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Verifying a Simplified Fuel Oil Field Measurement Protocol

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Advanced Residential Integrated Energy Solutions Collaborative (ARIES)

July 2013

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Verifying a Simplified Fuel Oil Flow Field Measurement Protocol

Prepared for:

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Definitions

BB	Better Buildings
CT	Current transducer
G(h)	Mathematical function to determine volume (gallons) of oil in tank based on oil height (inches)
GAL_{rt}	Oil use (gallons) determined from measure runtime, know nozzle size and other factors
GAL_{vol}	Measured oil use (gallons) between readings i and i+1
gpd	Gallons per day
gph	Gallons per hour
h	Height of oil in tank (inches
H	Height of tank (inches)
i and i+1	Previous and current readings
L	Length of tank (inches)
mV	Millivolt
psi	Pounds per square inch
psig	Pounds per square inch gauge
R	Value determined by runtime method
V	Value determined by volume measurement method
W	Width of tank, or twice radius R (inches)

Executive Summary

The Better Buildings (BB) program is a U.S. Department of Energy program funding energy efficiency retrofits in buildings nationwide. The BB program and the wider weatherization industry are in need of an inexpensive method for measuring fuel oil consumption that can be used in evaluating the impact that retrofits have in existing properties with oil heat. This project developed and verified a fuel oil flow field measurement protocol that is cost effective and can be performed with little training for use by the BB program as well as other weatherization programs and building science researchers.

1 Problem Statement

1.1 Introduction

The BB program is sponsoring energy retrofits of numerous residential properties. The program and the weatherization industry lack a method for measuring fuel oil consumption that is inexpensive and can be conducted quickly by field technicians. Measuring fuel oil consumption is necessary to quantify the reduction in heating energy use as a result of efficiency improvements funded by the program.

1.2 Background

The BB Neighborhood Program was first announced by Vice President Biden as "Retrofit Ramp-Up" on April 21, 2010. It is presently helping more than 40 competitively selected state and local governments develop sustainable programs to improve the energy efficiency of more than 150,000 buildings (DOE 2011).

1.3 Relevance to Building America's Goals

A low-cost, simple-to-implement, yet accurate fuel oil flow field measurement protocol will enable implementers to quantify fuel savings as a result of energy efficiency retrofits. Currently analysis of oil delivery logs (and correlation with ambient temperature) is the only practical method to determine retrofit impacts. This approach requires many months (and even years) of data collection across the pre- and post-retrofit periods as well as significant cooperation of the homeowners. While this approach can be accurate, it requires significant calendar time to determine impacts. This project furthers Building America goals by developing a timely method to estimate the savings associated with efficiency measures that reduce oil use. There are about 15 million homes in the United States (13%) heated by oil (EIA 2009).

1.4 Cost Effectiveness

This effort developed a cost-effective protocol that can replace more costly and technically challenging methods of measuring fuel oil consumption over a relatively short time span. The data logger to record burner runtime for conventional, nonmodulating burners costs less than $200 and the current switch to detect runtime cost about $30. The time to install the equipment and record the necessary data at each site should be less than 2 hours. Installing oil flow meters or ultrasonic level indicators are much more expensive options.

2 Experimental Approach

2.1 Research Questions

This research addressed the following two questions:

1. What is an accurate, robust, and cost-effective measurement technique for residential boiler fuel oil use?
2. How accurate is the proposed technique?

2.2 Protocol for Confirming Savings

Low-cost data loggers are now available to measure oil burner runtime. By knowing the runtime of the burner fan and pump and the size of the nozzle (expressed in gallons per hour [gph] at a nominal pressure) it is possible to predict oil use. Because runtime can be used to predict oil use on a daily basis, a simple load line approach can be used to predict the trend of oil consumption with respect to ambient temperature data (usually collected from a nearby weather station). The trends developed from daily oil use data from before and after a retrofit can be compared in order to estimate annual savings. An example of a plot of daily runtime is shown in Figure 1. If a retrofit had been implemented at this house, two distinct linear trends would be apparent and multilinear regression with a dummy variable could be used to statistically discern the impact of the retrofit (also see the Protocol at the end of this document).

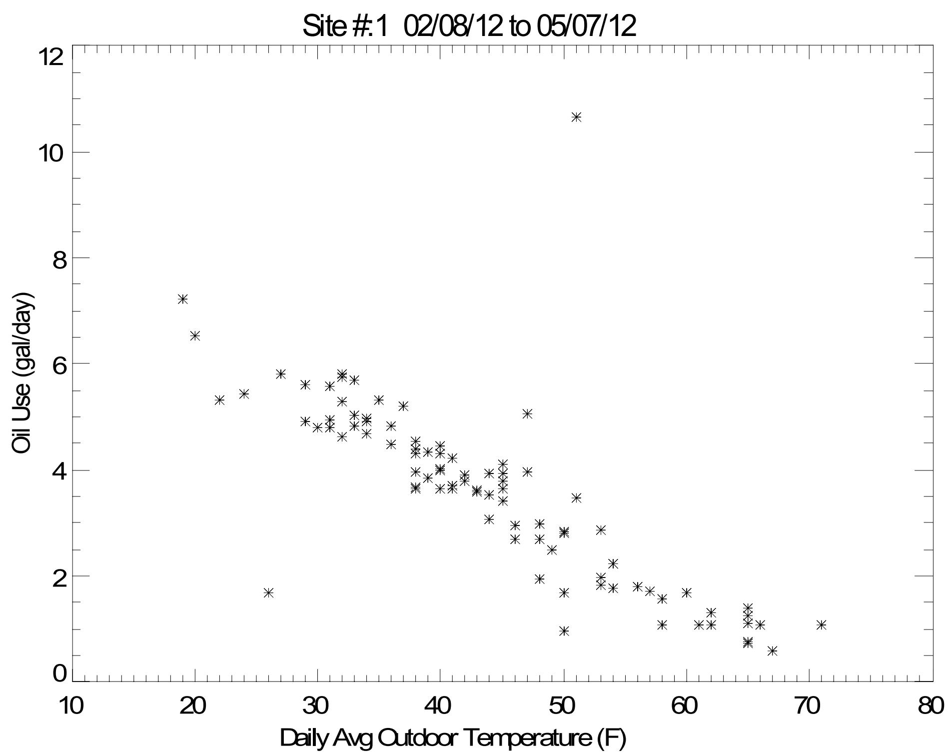


Figure 1. Plot of daily oil use (predicted from burner runtime data) verses ambient temperature.

One example of a runtime logger is the HOBO UX120-017 shown in Figure 2. The logger can count pulses or events as well as record the runtime of equipment. Wiring a self-powered current switch, such as a Veris H300, to the HOBO provides a low-cost means to sense the times when current flows to the burner component (fan and oil pump combined).

HOBO Logger (UX120-17)

Veris Current Switch (H300)

Figure 2. HOBO data logger (from Onset Computer Corp.) and current switch (Veris Industries).

Nearly all burners in the U.S. residential market are made by one of two vendors:

- Beckett (www.beckettcorp.com/index.asp)
- Riello (www.riello-burners.com/default.asp).

Beckett is used mainly by domestic manufacturers of furnaces and boilers while Riello tends to be used on European-manufactured products (such as Buderus). Nearly all these units are single-stage burners that do not modulate. Modulating burners have a negligible share of the U.S. residential market and therefore were not considered in developing the low-cost protocol for measuring oil use.

Typically, oil burners are assembled such that the draft fan and oil pump are different shafts of the same motor. Newer burners have a solenoid that does not allow oil to flow to the nozzle until the desired draft has been established in the combustion chamber. It typically takes a short time (5–15 seconds) for the solenoid to open.

To sense burner runtime, the current switch is snapped onto the 120-V power wire from the controller to the burner assembly, as shown in Figure 3. The switch closure signal from the current transducer (CT) is connected to the data logger by a two-conductor wire. The data logger records the runtime to the nearest second (or nearest 0.11% for 15-minute data). The current switch has a threshold of 0.5 amps. The current draw for the burner was 2 to 4 times that threshold, so the runtime was measured to within ± 1-2 seconds. Therefore the uncertainty in runtime measurement is ± 0.1–0.2%.

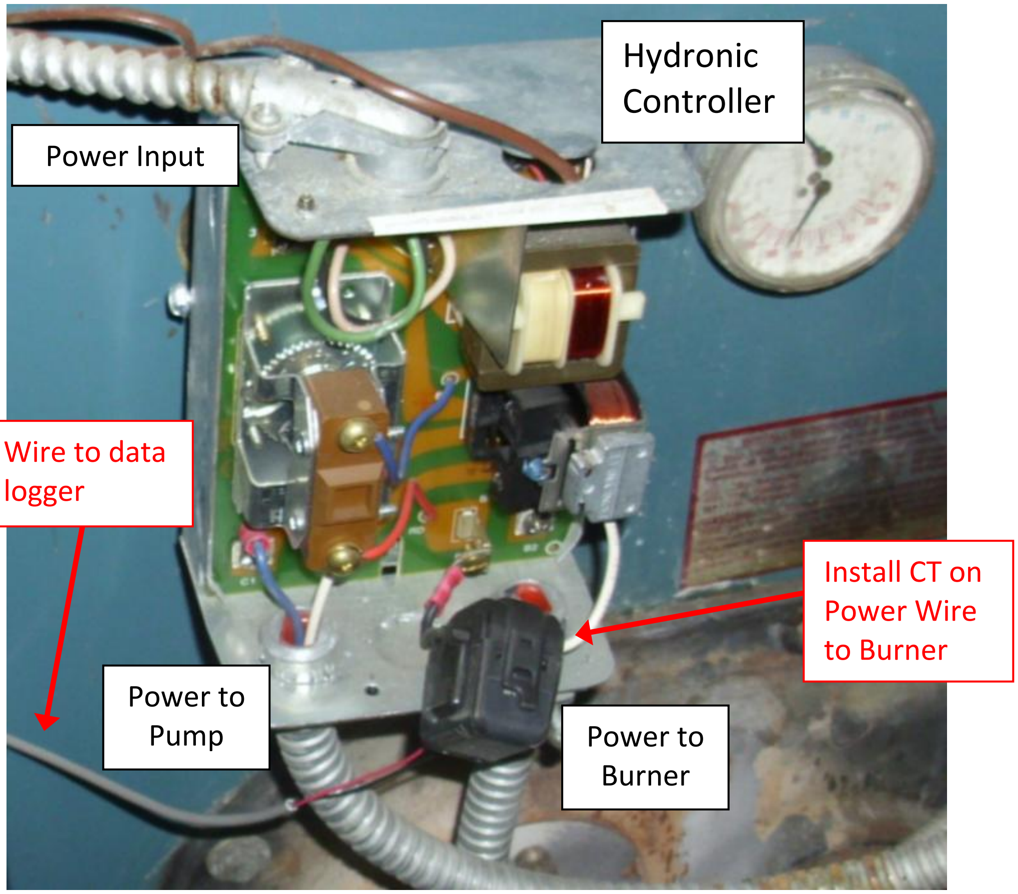


Figure 3. Photo of boiler hydronic controller with CT installed.

2.3 Verification Approach and Measurements

In order to measure the accuracy of the low-cost approach, a secondary oil consumption measurement was needed that had proven accuracy. The two methods would be compared to each other. The initial intent for the secondary measurement was to install an oil flow meter on the oil line feeding the boiler. This approach was found to be ineffective because the oil flow meter disrupted oil flow to the burner. Appendix E provides details about the direct flow measurement method that was attempted.

Therefore, a simpler approach of measuring tank volume along with the height of oil in the tank was implemented. Figure 4 shows a typical oil storage tank used in the United States. All tanks in this study were of this type. Oil tanks are usually located in the basement near the furnace or boiler. Appendix A shows the detailed calculations to determine the volume of oil from height of oil (h) in the tank. The three basic tank dimensions (height H, length L, and width W) were recorded at the beginning of the test along with the height of oil (h).

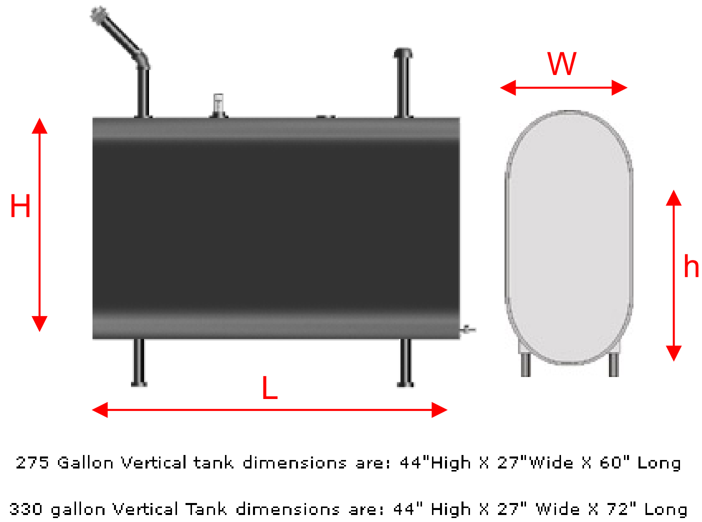


Figure 4. Geometry of typical oil tank.

Figure 5 compares the exact calculations (from Appendix A) for tank volume as a function of oil height (green and black lines) to the values commonly listed oil capacity tables used by the industry (diamond symbols). The radius (R) in the figure below and Appendix A is equal to W divided by 2. The green line uses the nominal tank measurements for a 275-gal tank from Figure 4. The black line uses slightly adjusted dimensions of 13.8 in. instead of 13.5 in. for R. Generally the industry standard tables were in good agreement with the geometric calculations after some adjustment. The industry tables served as a check to confirm the analytical volume method.

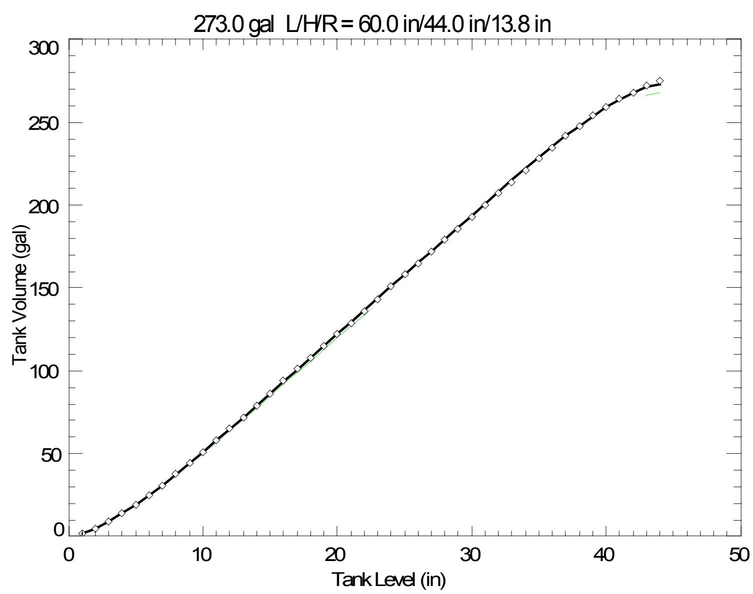


Figure 5. Comparing published and calculated tank volume as a function of tank level (symbols are the values from industry table; green line is geometric calculations using nominal dimensions from Figure 2, 60 in., 44 in., and 13.5 in; black line is calculations using corrected dimensions of 13.8 in. required to get close to the published volume).

For each site, actual tank measurements were used to calculate the volume of oil in the tank. Some tanks were slightly indented on the ends. In those cases the length of the tank interior was estimated. Assuming the height measurement in the tank was determined to within ± 0.125 inches, then the oil volume was determined to within ± 0.75 ga, on average (see Figure 6). To determine oil consumption based on runtime, some additional parameters are also required, including:

- The rating or size of the nozzle expressed in gph
- The operating pressure of the nozzle (psig)
- The delay time (if any) between burner fan operation and solenoid operation (or combustion). The delay time is measured in seconds and is assumed to be the same for each starting cycle (we confirmed this with several observations).

Figure 6. Photo of oil tank level being measured with a tape measure.

Researchers visited each site with a trained oil technician to check the nozzle size, measure the oil pressure at the nozzle, measure the height of the oil in the tank, measure the time delay for the nozzle to open with a stop watch, and measure the oil tank. The multichannel data logger was wired to count the number of events or boiler cycles. This was accomplished by jumpering the wires from input channel 1 to input channel 2 on the data logger. Then channel 2 was programmed to count events. Both event and runtime data were collected at 15-minute intervals.

Researchers made several return trips to each site to retrieve data from the data logger and to take new oil height measurements. The time and date were noted. The homeowner was also asked to provide copies of any delivery logs if oil had been added to the tank since the last visit.

From these data, the gallons used for the period between two readings were calculated by two independent means. The oil use over the period determined by the volume method (GAL_{vol}) is:

$$GAL_{vol} = G(h_{i+1}) - G(h_i) + GAL_{fill}$$

where:

G(h)	the volume of oil in the tank when the oil height is h (gal). Defined in Appendix A.
i, i+1	the current (i+1) and previous (i) height readings
GAL_{fill}	the total amount of oil added to the tank during the period (gal)

The gallons of fuel used during the period determined by the runtime method (GAL_{rt}) is:

$$GAL_{rt} = \left(RT - CYC \; x \; t_{delay}\right) x \; GPH_{noz} \; x \sqrt{P_{noz}/100}$$

Where:

RT	runtime of the burner in the period (hours)
CYC	number of burner operating cycles in the period (-)
t_{delay}	time delay before the solenoid opens (converted to hours)
GPH_{noz}	rated performance of the nozzle in the burner (Gallons per hr at 100 psi)
P_{noz}	operating pressure measured at the nozzle (psig)

3 Measured Results

3.1 Site Characteristics

The measurement approach described above was applied at 15 different sites near Cazenovia, New York. The key characteristics of the burner and storage tanks at each site are listed in Table 1. Nine of the 15 sites were Beckett burners, four were Riello, and two were other brands. Ten of the 15 systems were boilers while the others were hot air furnaces. Five of the sites had double tanks for added storage. Each of the Riello burners had a solenoid on the pump, which opened 11–15 seconds after fan startup. One Beckett burner had a solenoid. The measured oil pressure ranged from the nominal value of 100 psi to 140 psi; the average was 118 psi.

Table 1. Summary of Key Characteristics of Test Sites.

Site No	Type of System	Nozzle Rating (gph)	Nozzle Operating Pressure (psi)	Nozzle Spray Angle	Burner Manufacturer	No. of Storage Tanks	Solenoid Time Delay (s)
1	Boiler	0.75	140	80 degrees (A)	Beckett	One	0
2	Boiler	0.75	140		Riello 40-F3	One	14.3
3	Boiler	0.85	100	80A	Beckett	One	0
4	Boiler	0.65	130	70A	Beckett	Two	0
5	Furnace	0.65	145	70A	Riello	One	11.25
6	Boiler	1	100	70A	Beckett	One	0
7	Boiler	1	100	80A	Beckett	Two	0
8	Boiler	1.75	110	80B	Beckett	Two	0
9	Furnace	0.75	140	70B	Riello	One	14
10	Furnace	0.65	100	70B	Beckett	One	15.2
11	Boiler	1	100	80B	Carlin	One	0
12	Furnace	0.6	100	80B	Wayne	One	0
13	Boiler	0.5	140	70A	Riello	Two	13
14	Boiler	0.85	130	45B	Beckett	Two	14.5
15	Furnace	0.65	100	80A	Beckett	One	0

Note: Nozzle spray pattern “A” is a hollow cone where all oil is delivered at the edge of the cone. Spray pattern “B” is a solid cone with the oil delivered uniformly across the cone.

3.2 Oil Measurements

Manual tank readings and data retrieval were completed two to five times at most sites from February to May 2012. Appendix B provides plots of the collected runtime data along with the reading times for each site. This provided a total of 58 separate readings of oil use that were determined by both the volume and runtime methods. The oil use per period ranged from less than 1 gal to more than 130 gal.

The results are listed in Table 2. For each reading the gallons were determined by the two methods and the difference, or error, is listed as both an absolute and a percentage basis.

Figure 7 compares the gallon readings determined by the Volume and Runtime methods. The correlation between the two readings is very high at 0.9936.

Some of the readings were found to be invalid and were therefore excluded from the overall analysis for the following reasons:

- The runtime data for the second reading at Site 3 were found to be invalid because the runtime CT had been placed on the overall power wire to the boiler control (including burner and pumps). So when the burner faulted,[1] the pumps continued to run for several hours, resulting in erroneous runtime readings.
- The reading at Site 12 where oil use was less than 1 gal was excluded.

Figure 8 shows the absolute and relative errors for each site, excluding the points mentioned above. The absolute error is simply the difference between the two values, Runtime (R) minus Volume (V). The relative error expresses the difference in percentage terms (dividing by volume). The average absolute value error is 2.4 gal. The standard deviation is 3.4 gal. The average of the readings is 35 gal (based on volume), so the average error and standard deviation represent 6.8% and 9.8%, respectively.

The average relative error is 9.6%. The standard deviation is 13.9%.

