1982	1	1	6	8:00:00 AM	8	-1.1	30.02	41.22	1.92	7.08
1/1/1982	1	1	6	9:00:00 AM	9	0.6	33.08	43.36	1.84	7.15
1/1/1982	1	1	6	10:00:00 AM	10	2.2	35.96	45.37	1.76	6.86
1/1/1982	1	1	6	11:00:00 AM	11	3.9	39.02	47.51	1.67	6.54
1/1/1982	1	1	6	12:00:00 PM	12	4.4	39.92	48.14	1.65	6.45
1/1/1982	1	1	6	1:00:00 PM	13	5	41	48.90	1.61	6.34
1/1/1982	1	1	6	2:00:00 PM	14	6.1	42.98	50.28	1.56	6.13
1/1/1982	1	1	6	3:00:00 PM	15	6.1	42.98	50.28	1.56	6.13
1/1/1982	1	1	6	4:00:00 PM	16	5.6	42.08	49.65	1.58	6.22
1/1/1982	1	1	6	5:00:00 PM	17	4.4	39.92	48.14	1.65	6.45
1/1/1982	1	1	6	6:00:00 PM	18	2.8	37.04	46.13	1.73	6.74
1/1/1982	1	1	6	7:00:00 PM	19	1.7	35.06	44.75	1.78	6.95
1/1/1982	1	1	6	8:00:00 PM	20	2.2	35.96	45.37	1.76	6.86
1/1/1982	1	1	6	9:00:00 PM	21	2.8	37.04	46.13	1.73	6.74
1/1/1982	1	1	6	10:00:00 PM	22	2.2	35.96	45.37	1.76	6.86
1/1/1982	1	1	6	11:00:00 PM	23	2.2	35.96	45.37	1.76	6.86
1/1/1982	1	1	6	12:00:00 AM	0	0.6	33.08	43.36	1.84	7.15
1/2/1982	1	2	7	1:00:00 AM	1	0.6	33.08	43.36	1.84	7.15
1/2/1982	1	2	7	2:00:00 AM	2	1.1	33.98	43.99	1.81	7.06
1/2/1982	1	2	7	3:00:00 AM	3	1.1	33.98	43.99	1.81	7.06
1/2/1982	1	2	7	4:00:00 AM	4	1.1	33.98	43.99	1.81	7.06
1/2/1982	1	2	7	5:00:00 AM	5	1.1	33.98	43.99	1.81	7.06
1/2/1982	1	2	7	6:00:00 AM	6	1.1	33.98	43.99	1.81	7.06
1/2/1982	1	2	7	7:00:00 AM	7	1.7	35.06	44.75	1.78	6.95
1/2/1982	1	2	7	8:00:00 AM	8	2.8	37.04	46.13	1.73	6.74
1/2/1982	1	2	7	9:00:00 AM	9	3.3	37.94	46.76	1.70	6.65
1/2/1982	1	2	7	10:00:00 AM	10	5	41	48.90	1.61	6.34
1/2/1982	1	2	7	11:00:00 AM	11	7.2	44.96	51.66	1.50	5.93
1/2/1982	1	2	7	12:00:00 PM	12	10.6	51.08	55.94	1.33	5.30
1/2/1982	1	2	7	1:00:00 PM	13	10.6	51.08	55.94	1.33	5.30
1/2/1982	1	2	7	2:00:00 PM	14	6.1	42.98	50.28	1.56	6.13
1/2/1982	1	2	7	3:00:00 PM	15	7.2	44.96	51.66	1.50	5.93
1/2/1982	1	2	7	4:00:00 PM	16	7.2	44.96	51.66	1.50	5.93
1/2/1982	1	2	7	5:00:00 PM	17	7.8	46.04	52.42	1.47	5.82
1/2/1982	1	2	7	6:00:00 PM	18	7.8	46.04	52.42	1.47	5.82
1/2/1982	1	2	7	7:00:00 PM	19	7.8	46.04	52.42	1.47	5.82
1/2/1982	1	2	7	8:00:00 PM	20	7.8	46.04	52.42	1.47	5.82
1/2/1982	1	2	7	9:00:00 PM	21	8.3	46.94	53.05	1.45	5.72
1/2/1982	1	2	7	10:00:00 PM	22	8.9	48.02	53.80	1.42	5.61
1/2/1982	1	2	7	11:00:00 PM	23	8.9	48.02	53.80	1.42	5.61
1/2/1982	1	2	7	12:00:00 AM	0	9.4	48.92	54.43	1.39	5.52

Figure 16. Generator 2 Post-Retrofit Temperature and Power Annualized Regression Calculations

*Generator 2 (CDOC)		*Generator 2 (CDOC)
Modeled Post Enclosure Air Temp (°F)	Post Heater Power (kW)	Final Savings (kW)
48.90	1.36	6.59
48.14	1.37	6.52
45.37	0.90	7.46
44.75	1.15	7.31
42.61	2.01	6.81
41.85	2.31	6.63
41.22	2.56	6.44
41.22	2.56	6.44
43.36	1.71	6.99
45.37	0.90	7.46
47.51	1.38	6.61
48.14	1.37	6.52
48.90	1.36	6.41
50.28	1.33	6.21
50.28	1.33	6.21
49.65	1.34	6.30
48.14	1.37	6.52
46.13	1.41	6.82
44.75	1.15	7.31
45.37	0.90	7.46
46.13	1.41	6.82
45.37	0.90	7.46
45.37	0.90	7.46
43.36	1.71	6.99
43.36	1.71	6.99
43.99	1.45	7.13
43.99	1.45	7.13
43.99	1.45	7.13
43.99	1.45	7.13
43.99	1.45	7.13
44.75	1.15	7.31
46.13	1.41	6.82
46.76	1.40	6.72
48.90	1.36	6.41
51.66	1.30	6.00
55.94	1.22	5.37
55.94	1.22	5.37
50.28	1.33	6.21
51.66	1.30	6.00
51.66	1.30	6.00
52.42	1.29	5.89
52.42	1.29	5.89
52.42	1.29	5.89
52.42	1.29	5.89
53.05	1.27	5.80
53.80	1.26	5.69
53.80	1.26	5.69
54.43	1.25	5.59

Figure 17. Post-Retrofit Temperature and Power Annualized Regression Calculation Boundary Conditions for Gen 1 and Gen 2

Min Temp. (°F)	Max kW	Max Temp. (°F)	Heat Pump Shut Off Temp. (°F)	Min Temp. (°F)	Max kW	Max Temp. (°F)	Heat Pump Shut Off Temp. (°F)
38	3.241691667	86	38	38	2.666716667	90	46

Figure 18. Combined Annualized Energy Usage and Savings

Pre-Retrofit Energy Consumption (kWh)	91,486.95
Post-Retrofit Energy Consumption (kWh)	19,214.17
Annual Energy Savings (kWh)	**72,272.79**

Figure 19. Combined Annualized Peak Demand and Savings

Pre-Retrofit Energy Demand (kW)	4.46
Post-Retrofit Energy Demand (kW)	1.06
Demand Savings (kW)/month	**3.40**