Similarly, the histograms in Figure 9 show the distribution of these 56 readings. The average error is 1.0 gal, or 0.4% for the relative error.

Finally, Figure 10 and Figure 11 show how the absolute and relative errors change with the magnitude of the reading. The absolute error is somewhat correlated with the magnitude of the reading, but the relative error tends to get smaller. As expected, even small absolute errors on small readings lead to large relative errors.

[1] When the sensor fails to detect a flame, the burner controls stop the fan and "lock out" until the user manually resets the burner controller.

Table 2. Summary of Readings.

Site	Period Start Date	Period End Date	Period Duration (days)	Avg Burner Cycles (cyc/h)	Intial Tank Reading (gal)	Final Tank Reading (gal)	Tank Fill (gal)	Volume GAL_v (gal)	Adjusted Burner Runtime (h)	Burner Delay Adj (h)	Runtime GAL_{rt} (gal)	Absolute Error (gal)	Relative Error (%)	Notes
1	2/8/2012	2/14/2012	6.1	0.0	71.2	38.7	0.0	32.5	39.2	0.00	34.8	2.3	7.0%	
	2/14/2012	3/7/2012	22.0	0.0	38.7	167.8	234.8	105.7	122.1	0.00	108.4	2.7	2.5%	
	3/7/2012	3/27/2012	19.9	0.0	167.8	122.1	0.0	45.7	54.5	0.00	48.3	2.6	5.7%	
	3/27/2012	5/9/2012	43.0	0.0	122.1	181.1	181.7	122.7	151.4	0.00	134.4	11.6	9.5%	
2	2/21/2012	3/1/2012	9.0	2.9	256.4	191.7	0.0	64.6	74.2	–2.48	63.6	–1.0	–1.5%	
	3/1/2012	3/19/2012	18.2	2.5	191.7	194.4	95.3	92.7	114.8	–4.30	98.0	5.4	5.8%	
	3/19/2012	4/4/2012	16.0	2.1	194.4	253.9	126.1	66.5	80.9	–3.21	69.0	2.4	3.6%	
	4/4/2012	4/18/2012	14.0	2.2	253.9	194.4	0.0	59.6	70.5	–2.90	60.0	0.4	0.6%	
	4/18/2012	4/30/2012	12.0	2.2	194.4	139.9	0.0	54.4	65.8	–2.53	56.1	1.7	3.1%	
3	2/21/2012	3/2/2012	10.2	1.4	144.5	117.3	0.0	27.2	29.6	0.00	25.2	–2.0	–7.3%	
	3/2/2012	3/19/2012	16.9	1.3	117.3	86.6	0.0	30.7	111.2	0.00	94.5	63.9	208.1%	runtime for pump, not burner
	3/19/2012	4/2/2012	14.1	1.2	86.6	213.6	150.0	23.0	26.4	0.00	22.4	–0.6	–2.6%	
	4/2/2012	4/18/2012	15.8	0.4	213.6	204.1	0.0	9.5	12.0	0.00	10.2	0.7	6.9%	
	4/18/2012	5/4/2012	15.8	2.6	204.1	179.6	0.0	24.5	31.9	0.00	27.1	2.6	10.5%	
4	2/21/2012	3/8/2012	16.0	2.2	249.0	211.0	0.0	75.9	102.2	0.00	75.7	–0.2	–0.3%	
	3/8/2012	3/19/2012	10.9	1.0	211.0	195.3	0.0	31.4	37.7	0.00	28.0	–3.4	–10.8%	
	3/19/2012	4/4/2012	16.0	1.1	195.3	174.3	0.0	42.1	56.2	0.00	41.6	–0.4	–1.0%	
	4/4/2012	4/18/2012	14.1	1.0	174.3	257.8	200.2	33.2	44.6	0.00	33.0	–0.2	–0.5%	
	4/18/2012	5/4/2012	16.1	1.0	257.8	237.3	0.0	40.9	53.8	0.00	39.9	–1.0	–2.5%	
5	3/1/2012	3/19/2012	18.0	1.1	194.7	170.5	0.0	24.1	33.0	–1.49	24.7	0.5	2.2%	
	3/19/2012	4/4/2012	16.0	0.8	170.5	152.4	0.0	18.1	22.0	–0.99	16.4	–1.7	–9.3%	
	4/4/2012	4/18/2012	14.0	1.0	152.4	136.0	0.0	16.4	22.4	–1.01	16.8	0.4	2.4%	
	4/18/2012	5/4/2012	16.0	0.9	136.0	121.4	0.0	14.7	23.6	–1.05	17.6	3.0	20.4%	
6	3/1/2012	3/19/2012	17.9	1.7	125.0	76.8	0.0	48.2	50.7	0.00	50.7	2.5	5.1%	
	3/19/2012	4/4/2012	16.0	1.4	76.8	227.3	193.0	42.5	38.0	0.00	38.0	–4.5	–10.6%	
	4/4/2012	4/18/2012	14.0	1.5	227.3	192.1	0.0	35.2	34.1	0.00	34.1	–1.1	–3.2%	

Site	Period Start Date	Period End Date	Period Duration (days)	Avg Burner Cycles (cyc/h)	Intial Tank Reading (gal)	Final Tank Reading (gal)	Tank Fill (gal)	Volume GAL_v (gal)	Adjusted Burner Runtime (h)	Burner Delay Adj (h)	Runtime GAL_{rt} (gal)	Absolute Error (gal)	Relative Error (%)	Notes
	4/18/2012	5/4/2012	15.9	1.4	192.1	156.8	0.0	35.3	35.4	0.00	35.4	0.1	0.3%	
7	4/4/2012	4/5/2012	1.2	1.2	176.6	175.7	0.0	1.8	1.3	0.00	1.3	–0.4	–24.4%	
	4/5/2012	4/10/2012	5.0	0.2	175.7	174.4	0.0	3.1	3.4	0.00	3.4	0.3	10.6%	
	4/10/2012	4/17/2012	7.0	0.1	174.4	262.7	183.0	4.1	3.6	0.00	3.6	–0.4	–10.7%	
	4/17/2012	5/4/2012	16.8	0.6	262.7	248.3	0.0	32.0	32.8	0.00	32.8	0.8	2.4%	
8	3/1/2012	3/7/2012	6.0	0.0	233.0	202.3	0.0	61.4	33.0	0.00	60.6	–0.9	–1.4%	
	3/7/2012	3/19/2012	12.0	0.0	202.3	188.1	0.0	28.3	14.3	0.00	26.3	–2.0	–7.0%	
9	3/8/2012	3/19/2012	11.0	0.5	213.6	193.6	0.0	20.0	24.9	–0.56	21.6	1.6	8.2%	
	3/19/2012	4/4/2012	16.0	0.6	193.6	163.8	0.0	29.8	38.3	–0.84	33.2	3.4	11.5%	
	4/4/2012	4/18/2012	14.0	0.6	163.8	134.0	0.0	29.8	36.0	–0.78	31.3	1.5	5.0%	
	4/18/2012	5/4/2012	15.9	0.6	134.0	103.3	0.0	30.6	41.0	–0.83	35.7	5.0	16.4%	
10	3/8/2012	3/19/2012	10.9	0.1	128.7	237.3	121.0	12.4	26.1	–0.11	16.9	4.5	36.4%	
	3/19/2012	4/4/2012	15.9	0.1	237.3	209.3	0.0	28.1	38.2	–0.17	24.7	–3.3	–11.9%	
	4/4/2012	4/18/2012	14.1	0.1	209.3	182.2	0.0	27.1	35.6	–0.18	23.0	–4.1	–15.1%	
	4/18/2012	5/4/2012	16.0	0.1	182.2	156.8	0.0	25.4	38.7	–0.19	25.0	–0.4	–1.6%	
11	4/17/2012	4/24/2012	7.1	0.6	176.0	154.1	0.0	21.9	21.4	0.00	21.4	–0.5	–2.4%	
	4/24/2012	5/4/2012	9.9	0.8	154.1	253.6	132.6	33.2	34.8	0.00	34.8	1.7	5.0%	
12	3/8/2012	3/19/2012	10.9	0.3	203.9	199.5	0.0	4.4	5.8	0.00	3.5	–1.0	–21.6%	
	3/19/2012	4/4/2012	16.0	0.1	199.5	196.8	0.0	2.7	2.3	0.00	1.4	–1.3	–48.5%	
	4/4/2012	4/18/2012	14.0	0.1	196.8	195.0	0.0	1.8	2.5	0.00	1.5	–0.3	–16.7%	
	4/18/2012	5/4/2012	15.9	0.0	195.0	194.1	0.0	0.9	0.1	0.00	0.1	–0.8	–91.0%	excluded, < 1 gal
13	3/8/2012	3/21/2012	13.0	2.0	156.6	191.9	100.3	29.6	48.3	–2.27	27.2	–2.4	–8.2%	
	3/21/2012	4/4/2012	14.0	2.7	191.9	172.9	0.0	38.0	67.7	–3.25	38.1	0.1	0.2%	
	4/4/2012	4/18/2012	14.0	2.3	172.9	270.2	222.3	25.4	61.8	–2.79	34.9	9.6	37.7%	
	4/18/2012	5/4/2012	15.8	2.0	270.2	254.4	0.0	28.4	63.8	–2.70	36.2	7.8	27.4%	
14	3/8/2012	3/19/2012	11.1	1.8	37.7	238.1	448.0	47.2	54.4	–1.95	50.9	3.7	7.9%	
	3/19/2012	4/4/2012	16.0	2.0	238.1	201.5	0.0	73.3	87.9	–3.06	82.2	8.9	12.2%	

Site	Period Start Date	Period End Date	Period Duration (days)	Avg Burner Cycles (cyc/h)	Intial Tank Reading (gal)	Final Tank Reading (gal)	Tank Fill (gal)	Volume GAL_v (gal)	Adjusted Burner Runtime (h)	Burner Delay Adj (h)	Runtime GAL_{rt} (gal)	Absolute Error (gal)	Relative Error (%)	Notes
	4/4/2012	4/18/2012	14.0	0.8	201.5	185.7	0.0	31.5	34.1	–1.08	32.0	0.4	1.4%	
	4/18/2012	5/4/2012	15.9	1.8	185.7	151.5	0.0	68.4	82.5	–2.85	77.2	8.8	12.9%	
15	3/21/2012	4/4/2012	14.0	0.8	247.6	230.3	0.0	17.3	24.2	0.00	15.7	–1.6	–9.5%	
	4/4/2012	4/18/2012	14.0	0.7	230.3	215.3	0.0	15.0	20.5	0.00	13.4	–1.6	–10.7%	
	4/18/2012	5/4/2012	15.8	0.6	215.3	197.1	0.0	18.2	22.3	0.00	14.5	–3.7	–20.3%	

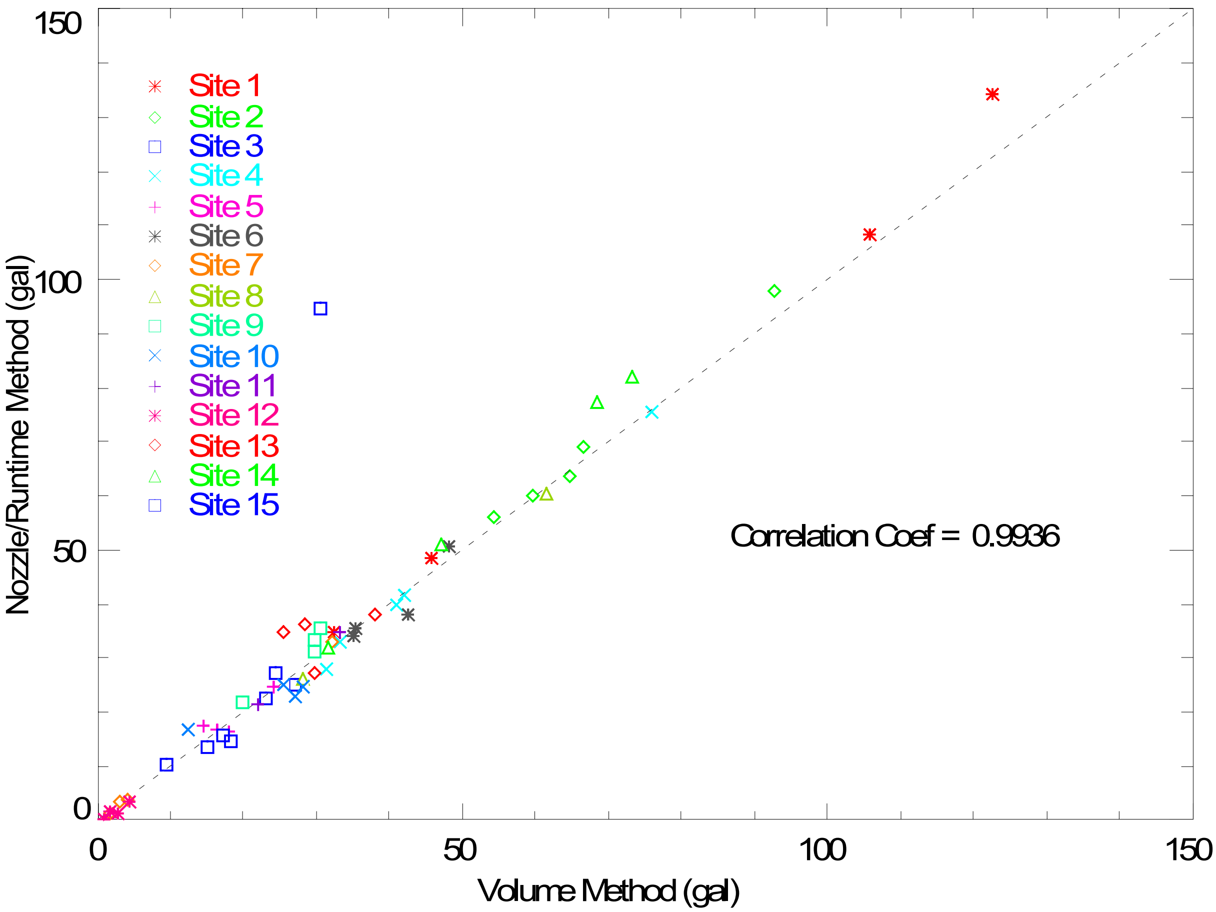


Figure 7. Comparing gallon readings determined by volume and runtime/nozzle method.

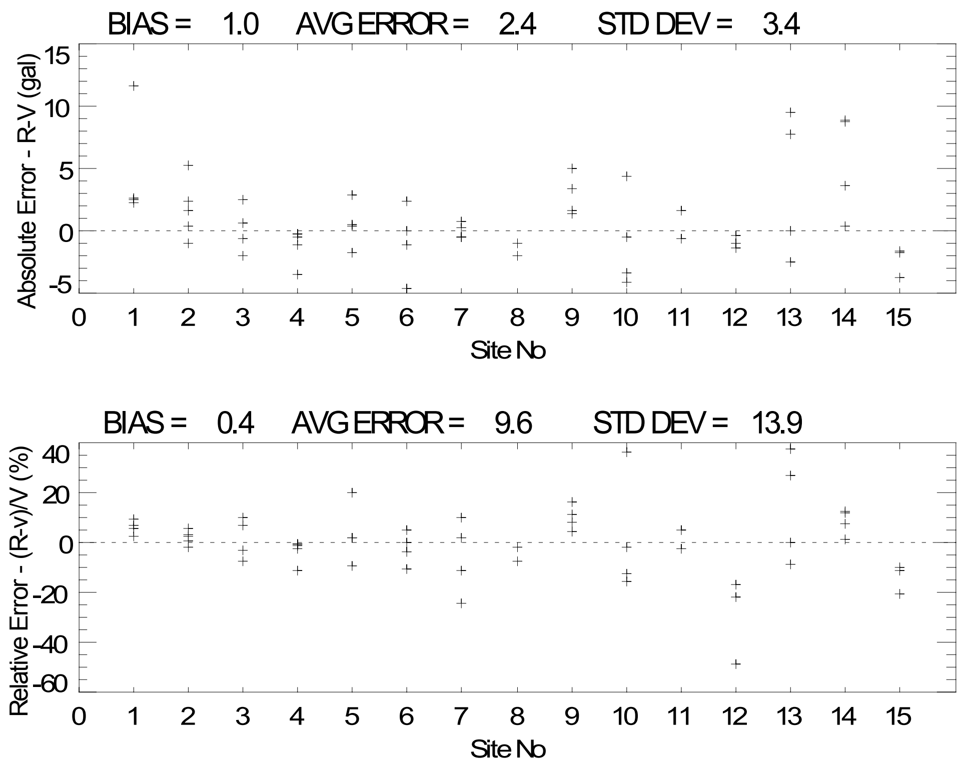


Figure 8. Absolute and relative error by site (R—runtime method, V—volume method).

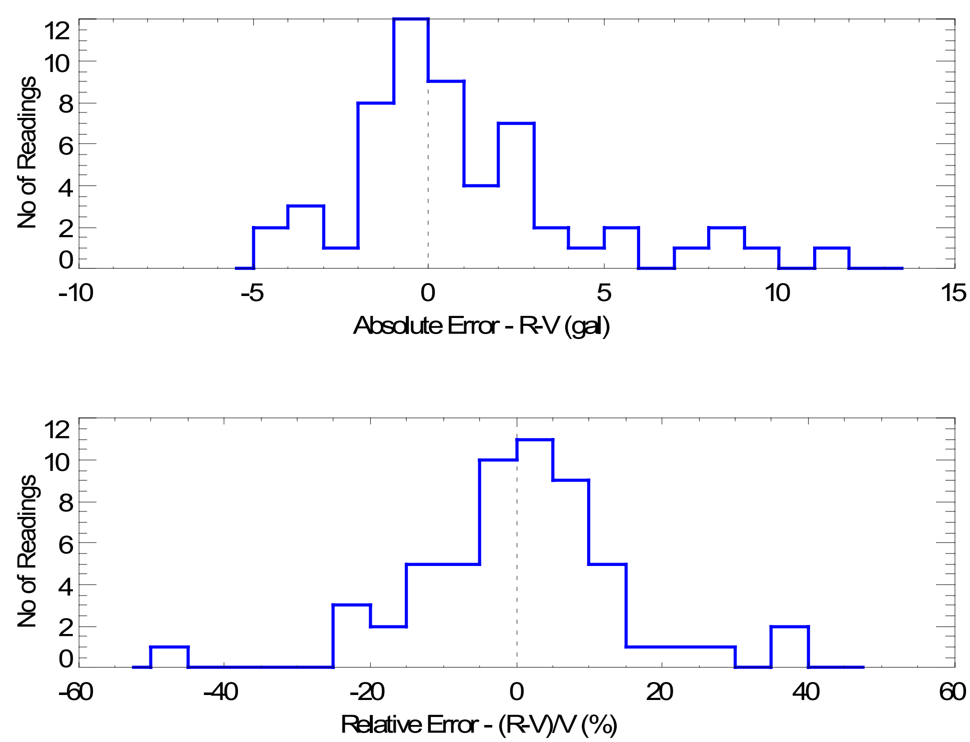


Figure 9. Distribution of absolute and relative errors (56 readings).

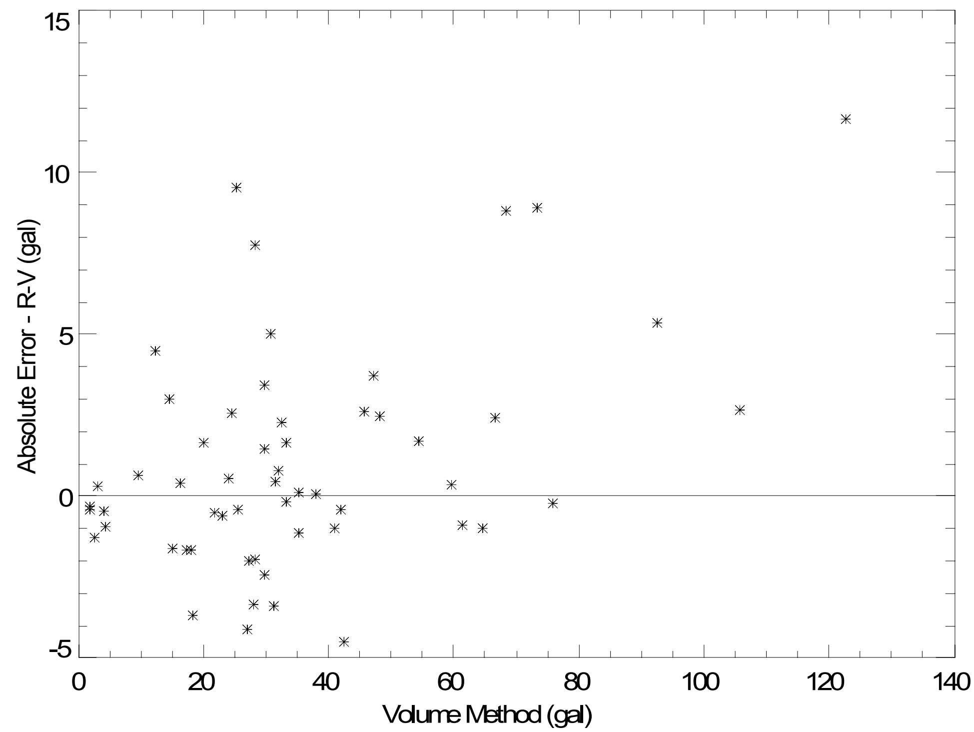


Figure 10. Variation of absolute errors with volume readings (R—runtime method, V—volume method).

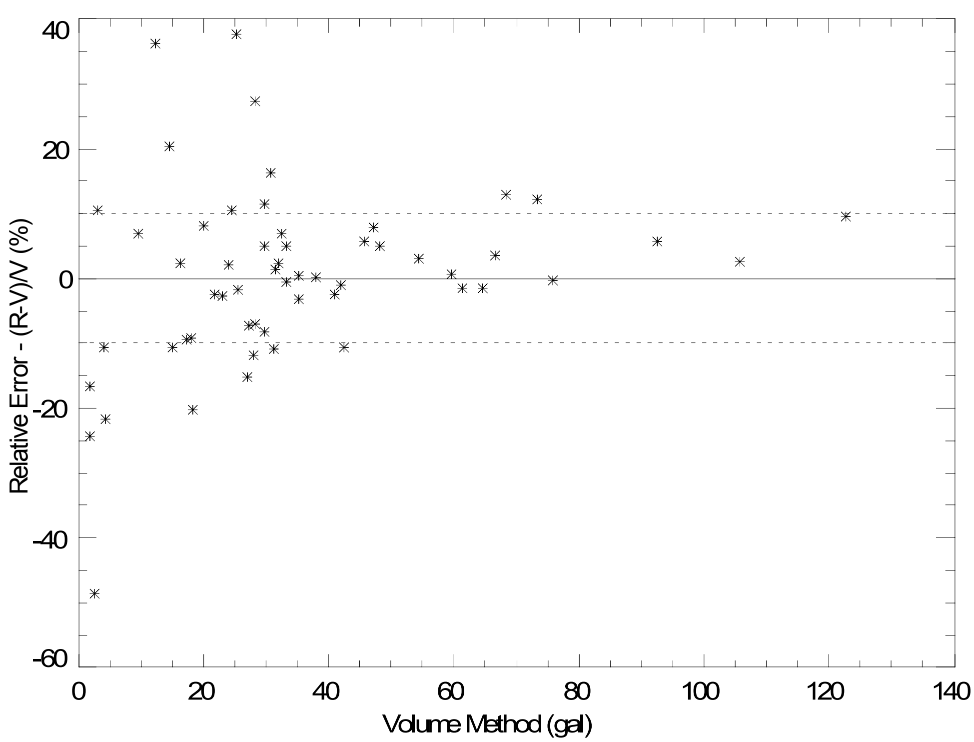


Figure 11. Variation of relative errors with volume readings (R—runtime method, V—volume method). Dotted lines mark ± one standard deviation.

3.3 Discussion and Analysis

Assuming the collection data are normally distributed—which is implied by the histograms in Figure 9—90% of the readings should fall within 1.64 standard deviations of the average (or zero error). The standard deviation of error divided by the average absolute reading is 9.7%. The standard deviation of the relative error was 13.9%. Therefore the calculated uncertainty at 90% confidence interval—or within 1.64 standard deviations—using these values of 9.7% and 13.9% would be ± 16% and ± 23%, respectively. Table 3 shows a portion of the actual dataset falling within various bounds. The analysis shows that 89% of the data fall between the ± 21% error bounds.

Table 3. Portion of Readings Within Various Bounds (56 points total).

Bounds	No. of Points Within Bounds	% of Points Within Bounds
–10% to +10%	35	63%
–15% to +15%	45	80%
–20% to +20%	48	86%
–21% to +21%	50	89%
–25% to +25%	52	93%

The standard deviation of the error in absolute terms is 3.4 gal (as shown on the top of Figure 8). As stated previously, the uncertainty of the volume measurement was estimated to be ± 0.75 gallons. Table 4 propagates the uncertainty with the volume measurement through the error calculations and demonstrates that the standard deviation of the error is essentially unchanged. The bias—i.e., the simple average of the difference between the two values—does change as expected. The average error—or the average of the absolute value of the differences between the two values—changes modestly. The propagation of the uncertainty with the volume measurements has very little impact on the resulting error.

Table 4. Propagation of Volume Measurement Uncertainty in Error Analysis.

Volume Uncertainty	Bias (gal)	Average Error (gal)	Standard Deviation (gal)
Reading	1.0	2.4	3.4
Reading + 0.75 gal	0.3	2.5	3.4
Reading - 0.75 gal	1.8	2.6	3.4

3.4 Sensitivity Analysis

One of the parameters collected in this study required an oil technician to install a specialized gauge to measure pressure at the nozzle during operation. Table 5 shows the impact of not taking the individual measurements but instead assuming all systems were at the average measured pressure (118 psi) or at the nominal pressure (100 psi). Surprisingly, using the average pressure instead of the actual pressure resulted in a very modest impact on the overall errors. The bias error was essentially unchanged, as expected. Using the nominal pressure, which results in a lower calculated oil consumption based on runtime, results in the expected[2] change in the bias error but no appreciable change in the standard deviation of errors.

Table 5. Impact of Different Assumptions for Pressure.

	Bias Error	Standard Deviation of Absolute Error	Standard Deviation of Relative Error
Using Measured Pressure	0.4%	9.8%	13.9%
Assuming Average Pressure (118 psi)	–0.2%	9.0%	13.2%
Assuming Nominal Pressure (100 psi)	–8.1%	10.4%	12.2%

[2] The change in bias error is expected because changing the pressure from 118 to 100 psi has an 8% impact on the equation for estimating nozzle flow as a function of pressure.

4 Summary

The results of this study show that the correlation between estimating oil use based on burner runtime and direct measurements of oil volume based on delivery and height in the tank were very good. The correlation was better than 0.99 and average bias of error was 0.4%. The difference in error between the two readings was found to be ± 20%–25% at the 90% confidence interval.

The results imply the method of determining oil use from runtime is a useful, low-cost approach with reasonable accuracy. The advantage of using runtime is that a prediction of daily oil use can be developed easily and quickly. Then daily predictions of oil use can be correlated to daily average ambient temperature data from a nearby weather station (see Appendix C for the load lines created for each site). By comparing the trends—or load lines—for days before and after a building retrofit, the heating energy savings associated with the retrofit can be determined from a few weeks of pre- and post-retrofit data.

A simplified protocol for measuring fuel oil consumption is provided in Appendix D.

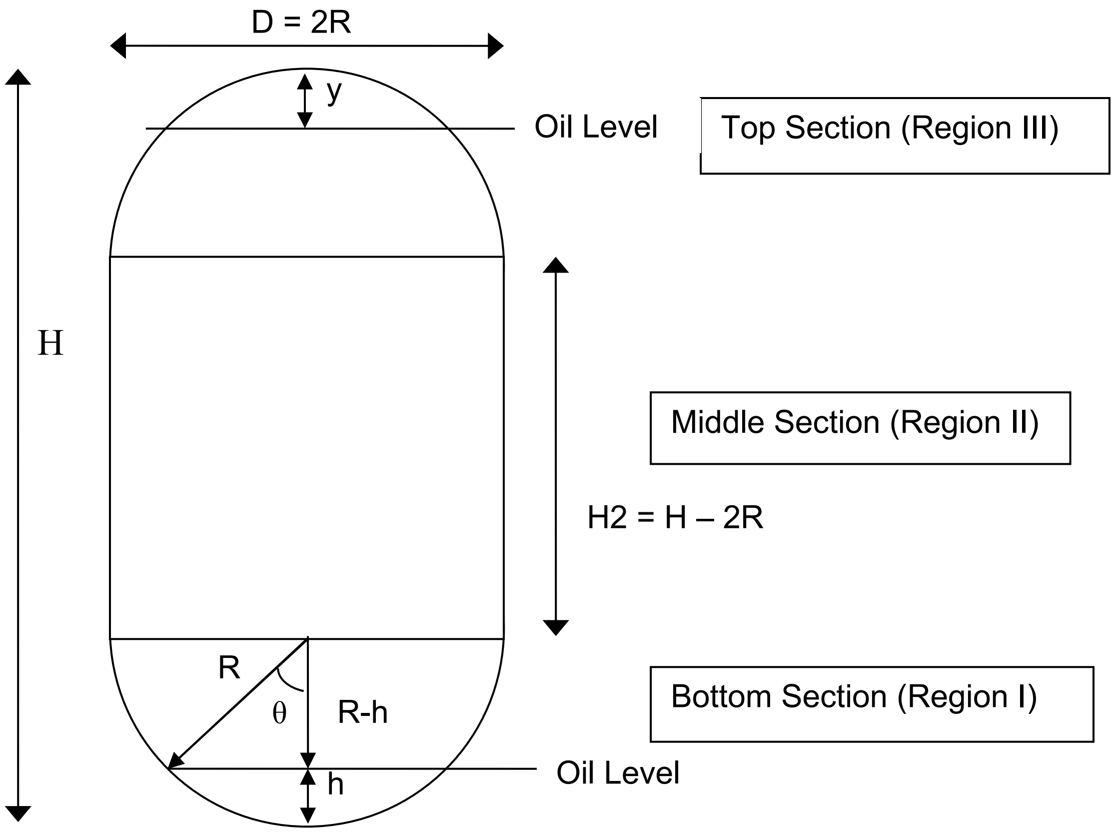
References

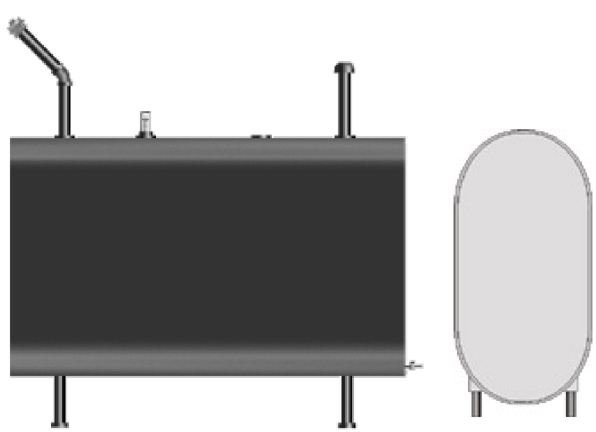
DOE. (2011). *Better Buildings Neighborhood Program.* Retrieved December 16, 2011, from U.S. Department of Energy, Energy Efficiency & Renewable Energy www1.eere.energy.gov/buildings/betterbuildings/.

EIA. (2009). *RECS Survey Data Tables.* Retrieved November 8, 2012, from U.S. Energy Information Administration: www.eia.gov/consumption/residential/data/2009/xls/HC1.1%20Fuels%20Used%20and%20End%20Uses%20by%20Housing%20Unit%20Type.xls

Appendix A: Calculations of Tank Volume as Functions of Oil Height

The general shape of oil tank is a rectangle with a semicircle on top and bottom. A nominal 275-gal tank is approximately 44 in. high (H), 27 in. wide (D) and 60 in. long (L).





275 Gallon Vertical tank dimensions are: 44"High X 27"Wide X 60" Long

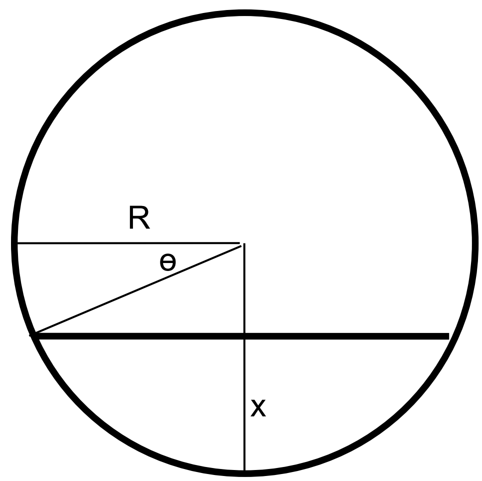
330 gallon Vertical Tank dimensions are: 44" High X 27" Wide X 72" Long

Calculating Volume of Oil in Tank

To get the area of the entire semicircle, we simply use the equation:

$$A = 0.5 * \pi R^2$$

The cross-sectional area of the tank is a segment of a circle defined by a chord.



If h < R (Region I):

To calculate the area of the segment of the circle the equation is:

$$\Theta = \arcsin\left(\frac{R-h}{R}\right)$$

$$A = \frac{R^2}{2} * (2\theta - \sin(2\theta))$$

If h > R and h < R+H2 (Region II):

$$A = \frac{\pi R^2}{2} + (\mathrm{h} - \mathrm{R}) * \mathrm{D}$$

If h > R+H2 (Region III):

In this case use the same method as in region I to calculate the void at the top of the tank. Subtract that from the total tank volume (Ao)

$$A_o = \pi R^2 + \text{ H2} * \text{D}$$

The height of the void

$$y = H - h$$

So the area of the void is

$$\Theta_1 = \arcsin\left(\frac{R - y}{R}\right)$$

$$A_v = \frac{R^2}{2} * (2\Theta_1 - \sin(2\Theta_1))$$

$$A = A_o - A_v$$

In all cases the volume is the cross-sectional area times the length of the tank. There are 7.4805 gal/ft^3.

Several sources publish the holding capacity of a 275-gal oil tank as a function of the level in the tank. The diamonds in Figure 12 show the published data and compare them to the values calculated by the procedure above. When we use the nominal numbers of 60 in., 44 in., and 13.5 in. we get the curve shown by the green line.

To minimize the error between the published values and the curve (Figure 13) we found that a value of 13.8 in. for the radius was a better fit.

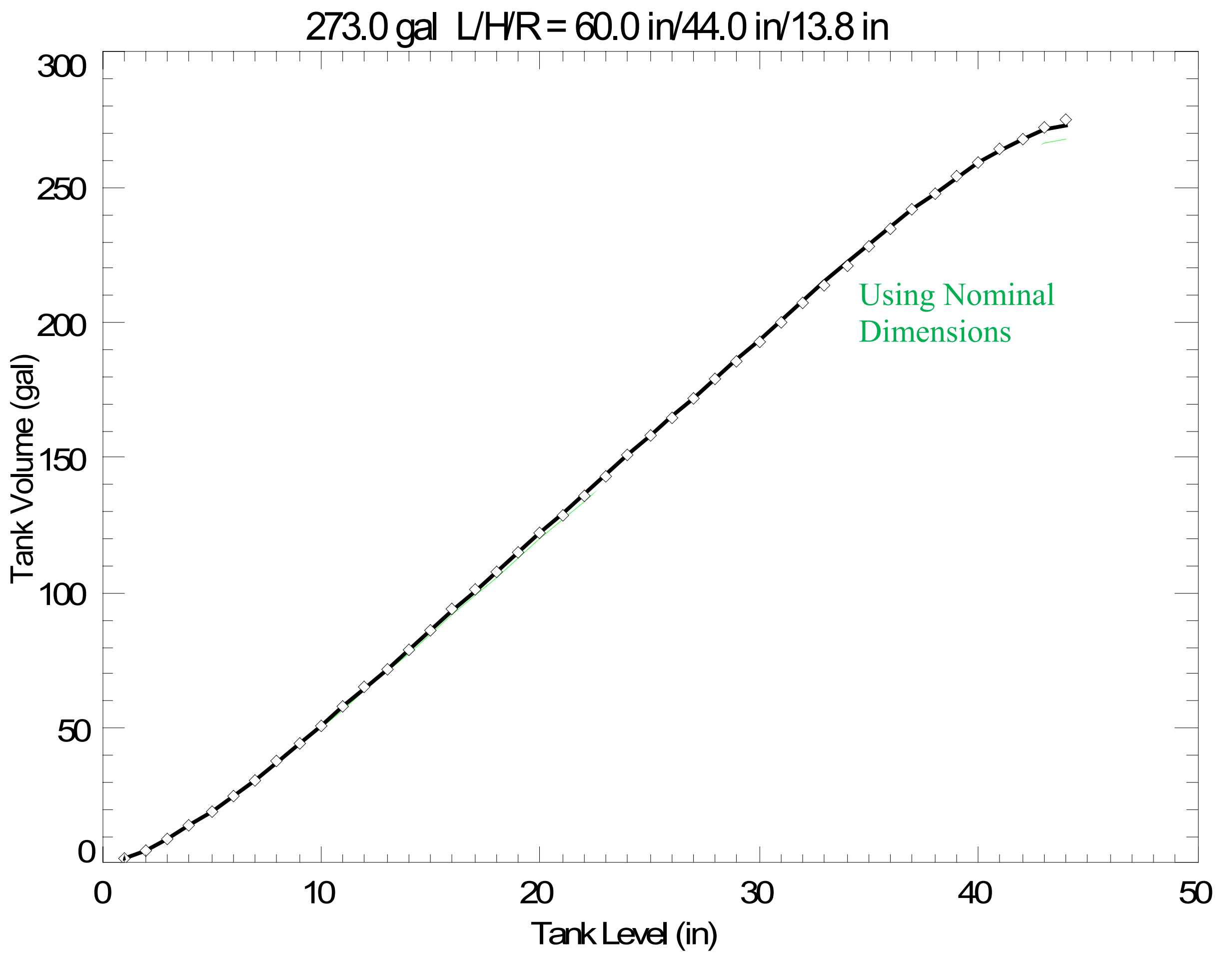


Figure 12. Comparing published and calculated tank volume as a function of tank level.

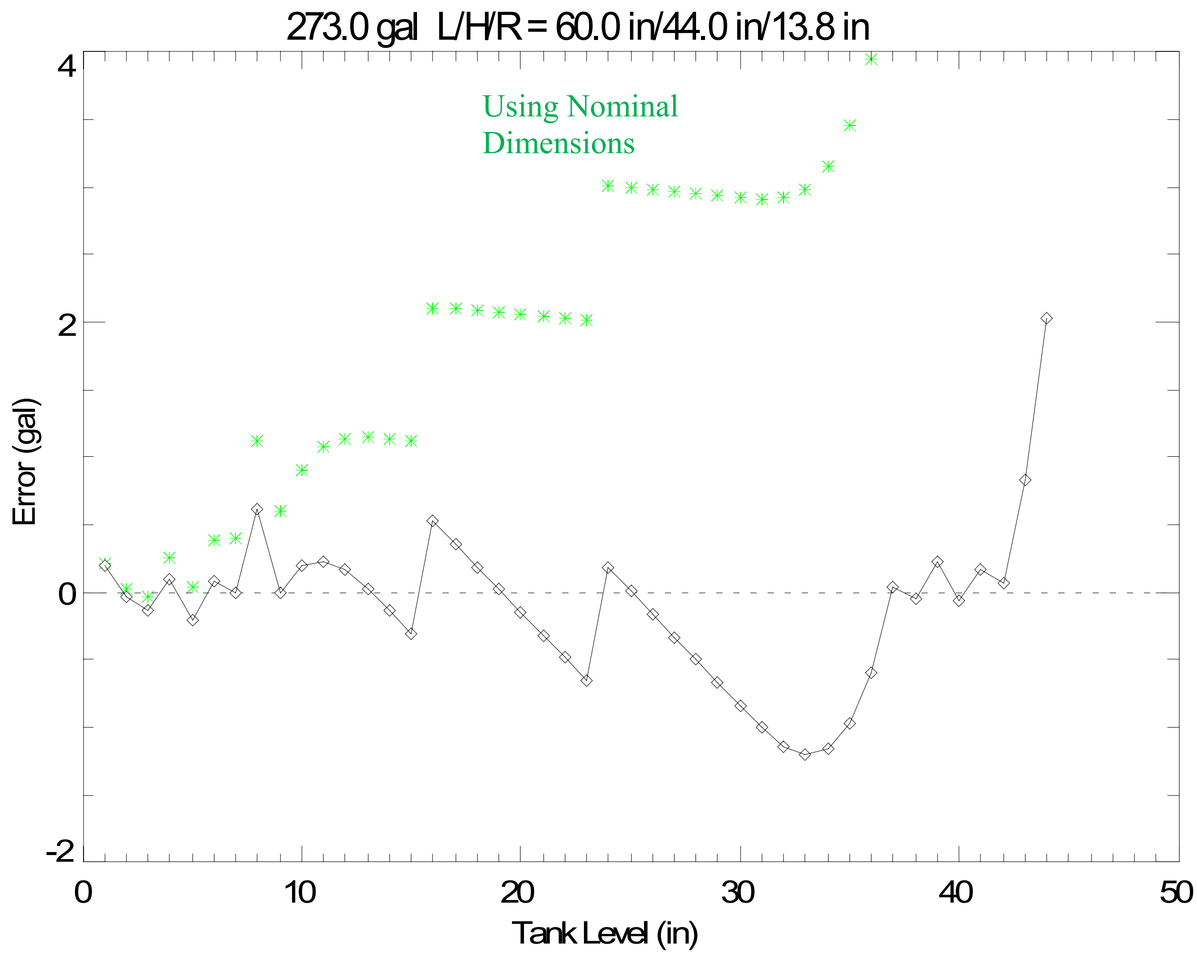
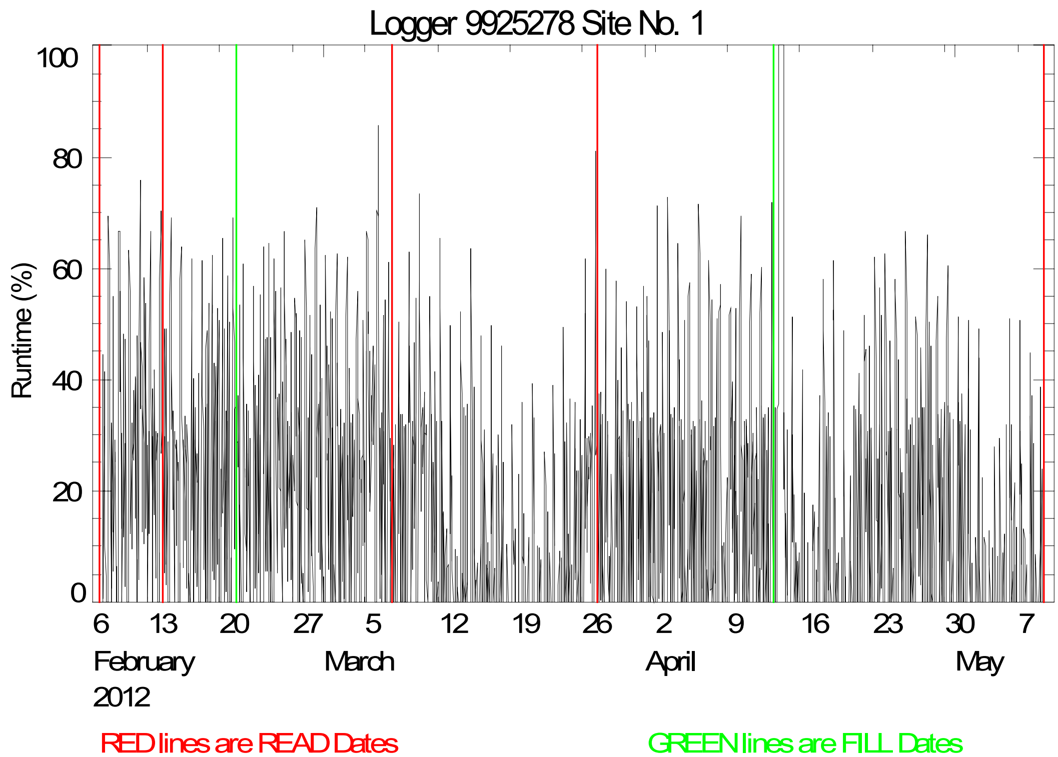
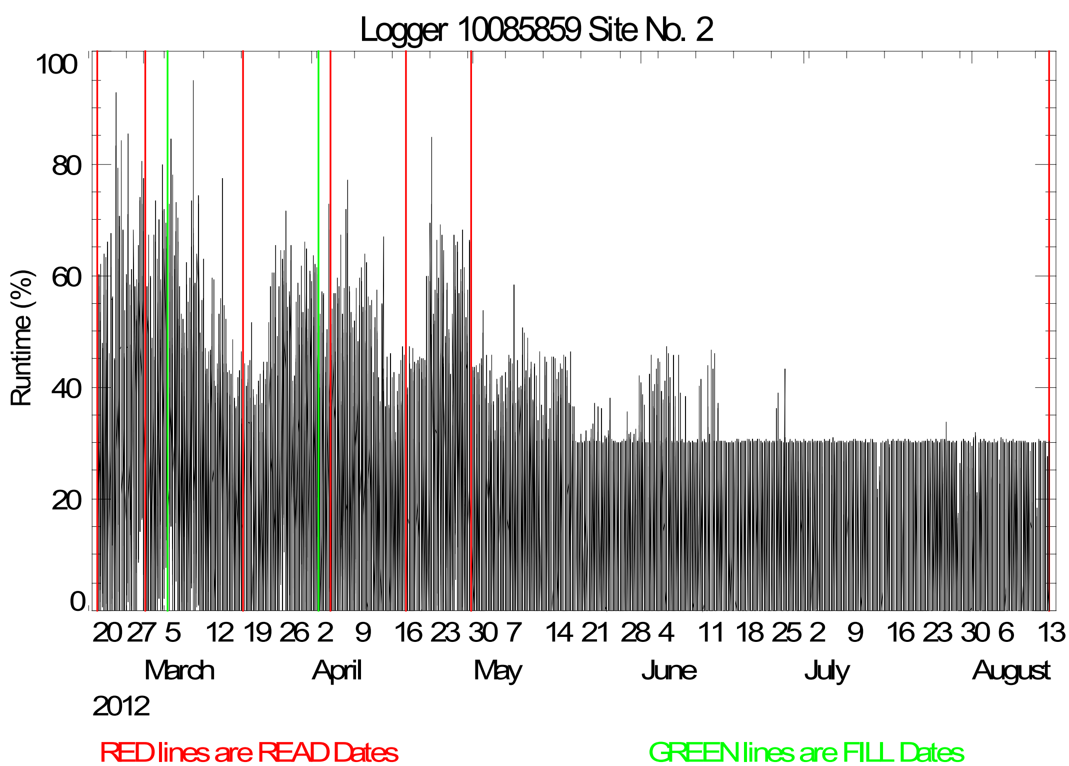


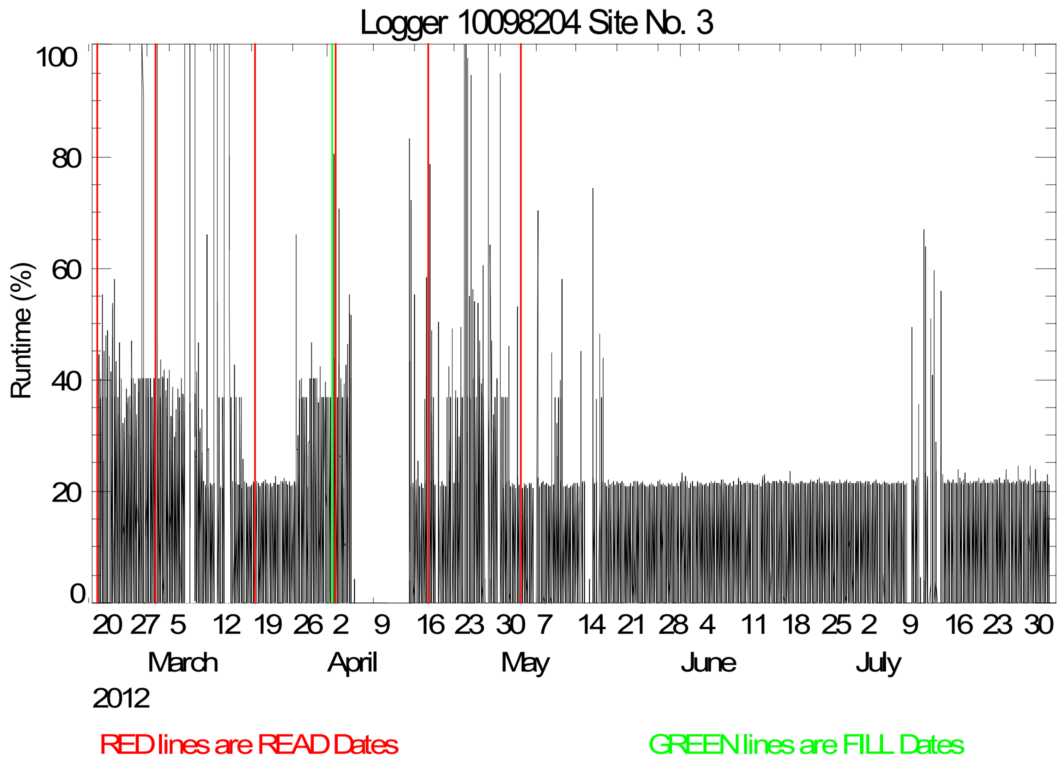
Figure 13. Error between published and calculated tank volume as a function of tank level.

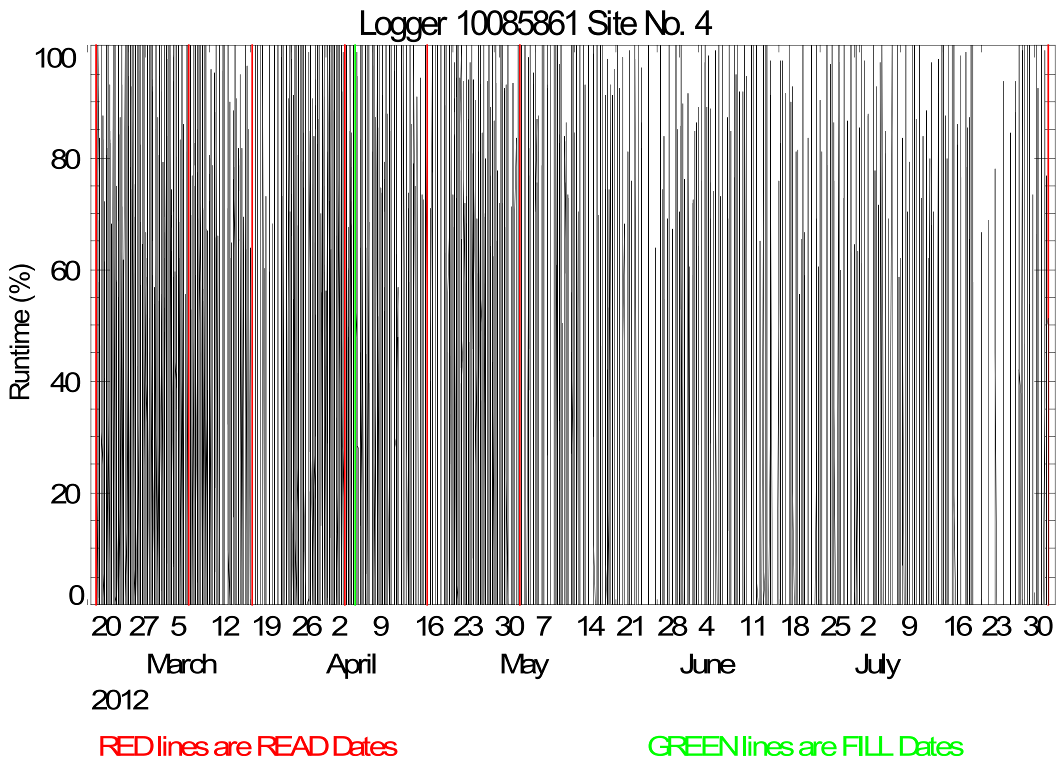
Standard US Fuel Tank Capacity Chart							
	1/8	1/4	1/2	3/4	By Gauge		
APPROXIMATE U.S. GALLONS FOR EACH 1-INCH LEVEL							
Size	275H	275V	330H	330V	500	550	1000
Width/Dia.	27X44"	44X27"	44X27"	27X44"	48"	48"	48"
Lenght	60"	60"	72"	72"	65"	72"	130"
Inches	GALLONS OF OIL IN TANK						
1"	6	2	8	2	2	3	5
2"	14	5	17	6	7	8	14
3"	23	9	28	11	13	14	26
4"	32	14	38	16	20	22	40
5"	42	19	50	23	28	30	55
6"	52	25	64	30	36	40	72
7"	63	31	76	37	46	50	90
8"	74	38	90	44	55	60	110
9"	85	44	103	52	66	71	130
10"	96	51	116	60	76	83	150
11"	108	58	131	68	88	95	173
12"	120	65	144	77	99	107	196
13"	132	72	158	85	111	120	219
14"	144	79	172	94	123	133	243
15"	156	86	186	102	135	146	267
16"	168	94	199	110	148	160	292
17"	179	101	214	119	161	174	317
18"	190	108	227	127	174	188	342
19"	201	115	240	136	187	202	368
20"	212	122	254	144	200	216	394
21"	223	129	266	152	214	230	420
22"	233	136	280	161	227	245	446
23"	243	143	292	169	241	260	473
24"	252	151	302	178	254	275	500
25"	261	158	313	186	268	290	527
26"	269	165	322	195	281	305	554
27"	275	172	330	203	295	320	580
28"		179		211	308	334	606
29"		186		220	321	348	632
30"		193		228	334	362	658
31"		200		237	347	376	683
32"		207		245	360	390	708
33"		214		253	373	404	733
34"		221		262	385	417	757
35"		228		270	397	430	781
36"		235		277	408	443	804
37"		242		285	421	455	827
38"		248		292	432	467	850
39"		254		299	443	479	870
40"		259		305	453	490	890
41"		264		311	463	500	910
42"		268		316	472	510	928
43"		272		320	481	520	945
44"		275		322	488	528	960
45"					495	536	974
46"					501	544	986
47"					506	547	995
48"					509	550	1000
http://www.sippin.com/oil%20tank%20measure%20chart.htm							

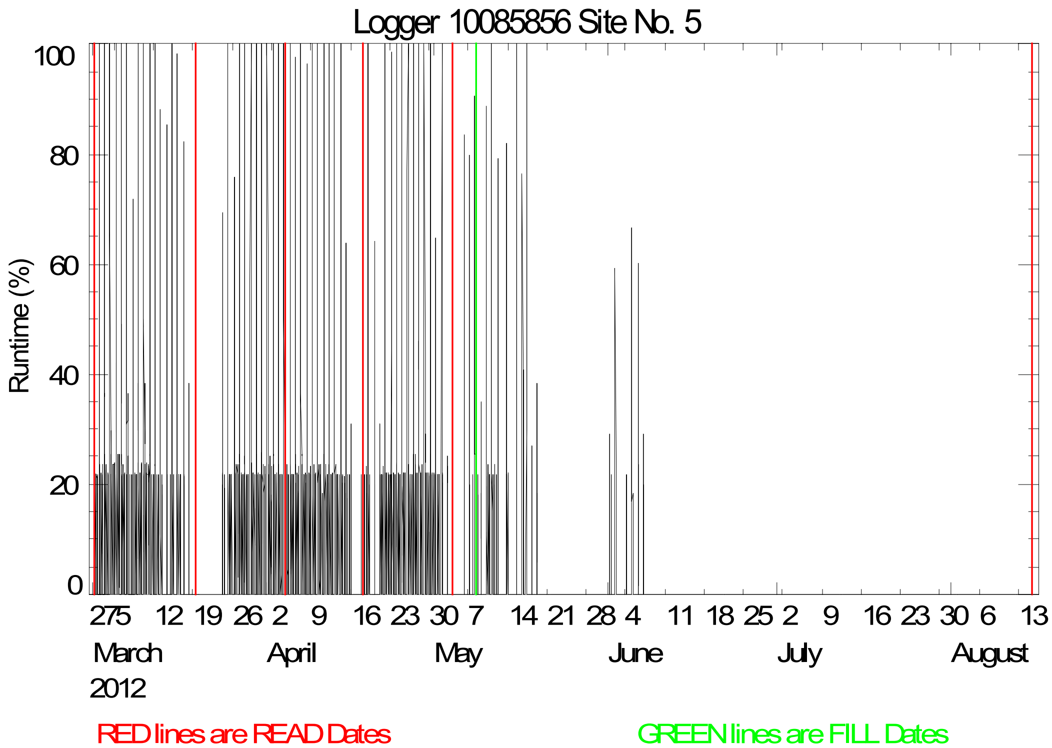
Appendix B: Plots of Runtime Data Collected at Each Site

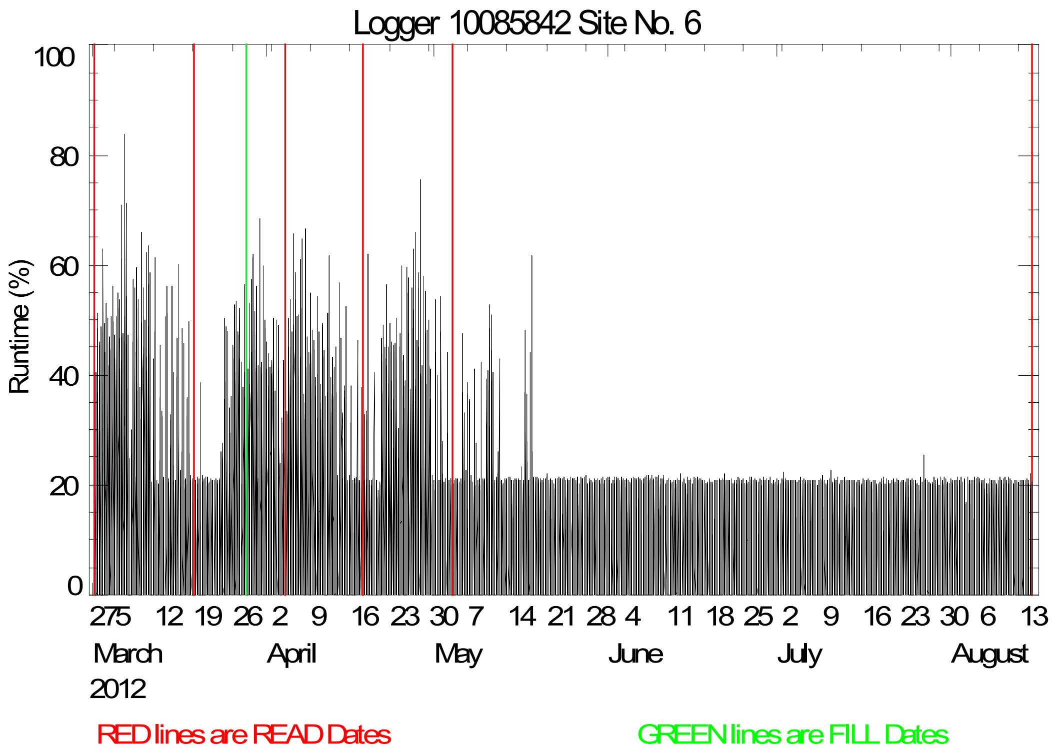





Logger 10098204 Site No. 3
100
80
60
40
20
0
Runtime (%)
20 27 5 12 19 26 2 9 16 23 30 7 14 21 28 4 11 18 25 2 9 16 23 30
March
April
May
June
July
2012
RED lines are READ Dates
GREEN lines are FILL Dates


Logger 10085861 Site No. 4
100
80
60
40
20
0
Runtime (%)
20 27 5 12 19 26 2 9 16 23 30 7 14 21 28 4 11 18 25 2 9 16 23 30
March
April
May
June
July
2012
RED lines are READ Dates
GREEN lines are FILL Dates


Logger 10085856 Site No. 5
Runtime (%)
0
20
40
60
80
100
27 5 12 19 26 2 9 16 23 30 7 14 21 28 4 11 18 25 2 9 16 23 30 6 13
March
April
May
June
July
August
2012
RED lines are READ Dates
GREEN lines are FILL Dates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Runtime (%)
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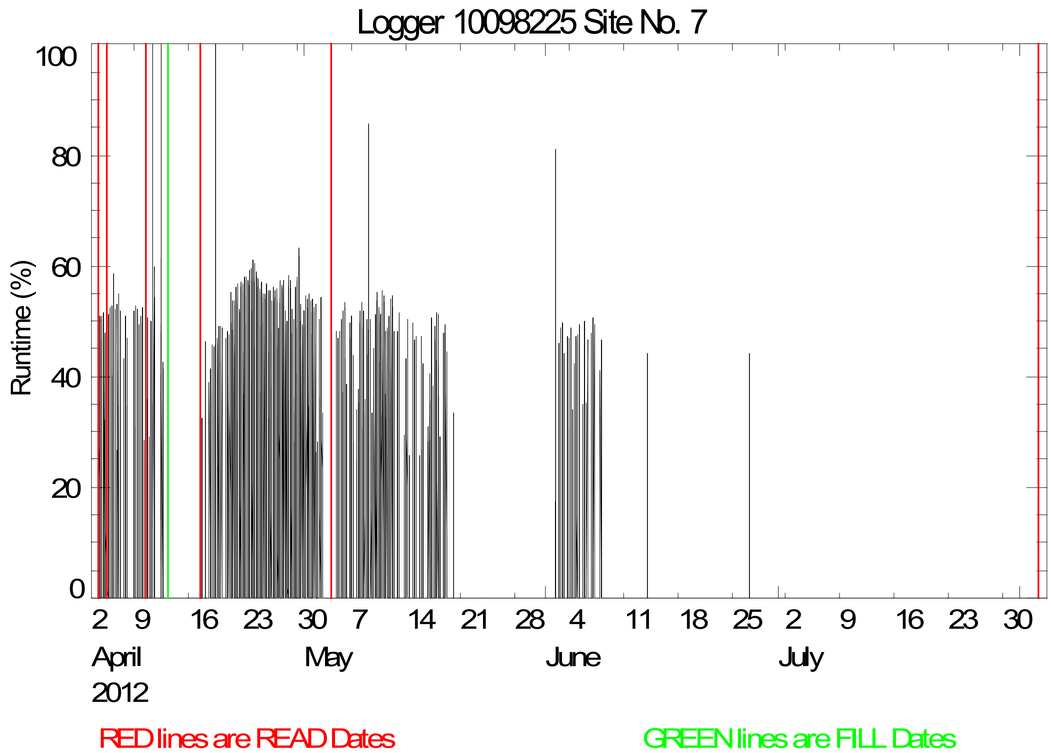
40
60
80
100
27 5 12 19 26 2 9 16 23 30 7 14 21 28 4 11 18 25 2 9 16 23 30 6 13
March
April
May
June
July
August
2012
RED lines are READ Dates
GREEN lines are FILL Dates


Logger 10098225 Site No. 7
Runtime (%)
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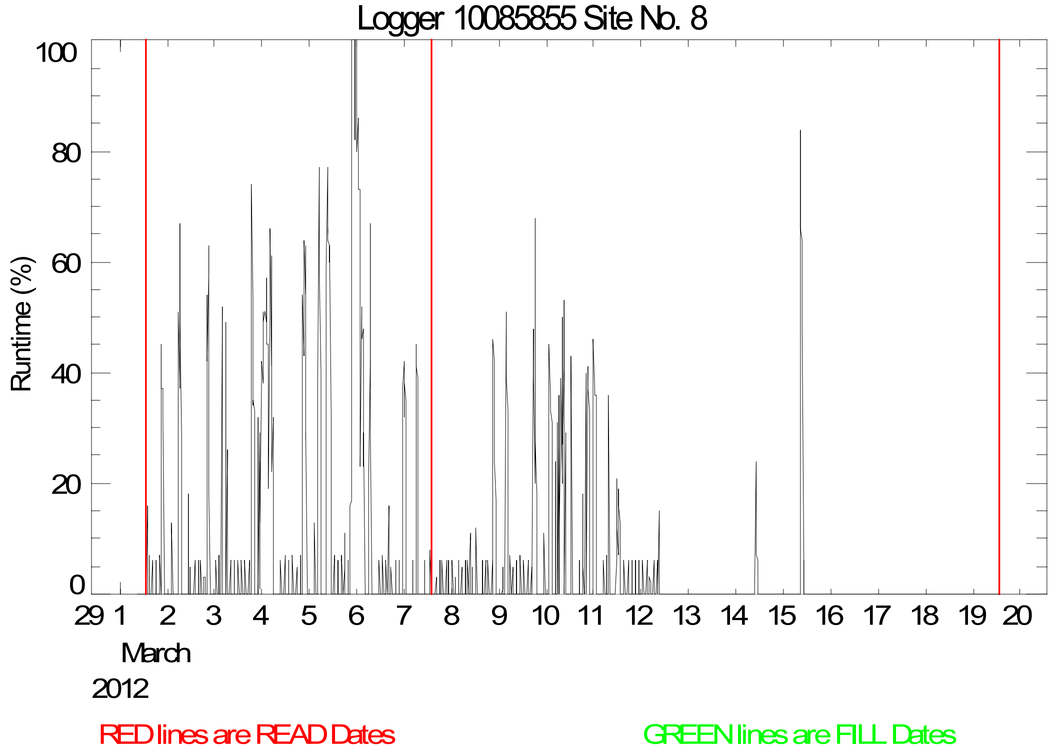
40
60
80
100
2 9 16 23 30 7 14 21 28 4 11 18 25 2 9 16 23 30
April
May
June
July
2012
RED lines are READ Dates
GREEN lines are FILL Dates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Runtime (%)
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40
60
80
100
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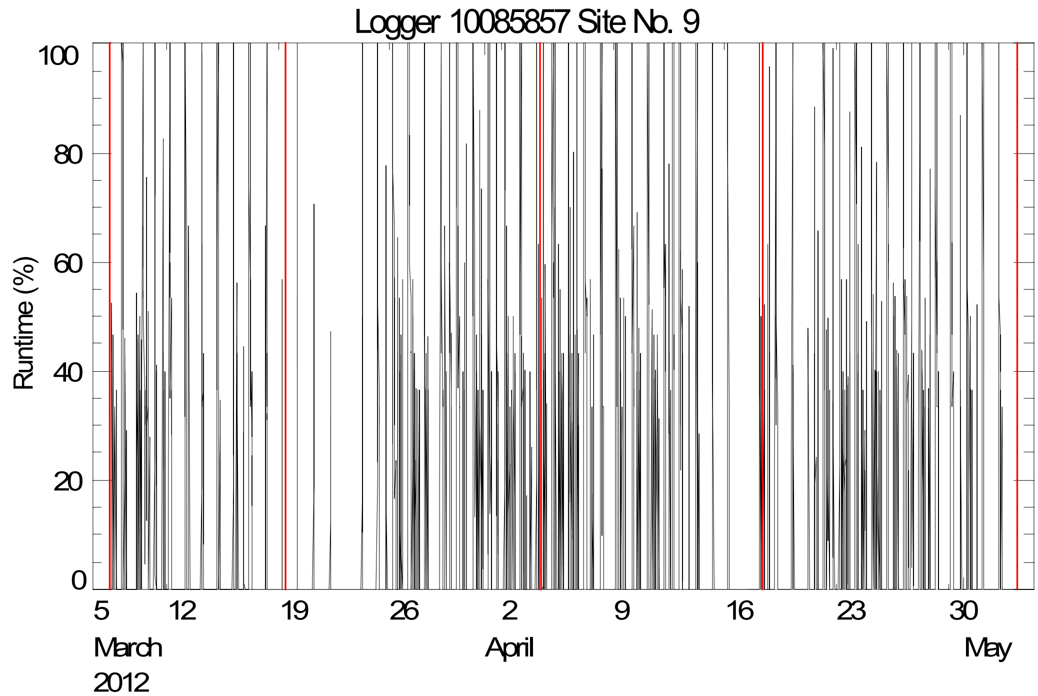
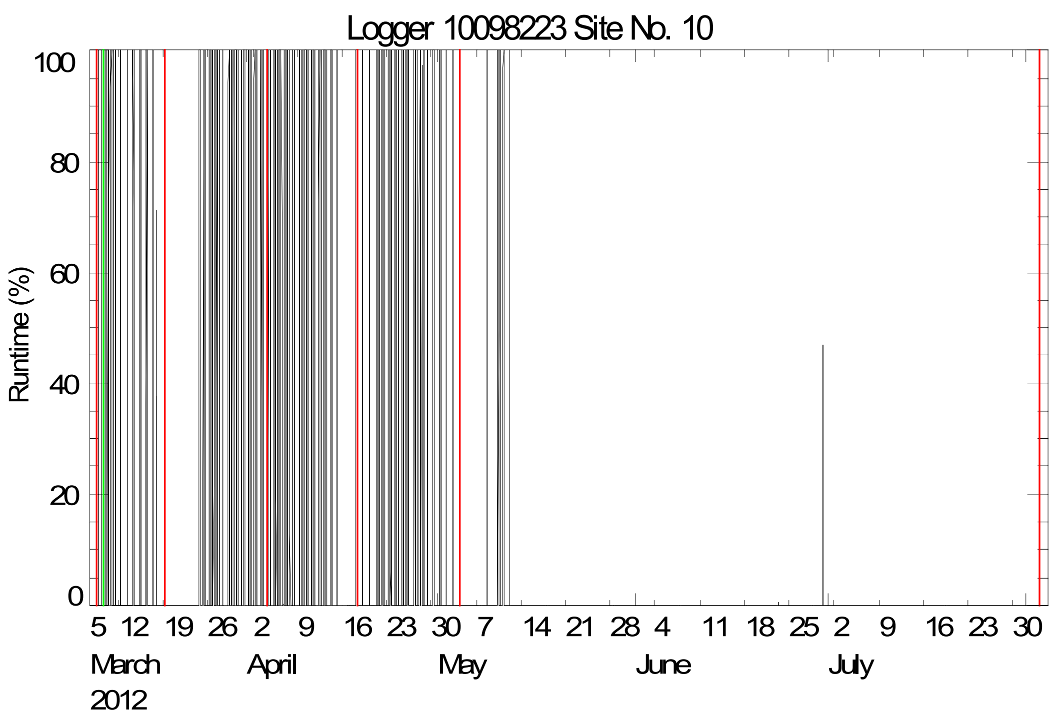
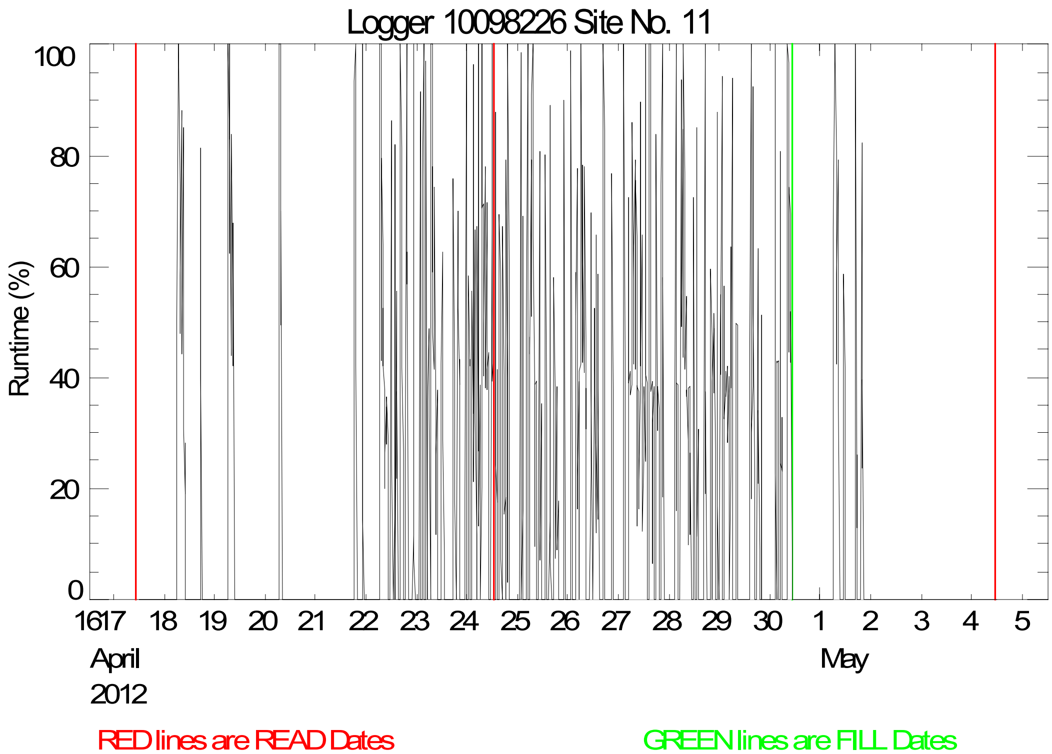
March
2012
RED lines are READ Dates
GREEN lines are FILL Dates



RED lines are READ Dates GREEN lines are FILL Dates



RED lines are READ Dates GREEN lines are FILL Dates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Runtime (%)
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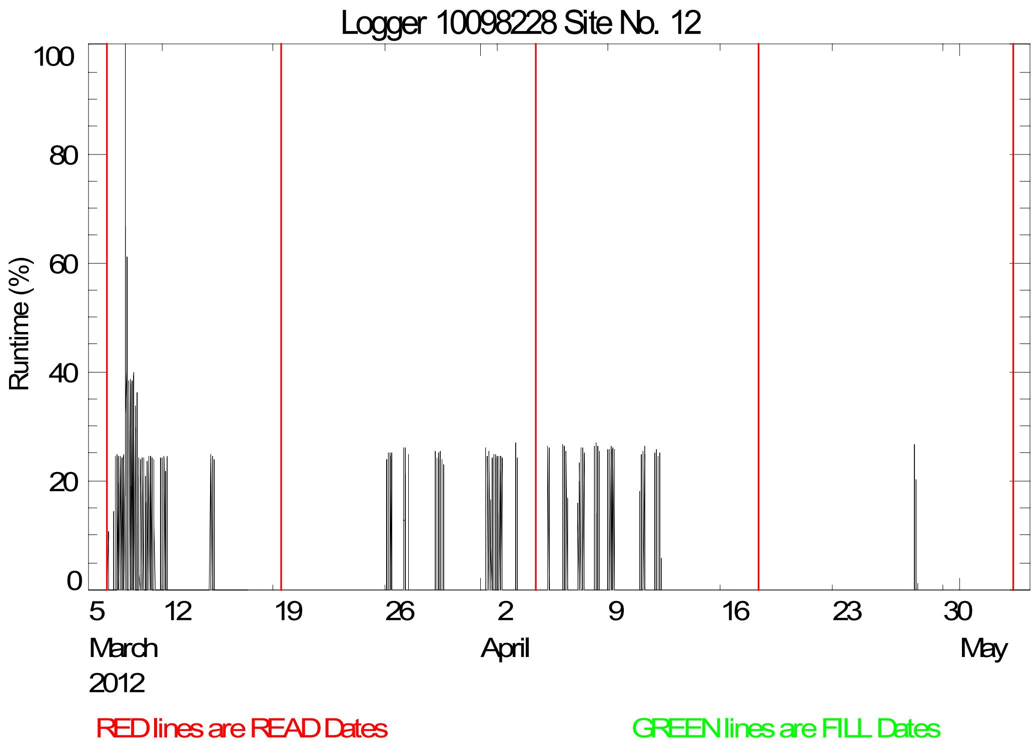
40
20
0
1617 18 19 20 21 22 23 24 25 26 27 28 29 30 1 2 3 4 5
April
2012
May
RED lines are READ Dates
GREEN lines are FILL Dates


Logger 10098228 Site No. 12
Runtime (%)
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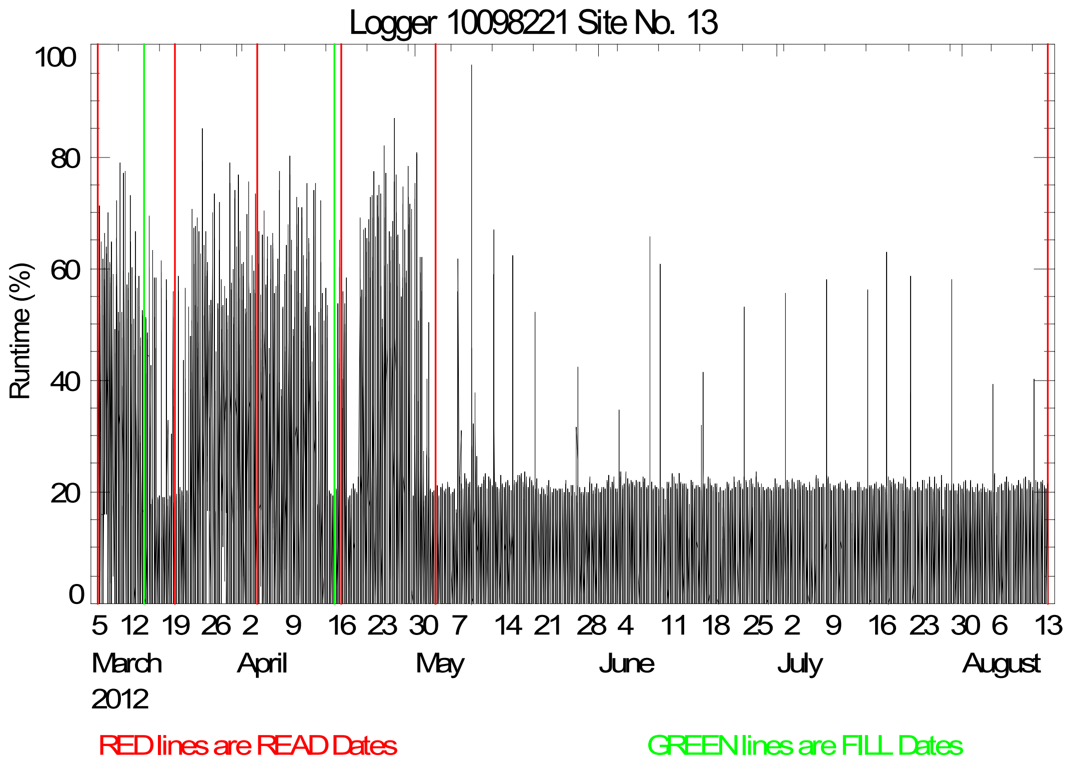
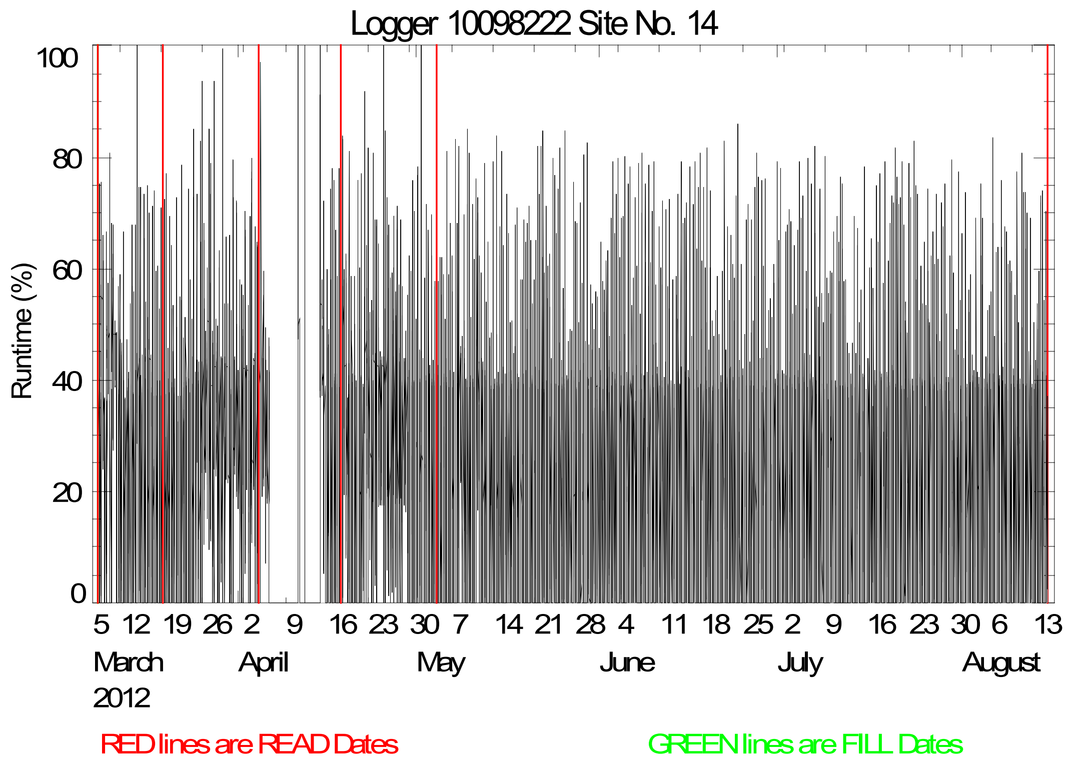
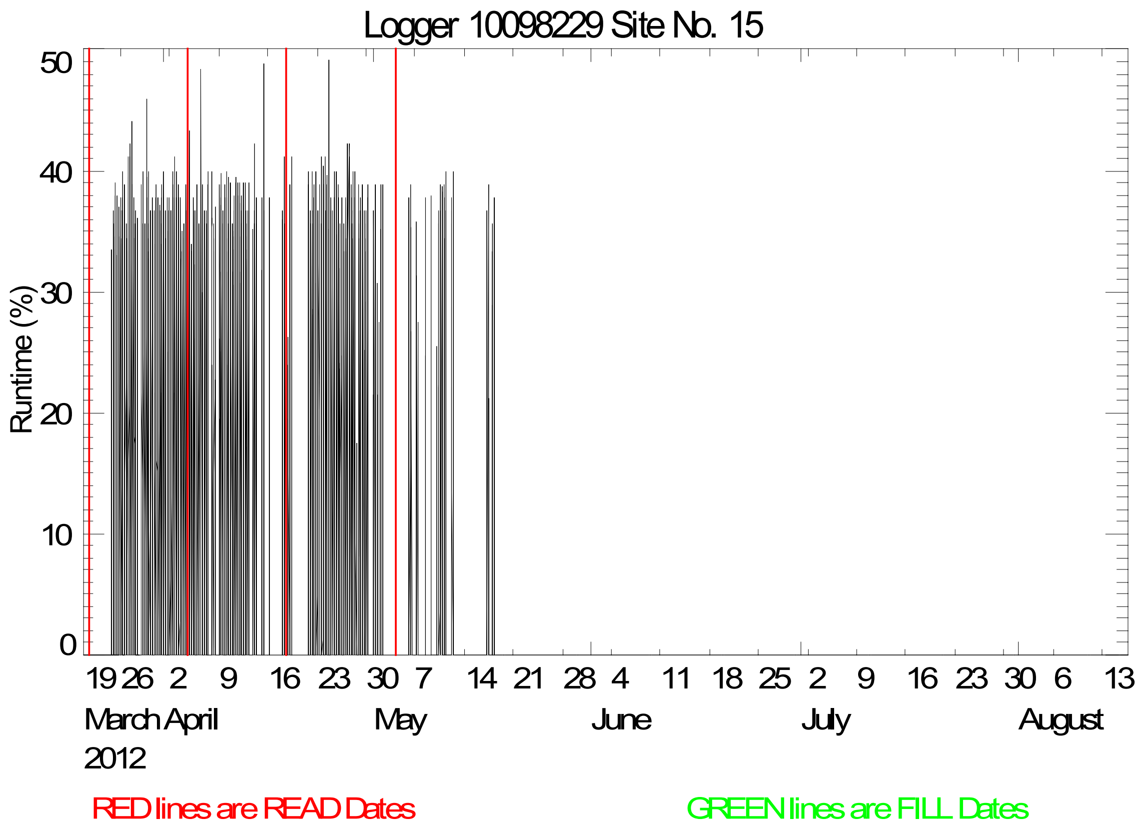
60
40
20
0
5 12 19 26 2 9 16 23 30
March
2012
April
May
RED lines are READ Dates
GREEN lines are FILL Dates


Logger 10098221 Site No. 13
Runtime (%)
100
80
60
40
20
0
5 12 19 26 2 9 16 23 30 7 14 21 28 4 11 18 25 2 9 16 23 30 6 13
March
April
May
June
July
August
2012
RED lines are READ Dates
GREEN lines are FILL Dates


Logger 10098222 Site No. 14
Runtime (%)
100
80
60
40
20
0
5 12 19 26 2 9 16 23 30 7 14 21 28 4 11 18 25 2 9 16 23 30 6 13
March
April
May
June
July
August
2012
RED lines are READ Dates
GREEN lines are FILL Dates

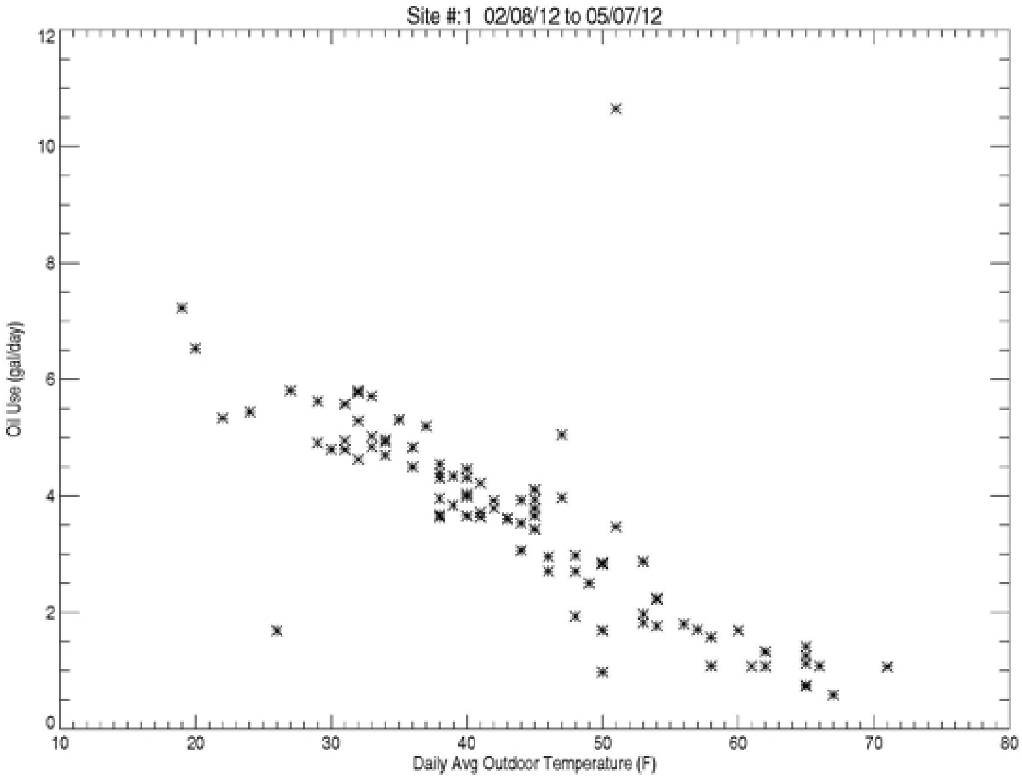

Logger 10098229 Site No. 15
Runtime (%)
0
10
20
30
40
50
19 26 2 9 16 23 30 7 14 21 28 4 11 18 25 2 9 16 23 30 6 13
March April May June July August
2012
RED lines are READ Dates
GREEN lines are FILL Dates

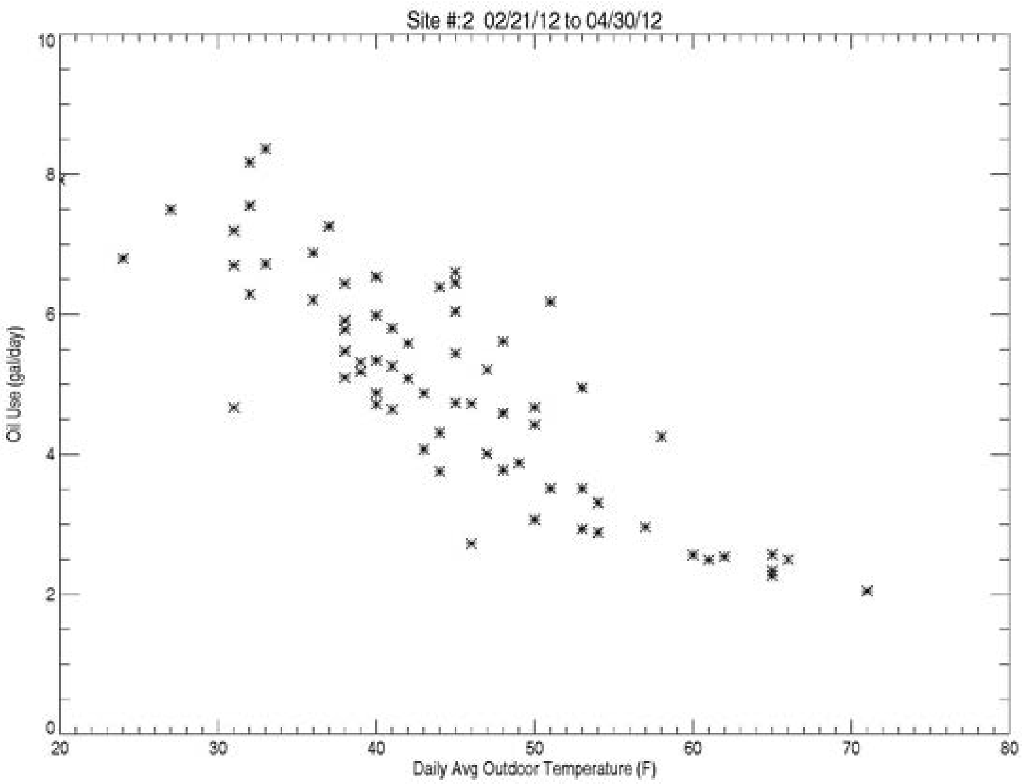
Appendix C: Daily Load Line Plots of Oil Use Versus Outdoor Temperature

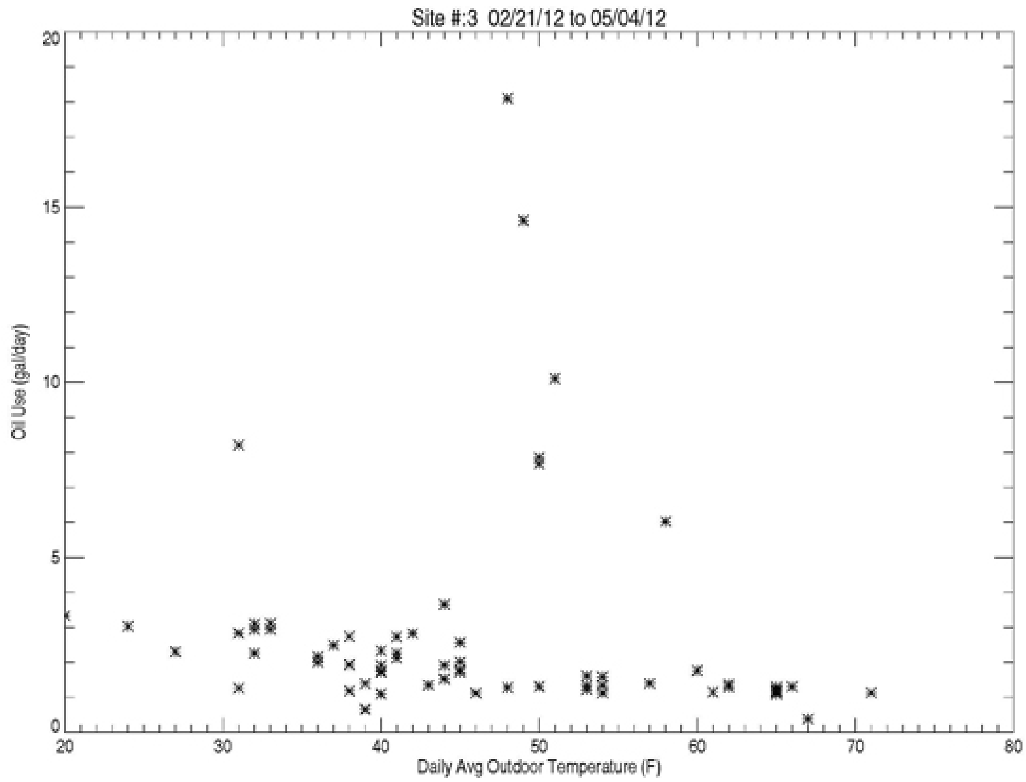
The plots on the following pages show the daily "oil use" load lines developed from the runtime data and local weather data for Syracuse Airport. Some of the plots show the expected linear trend while others do not. The table below provides a brief explanation for the trends observed for each site.

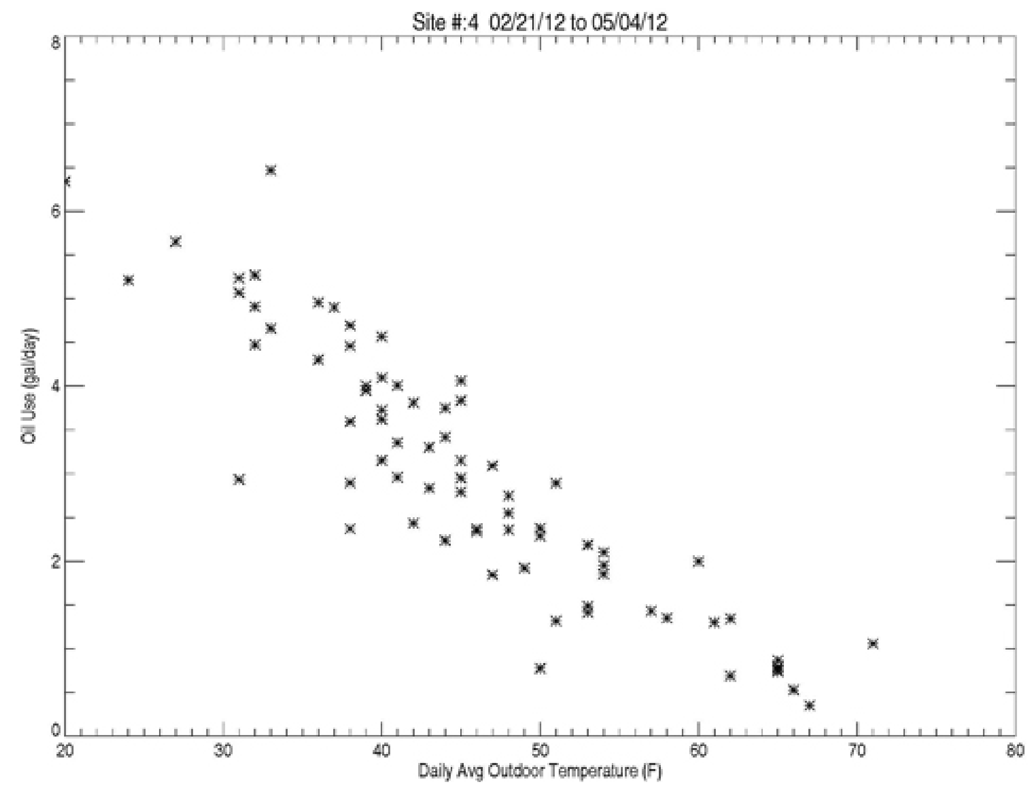
Table 6. Site Trends.

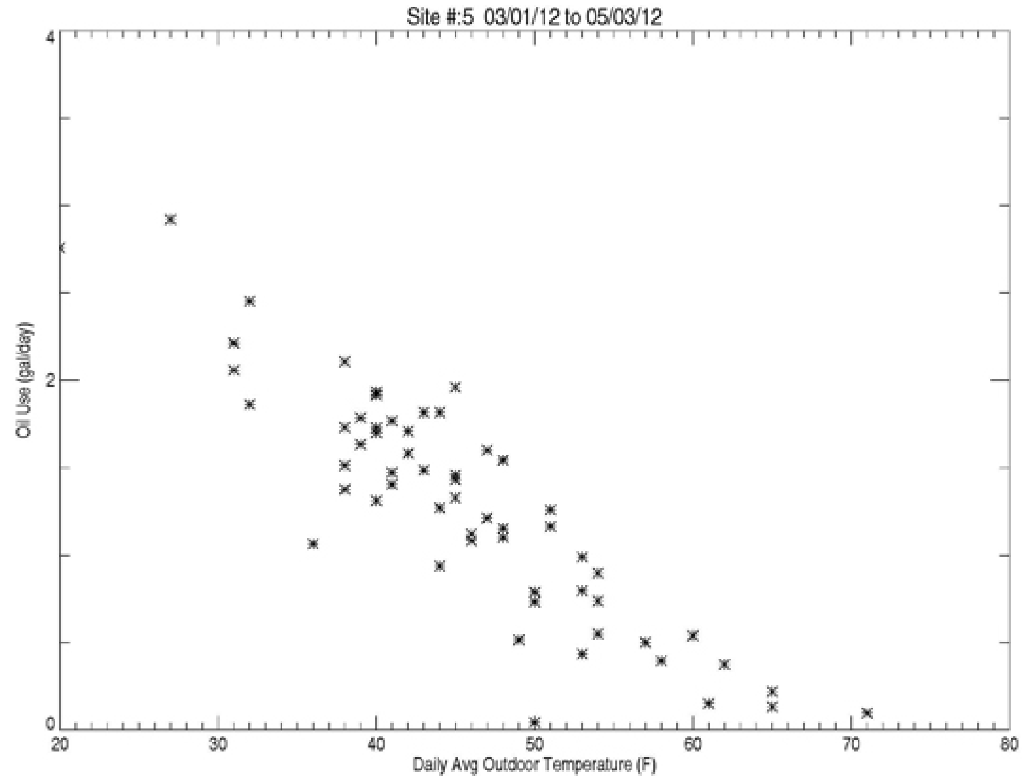
Site 1	Oil use includes DHW (indirect tank). Deviations from trend due to days with high hot water use.
Site 2	Oil use includes DHW for office and apartment. Space heating balance point appears to be under 60°F because of high internal gains. Appear to use about 2 gal/day for water heating.
Site 3	Oil use for DHW. Used a woodstove with oil as backup. Days with very high use caused by boiler fault combined with improper placement of CT (i.e., the CT measured pump and burner runtime).
Site 4	Oil Use for DHW. Generally a good trend with temperature.
Site 5	Generally a good trend with temperature.
Site 6	Oil use for DHW. Reasonably good trend with temperature.
Site 7	Intermittent occupancy
Site 8	Commercial warehouse with intermittent use.
Site 9	Good trend with temperature
Site 10	Reasonably good trend with temperature.
Site 11	Oil use for DHW. Intermittent use of wood stove.
Site 12	Small auto shop. Intermittent use of the wood stove.
Site 13	Oil use for DHW. Reasonably good trend with temperature.
Site 14	Vacation week during cold period.
Site 15	Good trend with temperature.

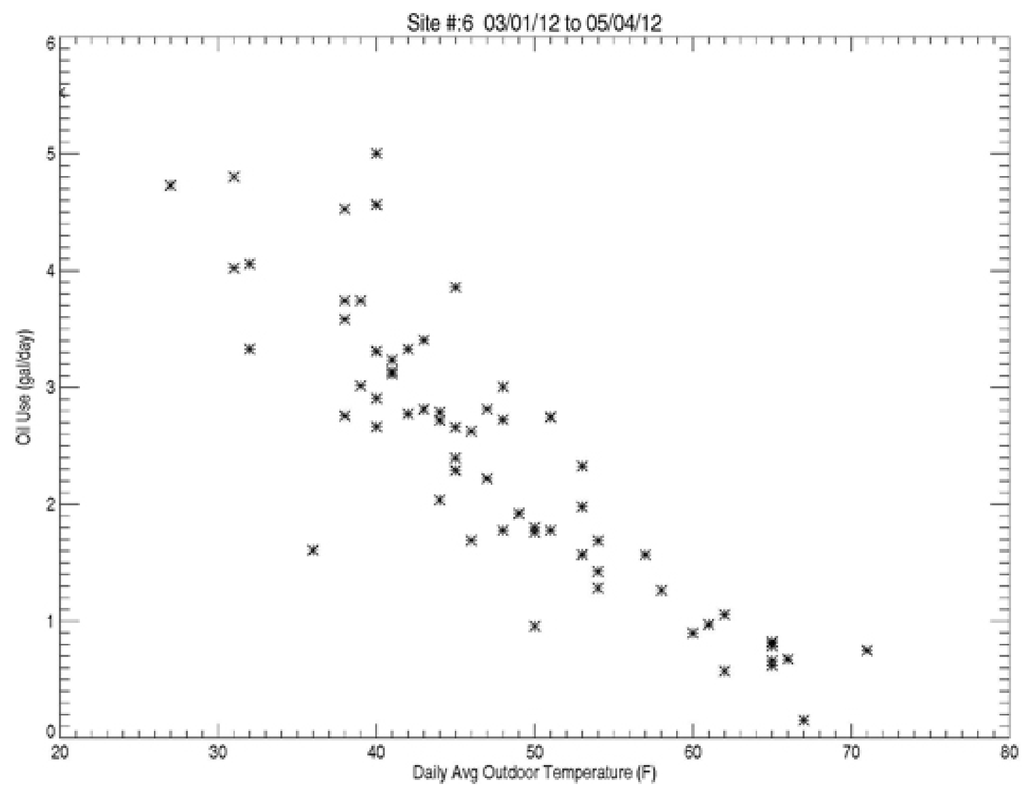

Site #:1 02/08/12 to 05/07/12
Oil Use (gal/day)
Daily Avg Outdoor Temperature (F)

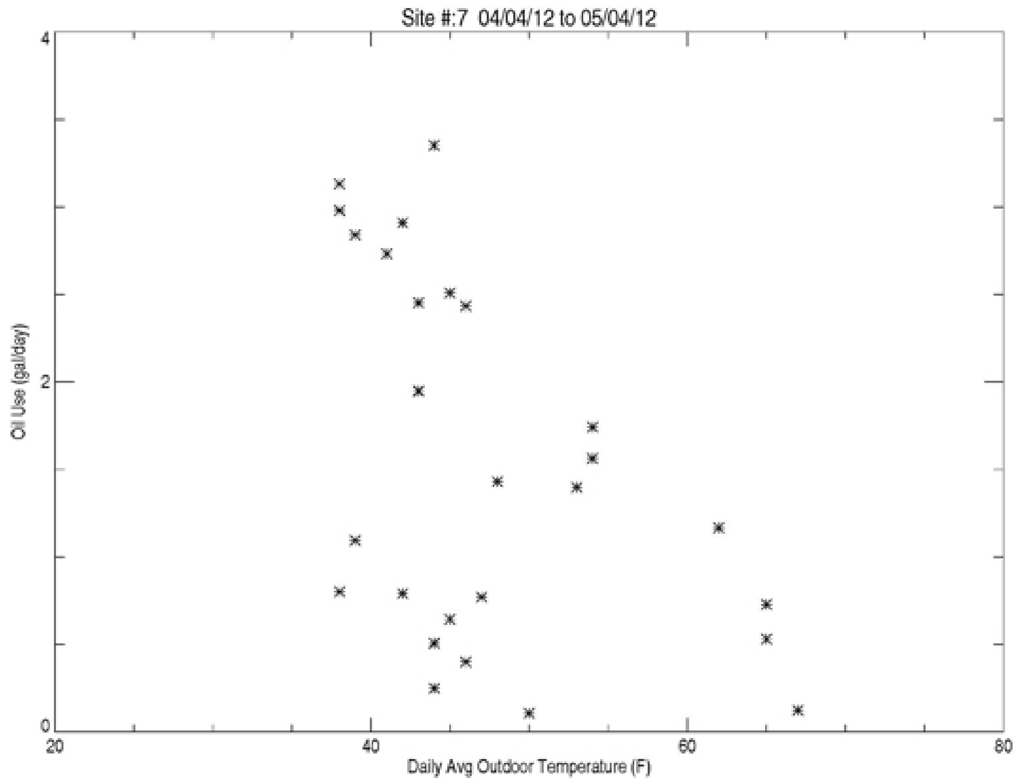

Site #:2 02/21/12 to 04/30/12
Oil Use (gal/day)
Daily Avg Outdoor Temperature (F)

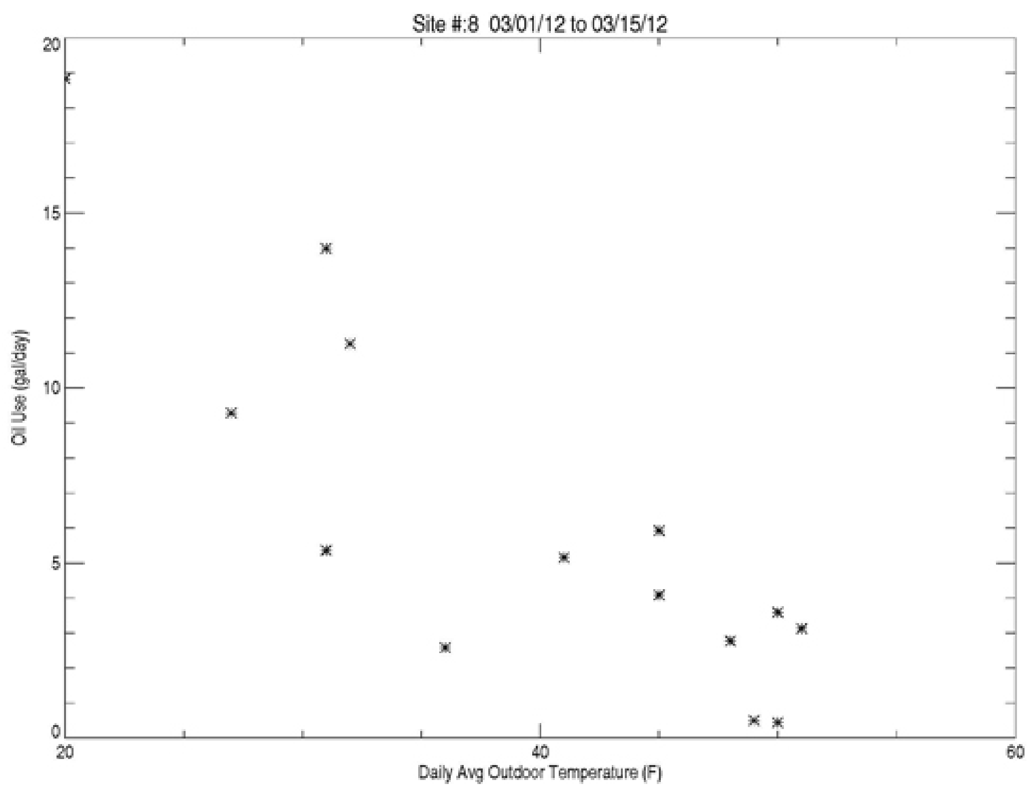

Site #:3 02/21/12 to 05/04/12
Oil Use (gal/day)
Daily Avg Outdoor Temperature (F)
0
5
10
15
20
20
30
40
50
60
70
80

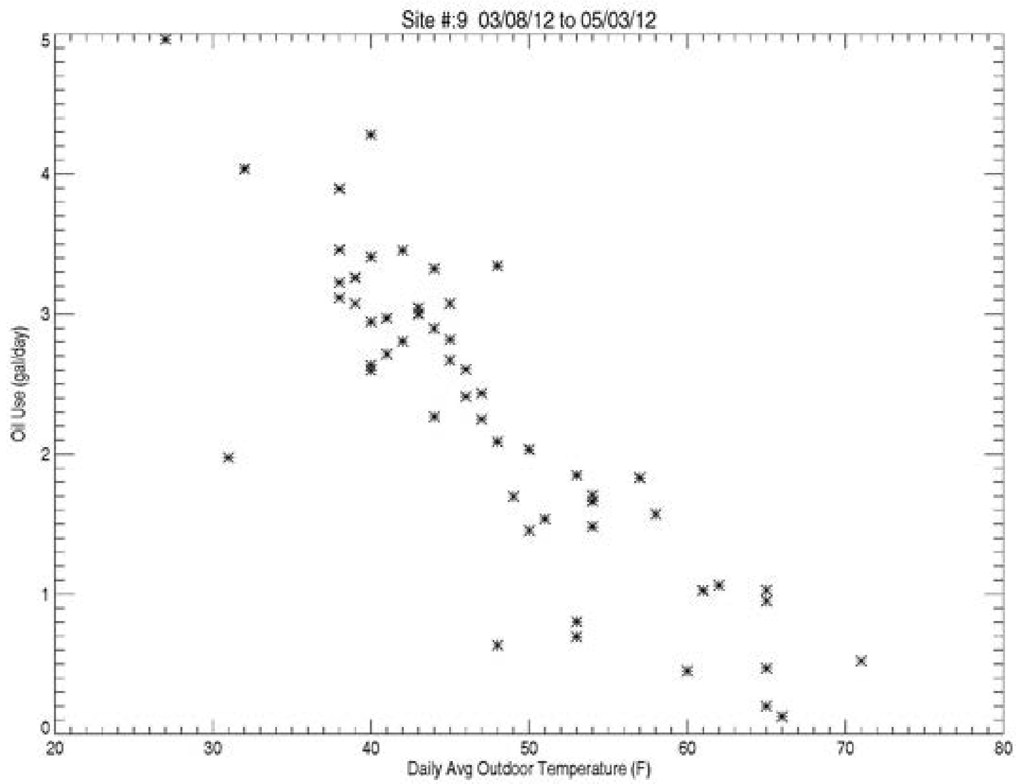

Site #:4 02/21/12 to 05/04/12
Oil Use (gal/day)
Daily Avg Outdoor Temperature (F)
0
2
4
6
8
20
30
40
50
60
70
80

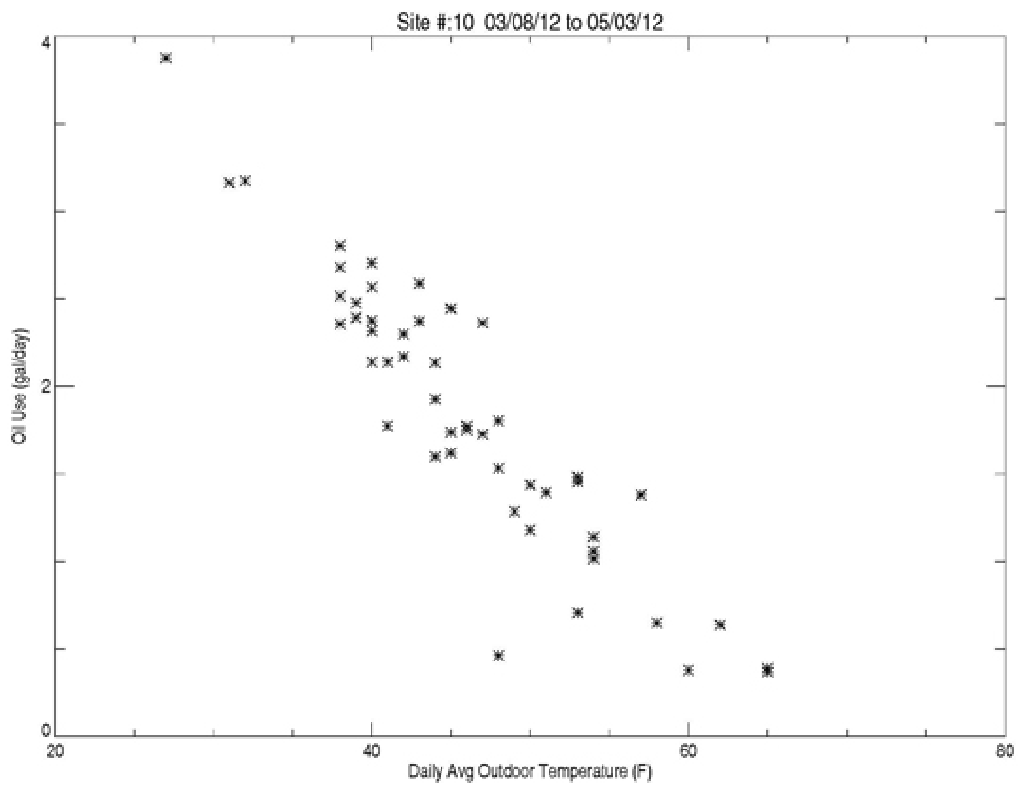

Site #:5 03/01/12 to 05/03/12
Oil Use (gal/day)
Daily Avg Outdoor Temperature (F)
0
2
4
20
30
40
50
60
70
80

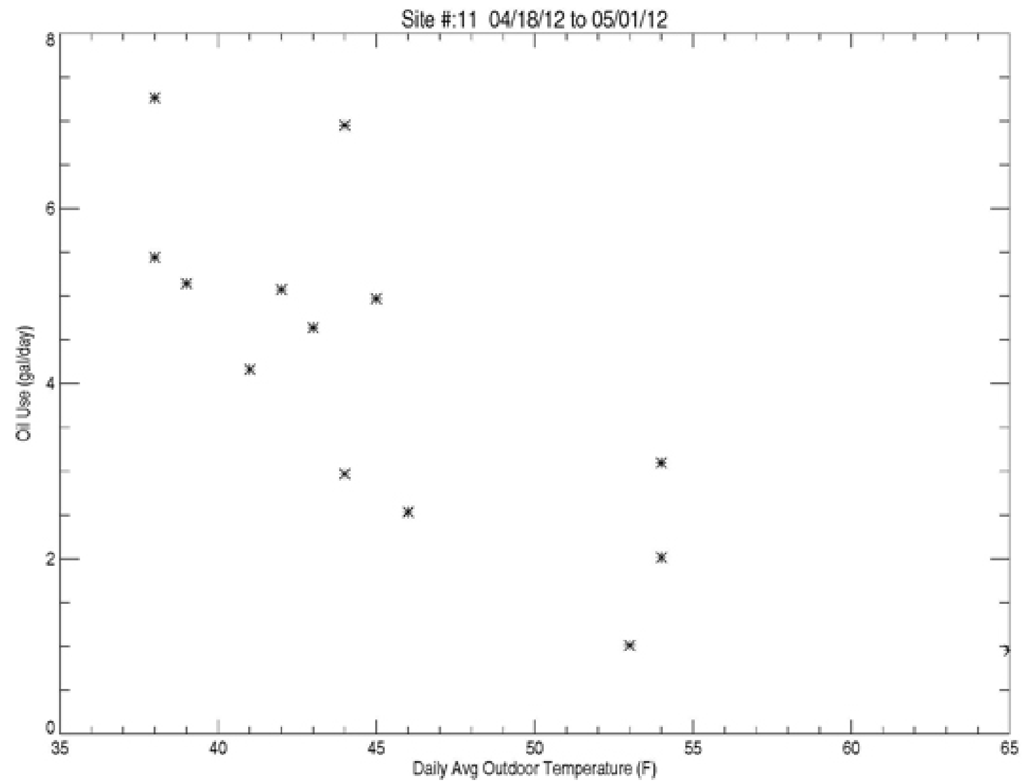

Site #:6 03/01/12 to 05/04/12
Oil Use (gal/day)
Daily Avg Outdoor Temperature (F)
0
1
2
3
4
5
6
20
30
40
50
60
70
80

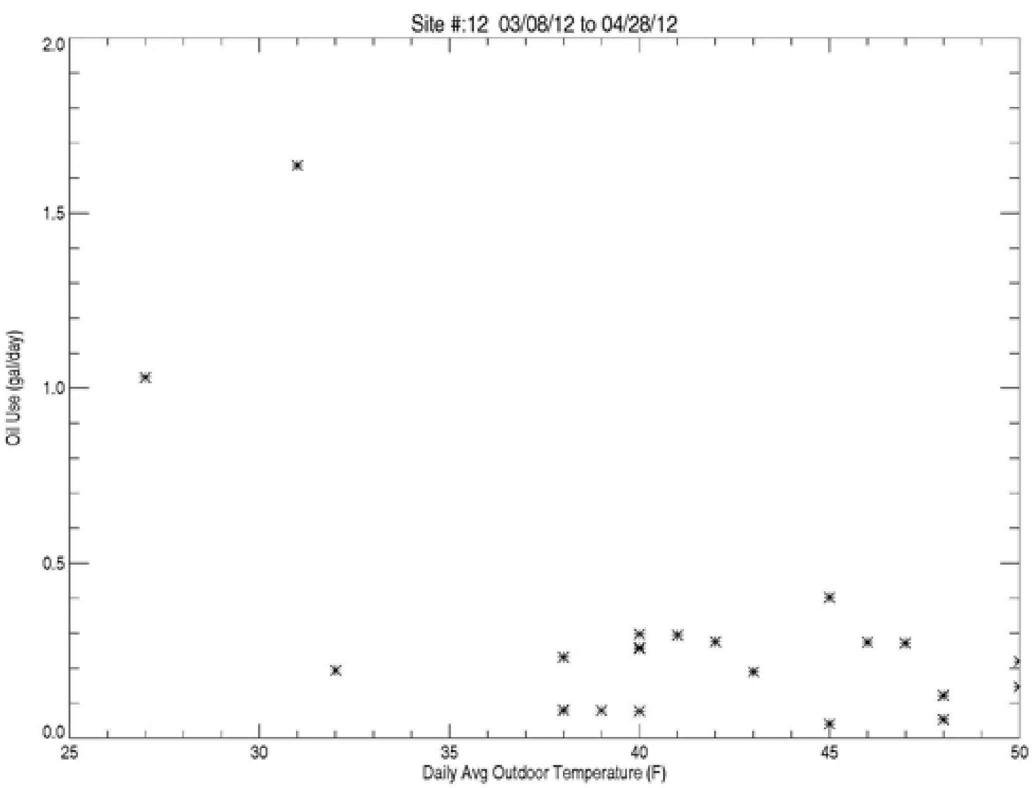

Site #:7 04/04/12 to 05/04/12
Oil Use (gal/day)
Daily Avg Outdoor Temperature (F)
0
2
4
20
40
60
80

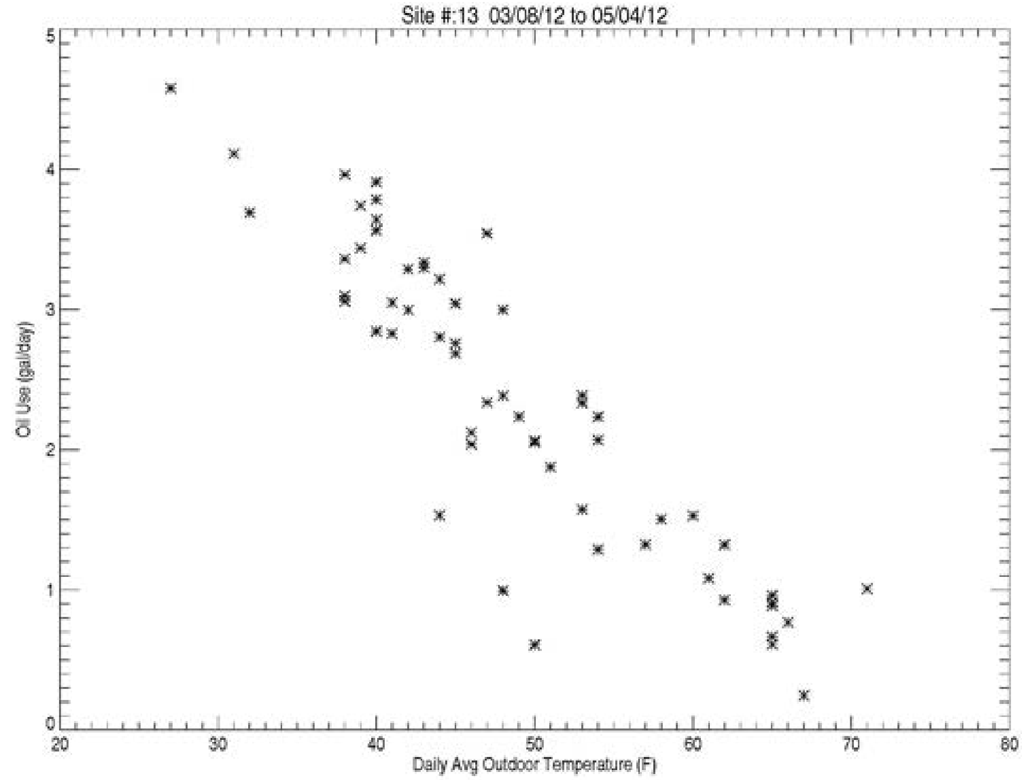

Site #:8 03/01/12 to 03/15/12
Oil Use (gal/day)
Daily Avg Outdoor Temperature (F)
0
5
10
15
20
20
40
60

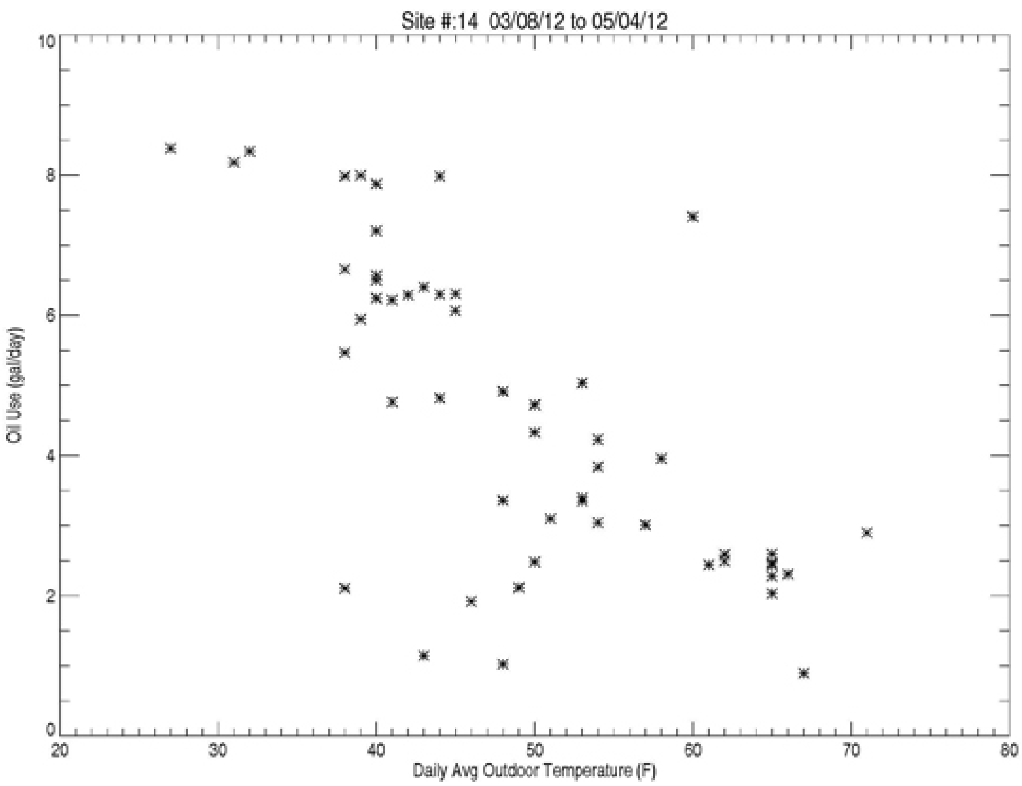

Site #:9 03/08/12 to 05/03/12
Oil Use (gal/day)
Daily Avg Outdoor Temperature (F)
0
1
2
3
4
5
20
30
40
50
60
70
80

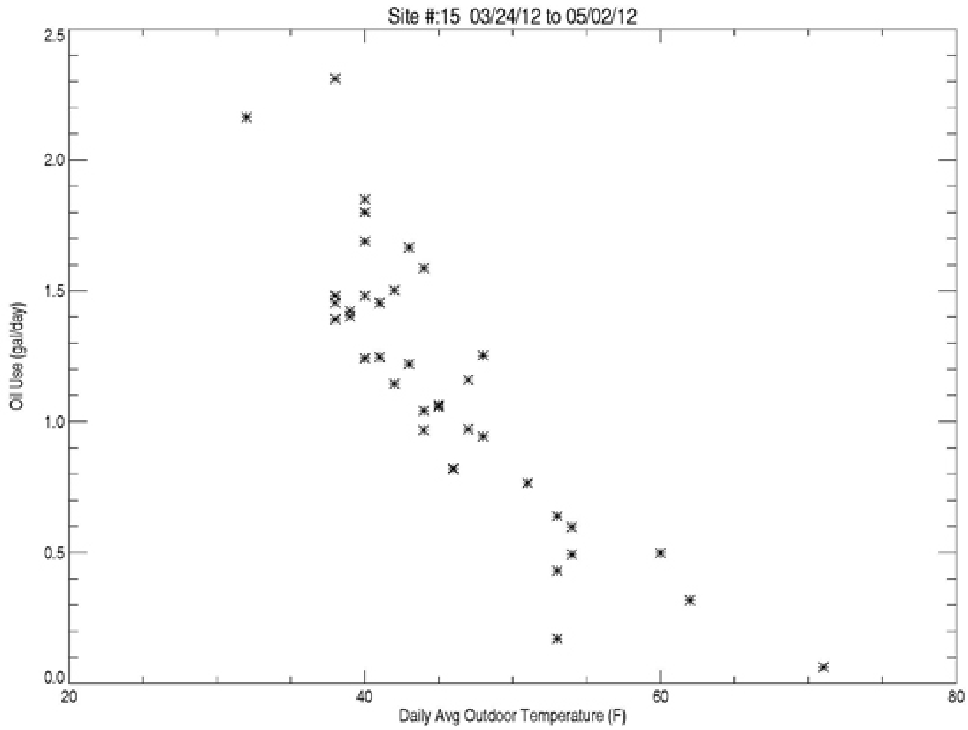

Site #:10 03/08/12 to 05/03/12
Oil Use (gal/day)
Daily Avg Outdoor Temperature (F)
0
2
4
20
40
60
80


Site #:11 04/18/12 to 05/01/12
Oil Use (gal/day)
Daily Avg Outdoor Temperature (F)
0
2
4
6
8
35
40
45
50
55
60
65


Site #:12 03/08/12 to 04/28/12
Oil Use (gal/day)
Daily Avg Outdoor Temperature (F)
0.0
0.5
1.0
1.5
2.0
25
30
35
40
45
50


Site #:13 03/08/12 to 05/04/12
Oil Use (gal/day)
Daily Avg Outdoor Temperature (F)
0
1
2
3
4
5
20
30
40
50
60
70
80


Site #:14 03/08/12 to 05/04/12
Oil Use (gal/day)
Daily Avg Outdoor Temperature (F)
0
2
4
6
8
10
20
30
40
50
60
70
80


Site #:15 03/24/12 to 05/02/12
Oil Use (gal/day)
Daily Avg Outdoor Temperature (F)
0.0
0.5
1.0
1.5
2.0
2.5
20
40
60
80

Appendix D: Simplified Protocol for Measuring Fuel Oil Consumption

This protocol describes a monitoring and verification approach that can be implemented to measure the energy impact of retrofitting or weatherizing a home that uses oil heat. The low-cost approach described here uses a runtime data logger to predict runtime which can be used to predict oil use trends.

Overview

The key element of this protocol is to install a battery powered data logger with a current switch sensor to record the daily runtime of the oil burner. The daily burner runtime is a good surrogate for daily oil use (using the nominal characteristics of the burner nozzle). By collecting daily runtime data both before and after a weatherization retrofit is complete (i.e., pre- and post-retrofit), the impact of a retrofit can be discerned by correlating oil use with outdoor temperature data. Outdoor temperature data are available from various sources, including the Weather Underground website (www.wunderground.com). Figure 14 shows the trend of oil use with ambient temperature with both the pre- and post-retrofit data shown with different symbols. The lines are the best fit to each dataset. The difference between the pre- and post-retrofit lines can be used with temperature bin data to predict the annual energy savings. Multilinear regression can be used to estimate the uncertainty of the difference between the best fit lines, as discussed below.

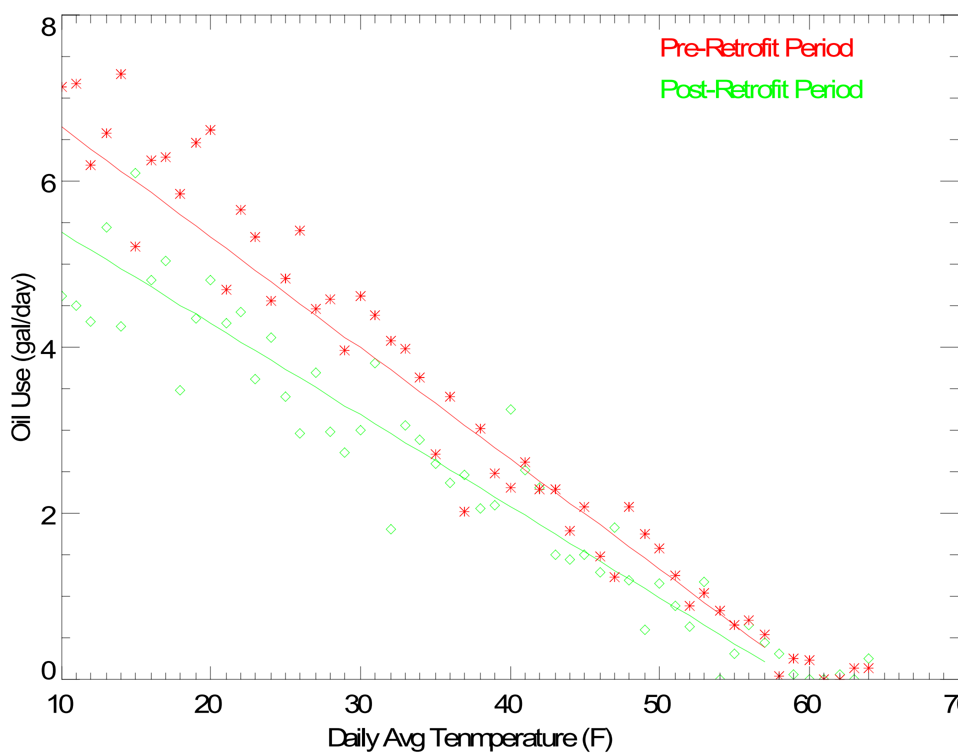


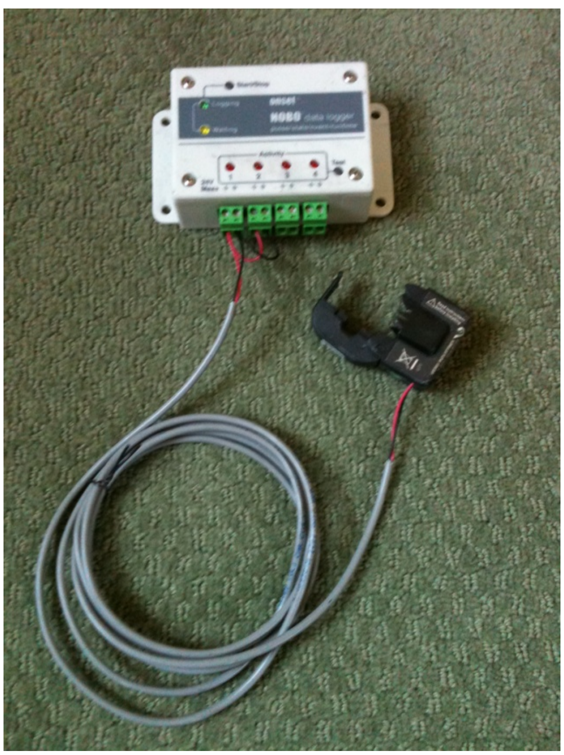
Figure 14. Data analysis procedure comparing pre- and post-retrofit oil use to predict savings.

Measurement Details

The measurement protocol is based around a HOBO data logger capable of recording the duration of a contact closure. The contact closure is provided by a Veris Current Switch Sensor (H300). Both of these components are shown in Figure 15. The total cost of these components is about $220. The split core H300 is clipped around the 120 Volt wire feeding the oil-fired burner assembly. When the burner operates, the H300 provides a contact closure that is sensed by the data logger. The duration of the switch closure is recorded by the logger to determine the burner runtime.

HOBO Logger (UX120-17)

Veris Current Switch (H300)



HOBO Logger with Current Switch wired to Channels 1 and 2

Vendor Websites:

www.onsetcomp.com

www.veris.com

Figure 15. HOBO data logger (from Onset Computer Corp.) and current switch (Veris Industries).

For boilers, the current sensor can be installed in the hydronic or boiler controller as shown in Figure 16. For furnaces other locations are possible. The current sensor can be clipped around the wire as shown (be sure to turn off the power to the unit first using the red power switch).

The burner firing rate is expressed in gph. This value is normally stamped on the nozzle inside the burner assembly. The nozzle can normally be removed from the burner with a wrench—you should recruit an oil technician if you are not sure how to do this. The service report for an oil burner from the annual cleaning typically has the nozzle size written on it.

Nozzles are rated to provide the nominal flow at a pressure of 100 psig. If possible have an oil technician measure the operating pressure of the oil pump on the burner. If a pressure measurement is not possible, then assume an operating pressure of 120 psig.

The HOBO data logger can be setup and launched using the HOBOware software. There are two options for data collection rates:

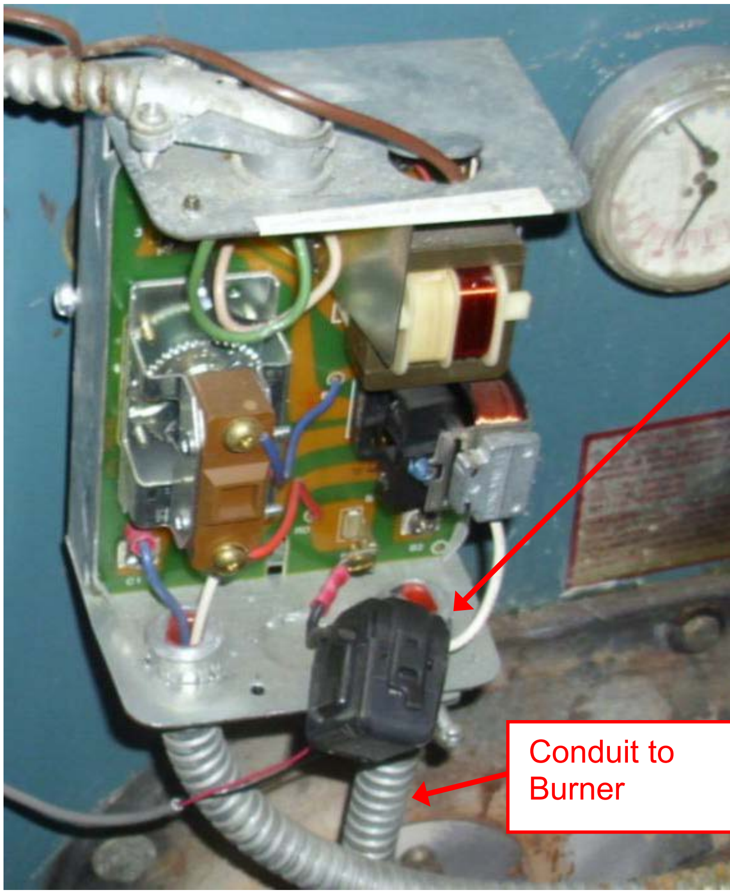
- Data can be collected at daily intervals.
- Data can be collected at hourly intervals.

Data are at required daily intervals only for an analysis like that shown in Figure 14, but hourly data can be collected to understand the daily use profile if that is desired. The hourly readings can be aggregated into daily totals. The data logger can hold more than 12 months of hourly data.

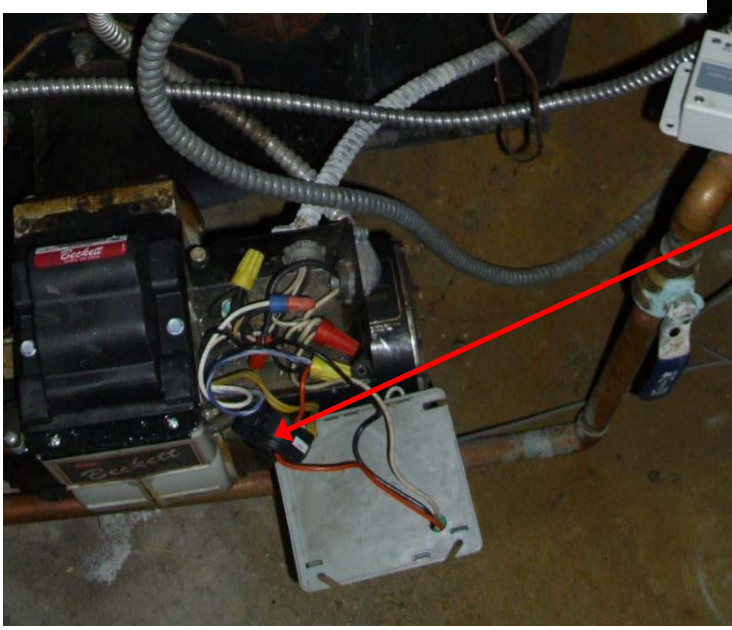
Special Considerations for Time Delay Burners

Some oil burners—including most new products—include a time delay from when the burner fan first starts to when the oil solenoid opens to allow oil to flow to the nozzle. This delay is typically a few seconds and can be audibly detected and timed with a stopwatch. On most systems this delay will be of constant duration and can be determined by a one-time reading.

If the burner has a time delay, the output from the current switch can be jumpered into channel 2 as well (see data logger wiring in Figure 16). Channel 2 can be programmed to count the number of operating cycles in each daily or hourly time interval. This number of cycles will be combined with the time delay duration to predict the oil use.



Current switch on boiler hydronic controller



Current switch installed on burner controller

Figure 16. Installation of current switch on burner power wire (switch off power before connecting).

Data Collection and Analysis

The data logger and current switch should be installed or deployed during the heating season at least a few weeks before the retrofit is started. Then data collection can continue after the retrofit has been completed for several weeks. We recommend at least 3 weeks of data collection from both the pre- and post-retrofit period. Once the runtime data are collected, they can be used as shown below.

The gallons of fuel used for each period or day (GAL_{rt}) can be determined with following equation

$$GAL_{rt} = \left(RT - CYC \cdot t_{delay}\right) \cdot GPH_{noz} \cdot \sqrt{P_{noz}/100}$$

Where:

RT	runtime of the burner in the period (hours)
CYC	number of burner operating cycles in the period (-)
t_{delay}	ime delay before the solenoid opens (converted to hours)
GPH_{noz}	rated performance of the nozzle in the burner (gph at 100 psi)
P_{noz}	operating pressure measured at the nozzle (psig). Recommended default is 120.

This process allows the oil use for each day to be determined. The daily oil use (gpd) can correlated with outdoor temperature data from a nearby weather station (see Weather Underground at www.wunderground.com or the National Climatic Data Center to obtain historic data).

The oil use and temperature data can be plotted as shown in Figure 14. Then regression analysis can be used to estimate the trend of oil use with ambient temperature in the two separate periods. For this approach to work effectively the data during retrofit transition period must be removed from the dataset. The regression analysis can be completed in two different ways:

Separate Regression Analysis in Each Period:

$$GPD_{pre} = \mathbf{a} + \mathbf{b} \cdot T$$

$$GPD_{post} = \mathbf{c} + \mathbf{d} \cdot T$$

Where **a** and **b** are the regression coefficients for the pre period and **c** and **d** are the regression coefficients for the post period (if retrofit included DHW measures, the analyst may want to consider a more complex three-parameter change point model to predict summertime oil use).

Multilinear Analysis with a "Dummy Variable" uses the additional independent variable "DUM" to discern the difference between the two periods (DUM=0 for pre-period data; DUM=1 for post-period data). This approach provides the advantage of using the statistics of the coefficients associated with the DUM variable to discern the uncertainty of the estimated differences between the pre- and post-periods. If the t-ratio associated with the coefficients **c** and **d** are greater than 2, then the impact of the retrofit is significant (i.e., not zero) at the 95% confidence interval.

$$GPD = (\mathbf{a} + \mathbf{c} \cdot DUM) + (\mathbf{b} + \mathbf{d} \cdot DUM) \cdot T$$

Where the estimated trend lines for each period are defined as:

$$GPD_{pre} = \mathbf{a} + \mathbf{b} \cdot T$$

$$GPD_{post} = (\mathbf{a} + \mathbf{c}) + (\mathbf{b} + \mathbf{d}) \cdot T$$

The estimated trend lines determined by either method can then be used with typical year weather data or temperature bin data for your location to discern the total annual savings from the heating retrofit. The bin analysis should only sum up oil use for days when the estimated use is greater than zero.

Appendix E: Summary of Initial (Failed) Approach to Measuring Fuel Oil Consumption

The initial measurement plan for this project (January 2012) described a detailed approach of directly measuring the oil flow rate into the burner. We had purchased two specialized oil flow meters (GPI GM001) and interfaced them with a Campbell Scientific data logger.

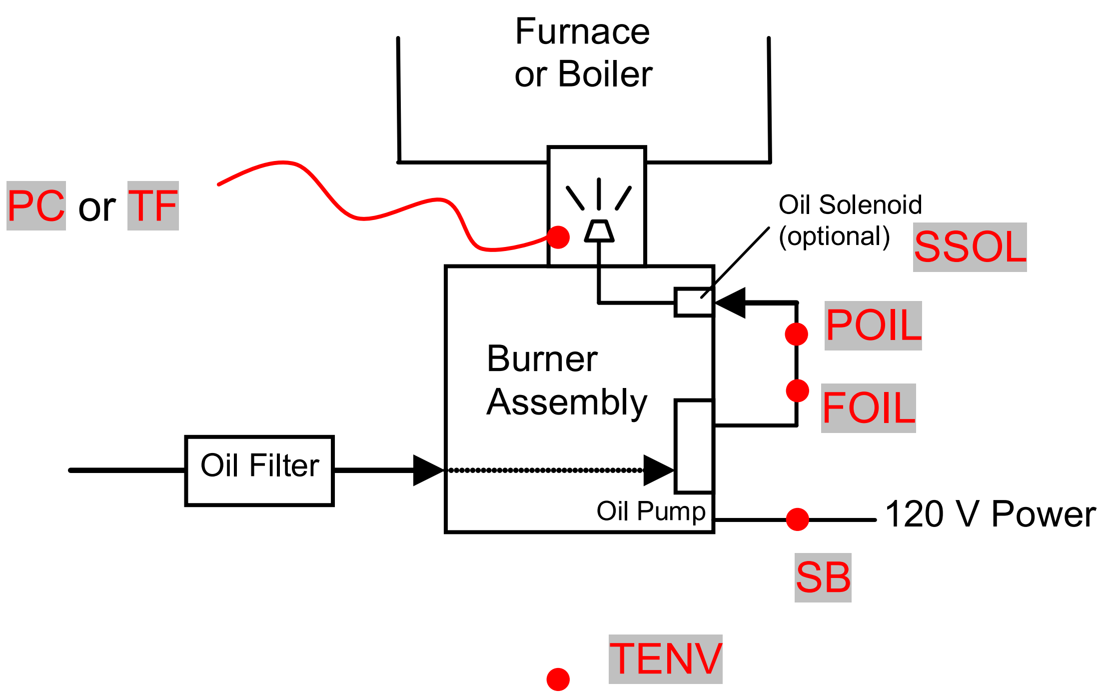


Figure 17. Sensor locations for oil burner measurements

This approach was attempted at two sites. At the first site we installed the flow meter as shown in Figure 17, between the oil pump and the nozzle. We attempted to run the boiler with the flow meter installed but the additional pressure drop restricted the oil flow and caused problems with combustion. We were never able to get the boiler to fire off with the meter in this location. We also put the flow meter on the inlet oil line between the tank and the burner. In this configuration we had better success but still had problems getting the burner to light-off, shutdown, and burn cleanly.

We attempted to set up the flow meter on the inlet on a second burner at a different site. At this second site we were still unable to establish normal operation. There was erratic operation and smoke generated at startup and shutdown.

Excerpt From Measurement Plan

The following text is excerpted from the project Measurement Plan:

> A self-contained instrumentation and data logging system will be developed and evaluated to determine the likely measurement uncertainty. It will be installed near the boiler to measure oil flow rate, burner runtime, burner flame status and room temperature. Two data collection systems will be constructed so that two burners can be tested simultaneously. Each system will be deployed for two to four days at each test site.
>
> For each burner the data logger system will measure:
>
> 1. Oil flow rate (gallons per hour)
> 2. Runtime of burner fan (seconds)
> 3. Environment temperature (°F)
>
> The measurement devices will be installed such that they do not affect burner operation by interfering with airflow to the burner or interrupting the trapdoor seal.
>
> The system will be programmed to collect data at 15-minute intervals for two (2) to four (4) days. It will also take event data to record the timing of each burner operating cycle at startup and shutdown (the logger will record the time of draft fan and oil pump start-up and shut-down as well as the time of flame initiation).

Figure 17 and Table 7 indicate the measurement locations and details. Table 8 provides the specifications for the oil flow meter (Figure 18). We considered several oil flow meters but this meter was the only meter with a good pulse resolution as well as an acceptable minimum flow.

Table 7. Oil Burner Measurements.

Data Point	Description	Engineering Units	Sensor
FOIL	Oil flow rate	gallons	GPI GM001
POIL	Oil pressure at nozzle	psig	C206 0-200 psig
PC	Photocell to detect flame—where possible (under 200 mv = flame)	mV	PV9001
TF	Flame temperature—where possible (over 100°F = flame)	°F	Type-T TC
TENV	Environment temperature	°F	Type-T TC
SB	Status/runtime of burner (120 V current, fan)	minutes	Veris 300
SSOL	Status/runtime of oil solenoid	minutes	Veris 300

Table 8. Specifications for the GPI GM001 Flow Meter.

Description	Specification
Minimum Flow (gph)	0.13
Maximum Flow (gph)	13.2
Accuracy	± 1%
Fitting Type and Size	1/8“ NPT female
Pulses per Gallon	5855.4
Meter Costs	$1,031

Figure 18. GPI oil flow meter.

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